Global Imbalances and Currency Wars at the ZLB

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Abstract

This paper explores the consequences of extremely low equilibrium real interest rates in a world with integrated but heterogenous capital markets and nominal rigidities. In this context, we establish five main results: (i) Economies experiencing liquidity traps pull others into a similar situation by running current account surpluses; (ii) Reserve currencies have a tendency to bear a disproportionate share of the global liquidity trap—a phenomenon we dub the "reserve currency paradox"; (iii) While more price and wage flexibility exacerbates the risk of a deflationary global liquidity trap, it is the more rigid economies that bear the brunt of the recession; (iv) Beggar-thy-neighbor exchange rate devaluations provide stimulus to the undertaking country at the expense of other countries (zero-sum); and (v) Safe public debt issuances, helicopter drops of money, and increases in government spending in any country are expansionary for all countries (positive-sum). We use these results to shed light on the evolution of global imbalances, interest rates, and exchange rates since the beginning of the global financial crisis.

JEL Codes: E0, F3, F4, G1,

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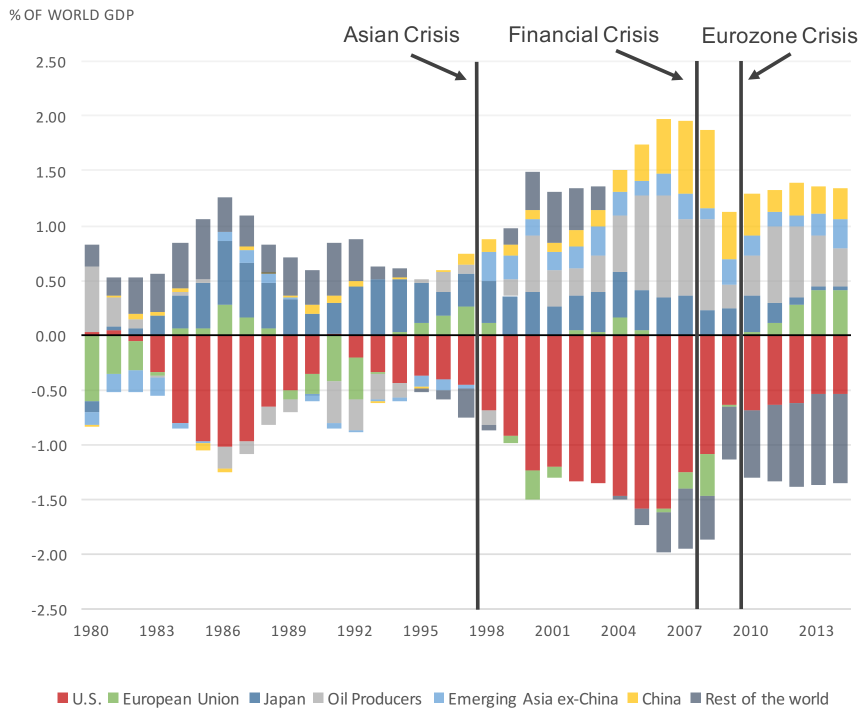
1 Introduction

In Caballero, Farhi and Gourinchas (2008a), (2008b), we argued that the (so called) "global imbalances" of the late 1990's and early 2000's (cf. Figure 1) and the low and declining world real interest rates (cf. Figure 2) were primarily the result of the diversity in the ability to produce safe stores of value around the world, and of the mismatch between this ability and the local demands for these assets—countries with a low capacity to produce safe assets and a high demand for them run current account surpluses and put downward pressure on world real interest rates.

Much has happened since then. Following the Subprime and European Sovereign Debt crises, we entered a world of unprecedented low natural interest rates across the developed world and in many emerging market economies. Figure 2 shows that global nominal interest rates have remained at or close to the Zero Lower Bound (ZLB) since 2009. With nominal rates so low, the equilibrating mechanism we highlighted in our previous work has little space to operate. Yet the global mismatch between local demand and supply of stores of value remains. The goal of this paper is to understand how this global mismatch plays out and shapes global economic outcomes, in an environment of extremely low global equilibrium real interest rates. We address questions such as: How do liquidity traps spread across the world? What is the role played by capital flows and exchange rates in this process? What are the costs of being a reserve currency in a global liquidity trap? How do differential inflation targets and degree of price rigidity influence the distribution of the impact of a global liquidity trap? What are the roles of public debt, helicopter drops of money, and government spending in attenuating the problem?

Building on our previous work, we provide a stylized model with nominal rigidities to answer these questions. In the model the ZLB emerges as a natural tipping point. Away from the ZLB, real interest rates equilibrate global asset markets: A shock that creates an *asset shortage* (a positive excess demand for assets) at the prevailing real interest rate results in an endogenous reduction in real interest rates which restores equilibrium in global asset markets. At the ZLB, real interest rates cannot play their equilibrium role any longer and global output endogenously becomes the active adjustment margin: Global output endogenously declines,

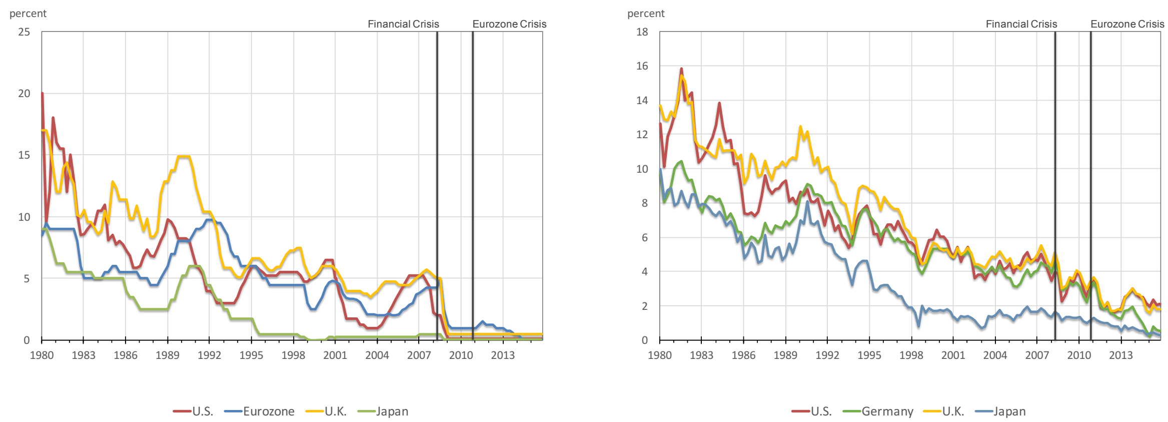


Note: The graph shows current account balances as a fraction of world GDP. We observe the build-up of global imbalances in the early 2000s, until the financial crisis of 2008. Since then, global imbalances have receded but not disappeared. Notably, deficits subsided in the U.S., and surpluses emerged in Europe. Source: World Economic Outlook Database (Oct. 2015), and Authors' calculations. Oil Producers: Bahrain, Canada, Iran, Iraq, Kuwait, Lybia, Mexico, Nigeria, Norway, Oman, Russia, Saudi Arabia, United Arab Emirates, Venezuela; Emerging Asia ex-China: India, Indonesia, Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand, Vietnam.

Figure 1: Global Imbalances

reducing income and therefore net global asset demand, and restoring equilibrium in global asset markets. The role of capital flows mutates at the ZLB. Away from the ZLB, current account surpluses propagate low interest rates from the origin country to the rest of the world. At the ZLB, current account surpluses propagate recessions. Indeed, Figure 3 shows that, following the financial crisis, large and persistent negative output gaps have appeared across most regions.

Our basic framework is a two country perpetual youth model with nominal rigidities, designed to highlight the heterogeneous relative demand for and supply of financial assets across different countries. In the core of the paper, we study a stationary world in which all countries share the same preferences for home and foreign goods (i.e. there is no home bias)



(a) Policy Rates (b) Long Rates

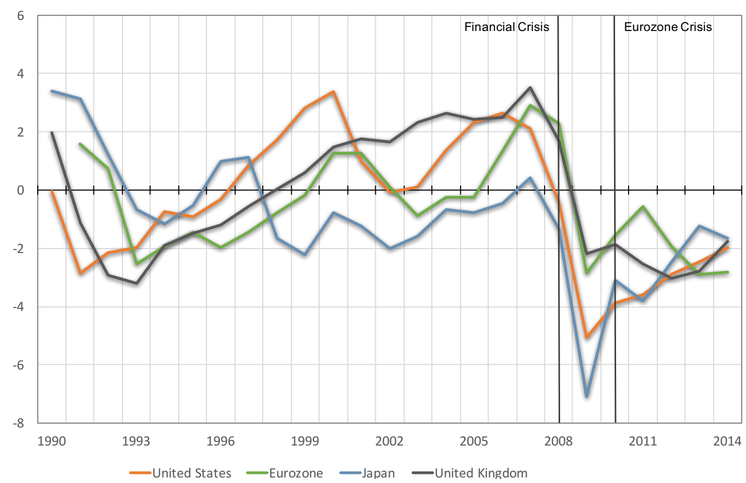
Note: Panel (a) reports policy rates while panel (b) reports nominal yields on 10-years government securities. We use Germany's 10-year yield as a proxy for the Eurozone 10-year yield. Both panels show the large decline in global interest rates. Following the financial crisis, the developed world remained at the Zero Lower Bound. Source: Global Financial Database.

Figure 2: Short and Long Nominal Interest Rates

and financial markets are fully integrated. This is an *all-or-none world*: Either all countries experience a *permanent* liquidity trap, or none.

We characterize global imbalances at the ZLB in terms of a *Metzler diagram in quantities,* that connects the size of the global recession and net foreign asset positions (and current accounts) to the recessions that would prevail in each country under financial autarky. This is analogous to the analysis away from the ZLB, where the world equilibrium real interest rates and net foreign asset (and current account) positions are connected to the equilibrium real interest rate that would prevail in each country under autarky. This analysis shows that, other things equal, when a country's autarky recession is more (less) severe than the global recession, that country is also a net creditor (debtor) and runs current account surpluses (deficits) in the financially integrated environment, effectively exporting its recession abroad. In turn, a country experiences a more (less) severe autarky recession than average when its autarky asset shortage is more (less) severe than the global asset shortage. In this environment, a large country with a severe autarky liquidity trap recession can pull the world economy into a global liquidity trap recession.

But other things need not be equal. In particular, the benchmark model has a critical degree of indeterminacy when at the ZLB (and not when away from it). This indeterminacy

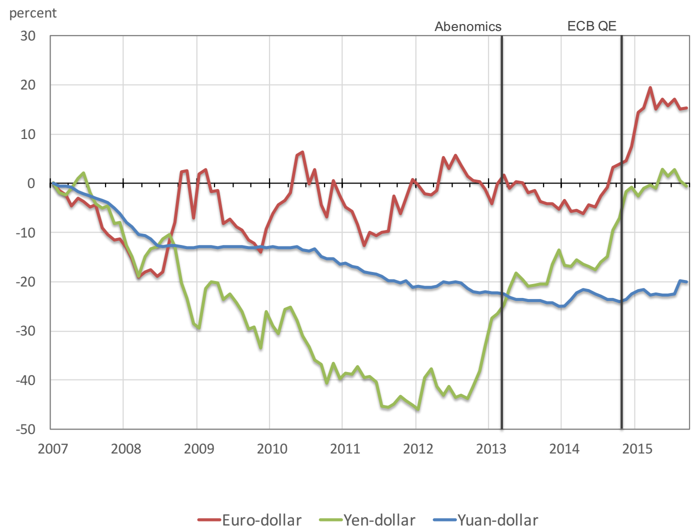


Note: The graph shows the persistent increase in the output gap following the global financial crisis and European sovereign debt crises. Source: World Economic Outlook, April 2015.

Figure 3: Output Gaps (percent).

is related to the seminal result by Kareken and Wallace (1981) that the nominal exchange rate is indeterminate in a world with pure interest rate targets. This is *de facto* the case when the economy is in a global liquidity trap, since both countries are permanently at the ZLB. However, in our framework and in contrast to the environments envisioned by Kareken and Wallace (1981), this indeterminacy has substantive real implications because of nominal rigidities. Different values of the nominal exchange rate correspond to different values of the real exchange rate, and therefore to different levels of output and the current account across countries. This mechanism means that, via expenditure switching effects, the exchange rate affects the *distribution* of recessions across countries in a global liquidity trap. To put it differently, at the ZLB global output needs to decline, but the precise distribution of this recession across countries varies with the exchange rate. This creates fertile grounds for *zero-sum* beggar-thy-neighbor devaluations achieved by direct interventions in exchange rate markets, stimulating output and improving the current account in one country at the expense of the others. Thus, our model speaks to the debates surrounding "currency wars".

By the same token, the indeterminacy implies that if agents coordinate on an appreciated exchange rate for a given country, as could be the case, for example, for a "reserve currency", then this country will experience a disproportionate share of the global recession in a global



Note: The graph shows the cumulated depreciation (+) or appreciation (-) of the euro, the yen, and the yuan against the dollar since January 2007. The 40% yen appreciation against the dollar between 2007 and 2012 was entirely reversed following the implementation of Abenomics (April 2013). The euro remained mostly stable against the dollar, until the second half of 2014, with increased expectations of Quantitative Easing by the European Central Bank (January 2015). Throughout the period the yuan appreciated agains the dollar, until the August 2015 yuan devaluation. Source: Global Financial Database. The figure reports $\ln(E/E_{2007m1})$ where E denotes foreign currency value of the dollar.

Figure 4: Global Exchanges Rates

liquidity trap. That is, while away from the ZLB, a reserve currency status is mostly a blessing as it buys additional purchasing power, at the ZLB the reserve currency status exacerbates the domestic recession, a form of "reserve currency paradox".

Section 2 contains our baseline model in which prices are fully rigid. In Section 3 we allow for milder forms of nominal rigidities by introducing Phillips curves, which can differ across countries. As usual, inflation is important because higher expected inflation reduces the impact of the (nominal) ZLB constraint. Our interest here is in studying the interaction between this mechanism and a *global* liquidity trap. In this setting, we show that if inflation targets in all countries are high enough, then there exists an equilibrium with no liquidity trap. But there is also an equilibrium with a global liquidity trap. In that equilibrium, wage and price flexibility plays out differently across countries and at the global level: Countries with more price or wage flexibility bear a smaller share of the global recession than countries with less price or wage flexibility; but at the global level, more downward price or wage flexibility exacerbates the global recession. And finally, there is an asymmetric liquidity trap equilibrium where only one country experiences a liquidity trap and a larger recession than in the global liquidity trap equilibrium.

In Section 4, we consider the role of fiscal policy. Our model is non-Ricardian. This gives a role both to public debt issuances and to helicopter drops of money, which are equivalent policies at the ZLB. In a global liquidity trap, additional debt issuance or a helicopter drop of money in one country alleviates the global asset shortage and stimulates the economy in *all* countries. This also worsens the current account and the net foreign asset position of the country issuing additional debt or money. The effect of a balanced-budget increase in domestic government spending in one country depends on the severity of nominal rigidities. When prices are perfectly rigid, it stimulates domestic output more than one-for-one and stimulates foreign output, albeit less, worsening the domestic current account. When some price adjustment is possible, the short-run increase in domestic and foreign output is even larger as increased government spending raises inflation and reduces real interest rates, further stimulating output. Over time, however, increased domestic government spending appreciates the domestic terms of trade, which rebalances spending away from domestic goods and toward foreign goods. The appreciation of the domestic terms of trade reduces the effect on domestic output and increases the effect on foreign output, but the overall effect on world output remains more than one-for-one and further worsens the domestic current account and its net foreign asset position. All in all, fiscal policy—be it in the form of public debt issuances, helicopter drops of money, or budget-balanced increases in government spending—is a *positive-sum* remedy in contrast with *zero-sum* exchange rate devaluations.

In our baseline model, agents are risk neutral and all financial assets are perfect substitutes. We relax the risk neutrality assumption in Section 5, where we introduce the concept of a *safe asset*. We consider two types of agents: "Knightians", who are locally infinitely risk averse and "Neutrals" who are risk neutral. This allows us to refine our view along three dimensions: (i) The relevant asset shortages pushing global interest rates down to the ZLB are now concentrated in *safe assets*, giving a prominent role to a new dimension of financial development in the form of a country's capacity to securitize and tranche out zero-net-supply safe assets from positive-net-supply real assets; (ii) differences along this dimension offer a possible rationalization of the "exorbitant privilege", whereby the country supplying more safe assets runs a permanent negative net foreign asset position and a current account deficit; and (iii) the presence of Knightians gives rise to an endogenous risk premium in the Uncovered Interest Parity condition (UIP), leading to the possibility of an asymmetric safety trap equilibrium with *real interest rate differentials.* This introduces another version of the "reserve currency paradox": A country issuing a reserve currency, i.e. a currency which is expected to appreciate in bad times, faces lower real interest rates and can enter a *safety trap* with zero nominal and real interest rates and a recession, while other countries experience positive nominal and real interest rates and remain outside the safety trap. We also show that policies that support private securitization (e.g., private-public debt issuance) in one country stimulate output and reduce risk premia in *all* countries.

Finally, we present several important extensions in an appendix, which we briefly summarize in Section 6. There, we introduce home bias, relax some elasticity assumptions, and consider a model with heterogeneities in propensities to save within and across countries.

A brief model-based tour of the world. We wrap up this introduction by providing a brief narrative of the evolution of global imbalances and global interest rates since the early 1990s through the lens of our model (cf. Figures 1 and 2), and of the role played by exchange rates in these dynamics. We divide the period into two sub-periods, before and after the onset of the 2008 Subprime crisis, when the ZLB starts binding in the U.S.

The first sub-period, from 1990 to 2008, was the focus of our earlier papers (Caballero et al. (2008a), (2008b)). We refer the reader to these papers for a detailed account and only provide here a quick summary. This period saw the emergence of large current account deficits in the U.S., offset by current accounts surpluses in Japan throughout the period, and, starting at the end of the 1990s, by large surpluses in emerging Asia (in particular China) and in commodity producers.

The second sub-period, 2008-2015, is the focus of this paper. During that period, the U.S. current account deficit was halved, Japan's current account surplus disappeared, Europe's current account surplus increased substantially, and China's current account deficit was considerable reduced (see Figure 1). Global interest rates accelerated their decline and eventually hit the ZLB in the developed world. The U.S. and Europe experienced the largest recessions since the Great Depression (cf. Figure 3). In our framework, these phenomena can be understood as the consequence of a combination of severe shocks and large exchange rate swings.

The Subprime crisis and European Sovereign Debt crisis shocks triggered a sharp contraction in the supply of safe assets—primarily U.S. "private label" safe assets and European Sovereign assets from crisis countries. They also triggered a surge in demand for safe assets, as households and the financial sector in both regions attempted to de-leverage. Taken together, these shocks exacerbated the global shortage of safe assets, pushing interest rates to the ZLB throughout the developed world, where they have remained since (Figure 2). They also increased domestic net asset scarcity in the U.S. and Europe, resulting in the sharp reduction in the U.S. current account deficit and the increase in European current account surpluses in the wake of both crises.[1]

In this new environment, the ultra-accommodating monetary policy of the U.S. is associated initially with a substantial depreciation of the dollar, especially against the yuan throughout the period and against the yen until 2014. This depreciation contributed further to the reduction of the current account surpluses of China and Japan. After this initial phase, the Bank of Japan in 2013 and the European Central Bank in 2014 started to implement aggressive expansionary monetary policies, leading to a sharp depreciation of the yen and the euro against the dollar.[2] The depreciation of these two currencies offset and began to shift back onto the U.S. a significant share of the global adjustment burden, slowing down the prospects of a normalization of U.S. monetary policy. In turn, the appreciation of the dollar, combined with domestic developments, forced China in August 2015 to de-peg its currency in order to mitigate the additional slowdown due to the imported appreciation. See Figure 4 for a graphical illustration of these exchange rate swings. Although the expression "currency wars"was originally coined by emerging market policymakers, we use it in this paper to capture the just described exchange rate trade-offs faced by economies like

[1] Some of the reduction in the U.S. current account deficits can also be attributed to the improvement in its petroleum trade balance caused by the expansion of U.S. shale oil production and lower oil prices.

[2] Through the lens of the model, it is natural to think of these interventions as coordinating the economy on equilibria with a more depreciated exchange rate.

the U.S., Japan, or the Eurozone at the ZLB, as well those of countries, like China, who effectively peg their currency to the dollar.

Finally, our framework helps us to understand the constraints faced by a regional reserve currency issuer such as Switzerland, illustrating our “paradox of the reserve currency”. Confronted with a surge in the demand for its currency and deposits in the wake of the European Sovereign Debt crisis, Switzerland either had to allow its currency to appreciate at the risk of a domestic recession, or to prevent its currency from appreciating, with a concomitant increase in risk in the Swiss National Bank's balance sheet. It chose the latter by imposing a floor in the value of the Euro in terms of Swiss francs, a highly contentious policy (inside and outside of Switzerland), until it was abandoned in early 2015.

Related literature. Our paper is related to several strands of literature. First and most closely related is the literature that identifies the shortage of assets, and especially of safe assets, as a key macroeconomic driver of global interest rates and capital flows (see e.g. Bernanke (2005), Caballero (2006), Caballero et al. (2008a) and (2008b), Caballero and Krishnamurthy (2009), Mendoza, Quadrini and Ríos-Rull (2009), Caballero (2010), Bernanke, Bertaut, DeMarco and Kamin (2011), Gourinchas, Rey and Govillot (2010), Maggiori (2012) and Coeurdacier, Guibaud and Jin (2015)). In particular, Caballero et al. (2008a) developed the idea that global imbalances originated in the superior development of financial markets in developed economies, and in particular the U.S. This paper analyzes how the same forces play out at when the world economy experiences ultra-low natural real interest rates and is constrained by the Zero Lower Bound. In particular, it articulates how adjustment now endogenously occurs through quantities (output) rather than prices (interest rates) and the role of exchange rates in allocating a global slump across countries.

Second, there is a literature which emphasizes another form of safety associated with public debt and close substitutes in the form of information insensitivity, i.e. the mitigation of information asymmetries and of incentives to acquire asymmetric information (see for example Gorton (2010), Stein (2012), Moreira and Savov (2014), Gorton and Ordonez (2013), Gorton and Ordonez (2014), Dang, Gorton and Holmstrom (2015) and Greenwood, Hanson and Stein (2015)). A recent literature also considers relative degrees of safety and what makes some assets 'safe' in equilibrium in the presence of coordination problems (see for example He, Krishnamurthy and Milbradt (2015)). Our model offers a different interpretation, where the "specialness" of public debt and close substitutes arises from their safety in bad aggregate states (see also Gennaioli, Shleifer and Vishny (2012), Barro and Mollerus (2014), and Caballero and Farhi (2015)).

Third, there is by now an extensive literature on liquidity traps (see e.g. Keynes (1936), Krugman (1998), Eggertsson and Woodford (2003), Christiano, Eichenbaum and Rebelo (2011), Guerrieri and Lorenzoni (2011), Eggertsson and Krugman (2012), Werning (2012), and Correia, Farhi, Nicolini and Teles (2013)). This literature emphasizes that the binding Zero Lower Bound on nominal interest rates presents an important challenge for macroeconomic stabilization. A subset of that literature considers the implications of a liquidity trap in the open economy (see e.g. Svensson (2003), Jeanne (2009), Farhi and Werning (2012), Cook and Devereux (2013a), (2013b) and (2014), Devereux and Yetman (2014), Benigno and Romei (2014) and Erceg and Lindé (2014)). While many of these papers share similar themes, our paper elucidates the link between the size and distribution across countries of the global recession and net foreign asset positions, with our *Metzler diagram in quantities*, allows for permanent liquidity traps and capital flows (global imbalances) via an OLG model, and introduces a distinction between risky and safe assets.

Fourth, there is an emerging literature on secular stagnation: The possibility of a permanent zero lower bound situation (see e.g. Kocherlakota (2014), Eggertsson and Mehrotra (2014), Caballero and Farhi (2015)). Like us, these papers use an OLG structure with a zero lower bound and nominal rigidities, but in a closed economy. Our contribution is to explore the open economy dimension of the secular stagnation hypothesis and the question of whether some but not all countries can be in a permanent liquidity equilibrium. In our base model all countries are either in or out of a permanent liquidity trap since they face the same real (and nominal) interest rate. By contrast, the model with inflation of Section 3 and the model with safe assets of Section 5 feature asymmetric equilibria where some countries are in a permanent liquidity trap but not others.

Overall, our model also elucidates the conditions under which it is possible for some but not all countries to experience a secular stagnation equilibrium. From this perspective, the paper closest to ours is the contemporaneous Eggertsson, Mehrotra, Singh and Summers (2015) which finds, like us, that exchange rates have powerful effects when the economy is in a global liquidity trap. Complementary to ours, their paper explores the role of varying degrees of capital market integration and capital controls. Our paper emphasizes other methodological and substantive dimensions, such as the Metzler diagram in quantities, the "reserve currency paradox", the spillovers of safe public debt issuance, the role of capital flows in spreading liquidity traps and macroeconomic policies, and the role of safe vs. risky assets.

2 A Model of the Diffusion of Liquidity Traps

In this section we introduce our baseline model and main analytical tool, which we label the *Metzler diagram in quantities*. We use these to illustrate how countries are pulled into and out of liquidity traps by capital flows, and to show how a depreciation shifts the burden of absorbing a global liquidity trap onto others.

2.1 Model

Time is continuous. There are two countries, Home and Foreign. Foreign variables are denoted with stars. We first describe Home, and then move on to Foreign.

Demographics. Population is constant and normalized to one. Agents are born and die at hazard rate θ, independent across agents. Each dying agent is instantaneously replaced by a newborn. Therefore, in an interval dt, θdt agents die and θdt agents are born, leaving total population unchanged.

Preferences. Agents only have an opportunity to consume, c_t, when they die. We denote by τ_θ the stopping time for the idiosyncratic death process.

Agents value home and foreign goods according to a Cobb Douglas aggregate, are risk neutral over short time intervals, and do not discount the future. More precisely, for a given stochastic consumption process of home and foreign goods $\{c_{H,t}, c_{F,t}\}$ which is measurable with respect to the information available at date t, we define the utility U_t of a an agent alive at date with the following stochastic differential equation:

$$U_t = 1_{\{t-dt\leq\tau_\theta<t\}} c_{H,t}^{\gamma} c_{F,t}^{1-\gamma} + 1_{\{t\leq\tau_\theta\}} \mathbb{E}_t[U_{t+dt}],$$

where we use the notation $\mathbb{E}_t[U_{t+dt}]$ to denote the expectation of U_{t+dt} conditional on the information available at date t.

Note that the information at date t contains the information about the realization of the idiosyncratic shocks up to t, implying that $1_{\{t-dt\leq\tau_\theta<t\}}$ and c_{Ht} and c_{Ft} are known at date t. Similarly, the conditional expectation $\mathbb{E}_t$ is an expectation over idiosyncratic death shocks.

Nominal rigidities, potential output and actual output. In an interval dt, potential output of the home good is given by $X_t dt$, where X_t grows at rate g.

The prices of home goods are fully rigid in the home currency and we normalize them to one $P_{H,t} = 1$, and we assume that the Law of One Price holds so that the price of home goods in the foreign currency is $P_{H,t}/E_t$ where E_t is the exchange rate. Because of the presence of nominal rigidities, actual output $\xi_t X_t dt$ is demand determined and might be lower than potential output. The endogenous equilibrium variable $\xi_t \in [0, 1]$ denotes capacity utilization (the ratio of output to potential output), and $\xi_t - 1$ denotes the *output gap*. When $\xi_t = 1$, output is at potential, with full capacity utilization and no output gap. When $\xi_t < 1$, output is below potential, with slack capacity utilization and a negative output gap. For short, and with some abuse of notation, *we refer to ξ_t as output from now on.* We refer the reader to Appendix A.1 for a microfoundation in the New Keynesian tradition with monopolistic competition and rigid prices à la Blanchard and Kiyotaki (1987).

Private incomes, assets, and financial development. Domestic income (output) has two components: income of newborns and financial income. In the interval dt, newly born agents receive income $(1-\delta)\xi_t X_t dt$. The remainder, $\delta\xi_t X_t dt$, is distributed as financial income. This financial income can be capitalized into home Lucas trees that can be traded between agents. Thus, $\delta\xi_t X_t dt$ represents the dividends on the stock of these home Lucas trees.

Each tree capitalizes a constant stream of dividends. With independent and instantaneous probability ρ each tree dies and the corresponding stream of dividends is transferred to a new tree. We assume that the stock of trees grows at rate g to accommodate growth in potential output. All new trees are also endowed to newborns.

The assumption that trees die, and that they only capitalize a constant (and not growing) dividend before they die, can be interpreted as a consequence of a process of creative-destruction, whereby technological innovations render older technologies and the associated dividend claims obsolete, or as a form of weak property rights that transfers without compensation claims on future output from old generations to new generations. This creative destruction reduces the share of future output that is capitalized into assets that are traded today.

In practice, δ captures many factors behind the pledgeability of income into tradable financial assets. At the most basic level, one can think of δ as the share of capital in production. But in reality only a fraction of this share can be committed to asset holders, as the government, managers, and other insiders can dilute and divert much of profits. For this reason, we refer to δ as an index of financial capacity of the home country, by which we mean an index of the extent to which property rights over earning are well defined and tradable in financial markets.

Overall, denoting by r_t the real interest rate, the present value of the economy's future output is $PV_t = \int_t^\infty X_s e^{-\int_t^s r_u du} ds$ while the current value of tradable private financial assets is $V_t = \delta \int_t^\infty X_t e^{-\int_t^s (r_u+\rho) du} ds$. Two factors lower the ratio V_t/PV_t: financial development (captured by the pledgeability parameter δ), and the process of creative destruction (captured by the death rate of trees ρ and the fact that a given tree capitalizes a constant dividend before its death while global output increases over time with new trees).

Public debt. There is a home government that issues short-term public debt D_t, which it services by levying taxes τ_t on the income $(1-\delta)\xi_t X_t$ of newborns. We denote by $d_t = D_t/X_t$ the home debt to potential output ratio.

The assumption that taxes are levied on the income of newborns is important. It ensures that public debt reduces the excess demand for assets at a given interest rate. This occurs both by increasing the net supply of assets (since public debt does not crowd out private assets) and by decreasing the demand for assets (since taxes reduce the income of newborns) at a given interest rate. These effects remain as long as taxes do not fall entirely on financial income. If taxes were levied entirely on financial income, then the environment would become Ricardian with respect to debt policy, despite the fact that there are overlapping generations: public debt would crowd out private assets one-for-one.

Monetary policy. We assume that home monetary policy follows a truncated Taylor rule

$$i_t = \max\{r_t^n - \psi_\xi(1-\xi_t), 0\}.$$

In this equation, i_t is the home nominal interest rates which, with rigid prices, is equal to the real interest rate r_t. The intercept of the Taylor rule r_t^n is the relevant *natural interest rate* at Home, consistent with full employment, which depends on whether we are analyzing the equilibrium with financial integration or with financial autarky. For simplicity, we place ourselves in the limit of very reactive Taylor rules $\psi_\xi \to \infty$. This specification of monetary policy guarantees that we either have $\xi_t = 1$ and $i_t > 0$, or $\xi_t \leq 1$ if $i_t = 0$.[3]

Foreign. Foreign is identical to Home except in three aspects. First, potential output of the foreign good is given by X_t^*, which also grows at rate g. Second, the financial capacity of the foreign country is given by δ^*.[4] Third, public debt in the foreign country is given by D_t^*, the debt to output ratio by d_t^*, and taxes by τ_t^*. Fourth, Foreign has its own currency

[3]As is customary in the ZLB literature, the ZLB on nominal interest rates $i_t \geq 0$ is motivated by the arbitrage with cash in a "cashless limit" economy (see e.g. Woodford (2003)). For example, cash could be introduced in the model via a Cash-In-Advance constraint requiring agents to hold cash (of their country of residence) in advance in a proportion ϵ of their consumption spending, which in our model would lead to total home and foreign cash holdings $\epsilon\theta W$ and $\epsilon\theta W^*$. Our model is exactly the cashless limit economy which obtains when $\epsilon \to 0$. See Caballero and Farhi (2015) for a detailed exposition in a closed-economy context.

[4]To a large extent, differences in propensity to consume θ play a similar role as differences in financial development δ in determining capital flows and interest rates, but the expressions of the model become more cumbersome when we introduce heterogeneity in θ. For this reason, we capture differences in $\theta\delta$ (an inverse index of country-specific asset shortage) only through differences in δ in the benchmark model. We refer the reader to Appendix A.5, where we introduce an alternative model featuring within country heterogeneity between borrowers and savers, which generates differences in propensity to save and consume across countries, driven by demographics (identifying borrowers with the young and savers with the middle-aged and the old) or credit markets (captured by the tightness of borrowing constraints). This model yields similar qualitative insights to the simpler baseline model.

and the prices of foreign goods are sticky in this currency. We normalize the price of the Foreign good to one in the foreign currency: $P^*_{F,t} = 1$.

We assume that there is no home bias and that the share γ of home consumption expenditure in total expenditures in both countries is equal to the share of potential output of home goods in total output: $\gamma = x$, where $x \equiv X_t/(X_t + X^*_t)$.

Wealth, asset values, interest rates, exchange rates, and output gaps. We denote by E_t the exchange rate between the home and the foreign currency, defined as the home price of the foreign currency, so that an increase in E_t represents a depreciation of the home currency; W_t and W^*_t are the total wealth of home and foreign households in their respective currencies; and V_t and V^*_t are the total value of home and foreign private assets (Lucas trees) in their respective currencies, so that the total value of home and foreign private and public assets in their respective currencies are $V_t + D_t$ and $V^*_t + D^*_t$.

Roadmap. We start with the simple observation that under financial integration, Uncovered Interest Parity (UIP) holds between Home and Foreign:

$$i_t = i^*_t + \frac{\dot{E}_t}{E_t}.$$

We *focus throughout the paper on steady state balanced growth paths* in the benchmark model and with some abuse of notation, we drop the time subscripts. In a steady state, the exchange rate is constant at E, and the home and foreign interest rates are necessarily equal to each other: $i = i^* = i^w$ and $r = r^* = r^w$ with $i^w = r^w$ since prices (and wages) are constant. This implies that under the maintained assumption of financial integration, either no country is in a liquidity trap $i^w = r^w > 0$, or all countries are in a liquidity trap $i^w = r^w = 0$, although, as we shall see, the severity of each country's liquidity trap depends on the exchange rate E.

2.2 No Liquidity Trap

Outside of a liquidity trap, we have $r = r^* = r^w > 0$ and $\xi = \xi^* = 1$. We take the latter as given and solve for the equilibrium r^w and E. This section illustrates in detail the steps we follow in finding equilibrium in this class of models, which are then repeated more succinctly in the more complex extensions found later in the paper.

Equilibrium equations. The equilibrium equations are as follows. First, there are the asset pricing equations for home and foreign Lucas' trees, taking into account depreciation (creative destruction):

$$r^w V = -\rho V + \delta X, \tag{1a}$$

$$r^w V^* = -\rho V + \delta^* X^*, \tag{1b}$$

Consider equation (1a). The return on home Lucas trees has two components: a dividend yield $\delta X/V$, and a capital loss associated with the depreciation of existing trees, $-\rho$. By arbitrage, this return should be equal to the global interest rate r^w, and equation (1a) follows. A similar argument yields equation (1b).

The second set of equations characterizes the evolution of home and foreign financial wealth:

$$gW = -\theta W + (1-\tau)(1-\delta)X + r^w W + (\rho + g)V, \tag{2a}$$

$$gW^* = -\theta W^* + (1-\tau^*)(1-\delta^*)X^* + r^w W^* + (\rho + g)V^*. \tag{2b}$$

Along the balanced growth path, home and foreign wealth grow at rate g. This change in wealth is composed of three terms. First, newborn's net of tax income $(1-\tau)(1-\delta)X$ is earned and consumption θW from dying agents is subtracted; Second, wealth earns a risk-free return r^w; Third, new trees with an aggregate value $(\rho + g)V$, accounting both for creative destruction and growth of potential output, are endowed to newborns.

The third set of equations characterizes the government budget constraints:

$$(r^w - g)D = \tau (1-\delta) X, \tag{3a}$$

$$(r^w - g)D^* = \tau^* (1-\delta^*) X^*. \tag{3b}$$

Note that positive taxes are required to sustain positive debt when the economy is dynamically efficient with $r^w > g$ but that when the economy is dynamically inefficient with $r^w < g$, positive debt is associated with tax rebates. We will return to this observation when we consider the use of public debt as a stimulus.

Lastly, the home and foreign goods market clearing conditions are:

$$\gamma\theta(W + EW^*) = X, \tag{4a}$$

$$(1-\gamma)\theta(W + EW^*) = EX^*. \tag{4b}$$

The asset market clearing condition

$$(V + D) + E(V^* + D^*) = W + EW^*$$

can be omitted since it is redundant by Walras' law.

Solving for the equilibrium. To solve for the equilibrium, we first note that since there is no home bias and $\gamma = x$, the home and foreign goods market clearing conditions (4a) and (4b) imply that the equilibrium exchange rate is:

$$E = 1.$$

Using the linearity of the equilibrium equations, we can combine the asset market clearing condition (1a) and (1b) with the wealth accumulation equations (2a) and (2b), and the government budget constraints (3a) and (3b) so as to characterize the asset pricing equation for world private assets $V^w = V + V^*$, and the accumulation equation for world wealth $W^w = W + W^*$ as a function of world output $X^w = X + X^*$ and world public debt $D^w = D + D^*$. Thus, world equilibrium is characterized by:

$$r^w V^w = -\rho V^w + \bar{\delta} X^w,$$

$$g W^w = -\theta W^w + (1-\bar{\delta})X^w - (r^w - g)\bar{d}X^w + r^w W^w + (\rho + g)V^w,$$

$$\theta W^w = X^w,$$

where $\bar{\delta} = x\delta + (1-x)\delta^*$ is the world's financial capacity, and $\bar{d} = xd + (1-x)d^*$ is the world's public debt to (potential) output ratio. Substituting $W^w = V^w + D^w$ into these equations and solving for the world interest rate r^w, yields:

$$r^w = r^{w,n} \equiv -\rho + \frac{\bar{\delta}\theta}{1-\theta\bar{d}},$$

where $r^{w,n}$ is the world *natural interest rate* consistent with full employment. This equilibrium is valid as long as $r^{w,n} \geq 0$. The natural interest rate decreases when global asset demand is high (low θ corresponding to a low propensity to consume), or global private asset supply is low (low $\bar{\delta}$ or high ρ, corresponding respectively to a low capacity to securitize financial claims, or a high rate of creative destruction), or global public asset supply is low (low $\bar{d}$ corresponding to a low public supply of assets).

Financial autarky. We can follow an identical set of steps to find the natural interest rate for Home and Foreign that would prevail in *financial autarky* (that is, in the absence of *intertemporal* trade). These *financial autarky natural interest rates,* denoted by $r^{a,n}$ and $r^{a,n*}$ respectively, will play a useful role in the characterization of capital flows and net external liabilities and are given by:

$$r^{a,n} \equiv -\rho + \frac{\delta\theta}{1-\theta d},$$
$$r^{a,n*} \equiv -\rho + \frac{\delta^*\theta}{1-\theta d^*}.$$

Under financial autarky, home and foreign equilibrium real interest rates satisfy:

$$r^a = \max\left\{r^{a,n}, 0\right\} \quad ; \quad r^{a*} = \max\left\{r^{a,n*}, 0\right\},$$

that is, they equate their financial autarky *natural* counterpart as long as the latter is positive.

Net Foreign Assets, Current Accounts, and (conventional) Metzler diagram. We can now characterize Net Foreign Asset positions and Current Accounts. For a given world interest rate r^w, we first return to the home asset pricing equation (1a), the home wealth accumulation equation (2a), and the home government budget constraint (3a) to find:

$$V = \frac{\delta}{r^w + \rho} X,$$

$$W = \frac{(1-\delta) - (r^w - g)d + (\rho + g)\frac{\delta}{r^w+\rho}}{g + \theta - r^w} X,$$

from which, using the fact that $NFA = W - (V + D)$ and $CA = N\dot{F}A = gNFA$, we obtain:

$$\frac{NFA}{X} = \frac{(1-\theta d)(r^w - r^{a,n})}{(g+\theta - r^w)(\rho + r^w)}, \tag{6a}$$

$$\frac{CA}{X} = g\frac{NFA}{X}. \tag{6b}$$

Equation (6a) tells us that the home Net Foreign Asset position increases with global interest rates r^w. Moreover, Home is a net creditor (resp. net debtor) if the world interest rate is larger (resp. smaller) than the financial autarky natural rate $r^{a,n}$.

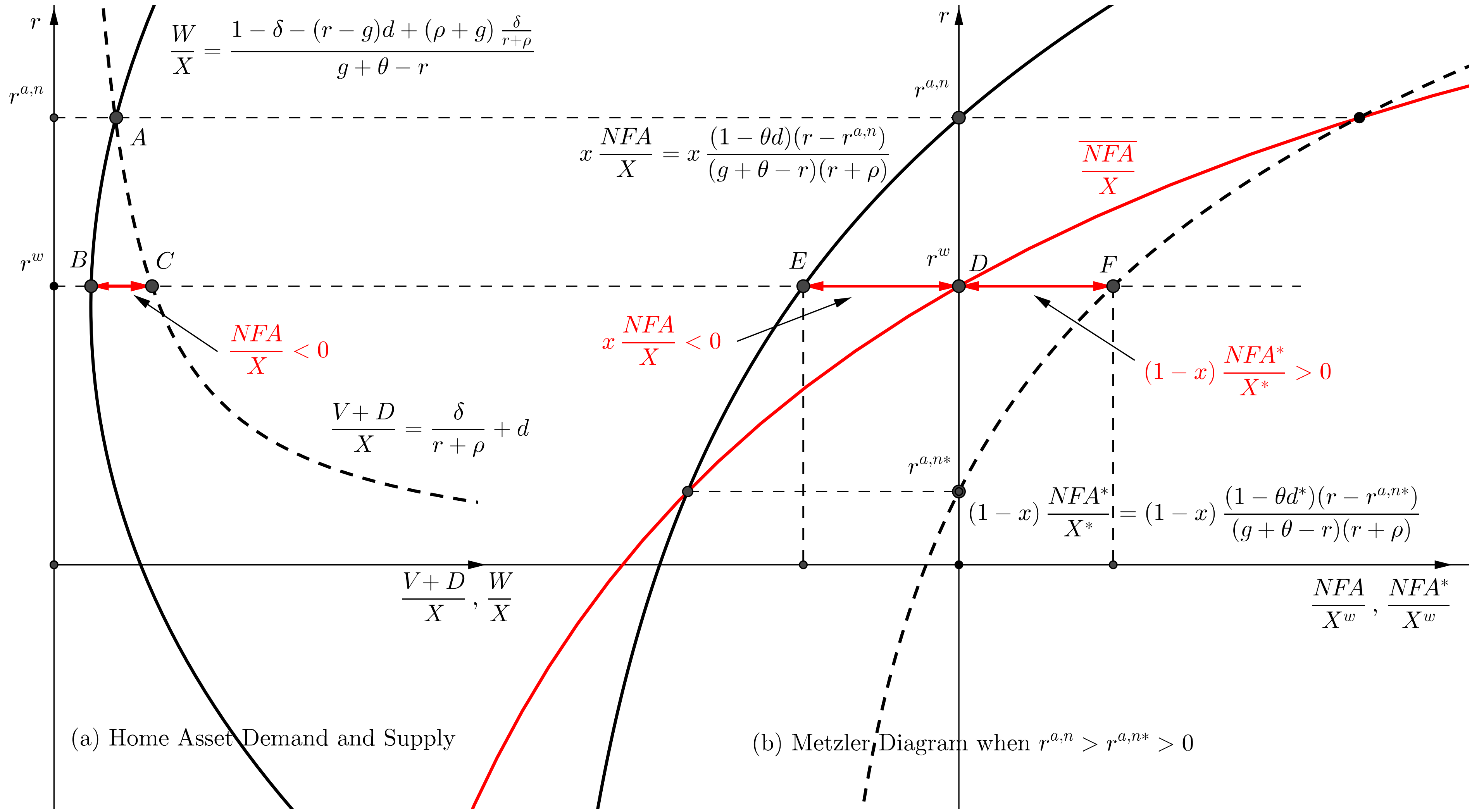
Similar equations hold for Foreign, which together with equilibrium in the world asset market

$$x\frac{NFA}{X} + (1-x)\frac{NFA^*}{X^*} = 0, \tag{7}$$

allow us to see the derivation of the financial integration world interest rate r^w in a conventional Metzler diagram (Figure 5).

Panel (a) of Figure 5 reports home asset demand W (solid line) and home asset supply $V + D$ (dashed line) scaled by domestic output X, as functions of the world interest rate r^w.[5] The two curves intersect at the financial autarky natural interest rate $r^{a,n}$,—assumed positive in the figure—where the country is neither a debtor nor a creditor (point A). For

[5] Asset supply $(V+D)/X$ is monotonically decreasing in the world interest rate r^w. Asset demand W/X is non-monotonous because of two competing effects. First, higher interest rates imply that wealth accumulates faster. But higher interest rates also reduce the value of the new trees endowed to the newborns, and increase the tax burden required to pay the higher interests on public debt. For high levels of the interest rate and low levels of debt, the former effect dominates and asset demand increases with r^w. For low levels of the interest rate, the latter effect dominates and asset demand decreases with r^w. Regardless of the shape of W/X, one can easily verify that NFA/X is always increasing in the interest rate.



Panel (a) reports asset demand W/X (solid line) and asset supply $(V+D)/X$ (dashed line). The two lines intersect at the autarky natural interest rate $r^{a,n}$ (point A). Panel (b) reports home (solid line) and foreign (dashed line) Net Foreign Assets scaled by world output, $xNFA/X$ and $(1-x)NFA^*/X^*$ when $r^{a,n} > 0$ and $r^{a,n*} > 0$. The world natural interest rate r^w is such that Net Foreign Asset positions are equilibrated, or equivalently, when the world's NFA (red line) $\overline{NFA/X} = xNFA/X + (1-x)NFA^*/X^*$ is equal to zero (point D). If $r^{a,n} > r^w$, Home is a net debtor ($NFA/X < 0$) and runs a Current Account deficit ($CA/X < 0$).

Figure 5: World Interest Rates and Net Foreign Asset Positions: the Metzler Diagram

lower values of the world interest rate, Home is a net debtor: $NFA/X < 0$. For higher values, it is a net creditor. Panel (b) reports the Net Foreign Asset positions of Home $xNFA/X$, Foreign $(1-x)NFA^*/X^*$, and the world $\overline{NFA/X} = xNFA/X + (1-x)NFA^*/X^*$, as a function of the world interest rate r^w. The figure assumes that $0 < r^{a,n*} < r^{a,n}$, so that both countries would escape the liquidity trap under financial autarky. The equilibrium world interest rate r^w has to be such that global asset markets are in equilibrium, i.e. equation (7) holds or equivalently $\overline{NFA/X} = 0$ (point D).

Under financial integration, the world interest rate is a weighted average of the home and foreign financial autarky natural interest rates, with:

$$r^{w,n} = x\frac{1-\theta d}{1-\theta\bar{d}}r^{a,n} + (1-x)\frac{1-\theta d^*}{1-\theta\bar{d}}r^{a,n*}.$$

To summarize, Home runs a Current Account deficit if and only if its financial autarky natural interest rate is above the financial autarky natural interest rate of Foreign, i.e. when net asset scarcity at Home is not as severe as in Foreign. This occurs occurs when financial capacity in Home is higher than that in Foreign, $\delta > \delta^*$, or when Home sustains a higher public debt ratio than Foreign $d > d^*$. Foreign's Current Account surplus helps propagate its asset shortage, increasing its interest rate and reducing the home interest rate all the way to the point at which they are equal to each other.

In the integrated equilibrium with $r^{a,n} > r^{a,n*}$, it is possible for Home to pull Foreign out of a liquidity trap, in the sense that $r^{w,n} > 0$ while $r^{a,n*} < 0$. In that case, financial integration helps prevent the occurrence of a liquidity trap in Foreign. It is also possible for Foreign to pull Home into a liquidity trap, in the sense that $r^{w,n} < 0$ while $r^{a,n} > 0$. We turn next to this global liquidity trap equilibrium.

2.3 Global Liquidity Trap

When $r^{w,n} < 0$, the global economy is in a liquidity trap. The economy is at the ZLB with $r = r^* = r^w = 0$. At this interest rate, and with output at potential, there is a global asset shortage, which cannot be resolved by a reduction in world interest rates. Instead, an alternative (perverse) equilibrating mechanism endogenously arises in the form of an equilibrium recession with $\min\{\xi, \xi^*\} < 1$. Here it is important to bear in mind that the quantities ξ and ξ^* are endogenous equilibrium variables in a rigid-price equilibrium, in a similar sense in which prices are endogenous equilibrium variables in standard Walrasian equilibrium theory—they are not "chosen"by any agent, but rather are pinned down by equilibrium conditions.

At a fixed zero interest rate, the recession *reduces asset demand more than asset supply* which restores equilibrium in the global asset market. This key property is about *endogenous* changes in asset supply and asset demand brought about by a reduction in output, and not about the exogenous movements in asset supply and asset demand directly caused by any exogenous shock that may trigger a recession. In other words, this property is entirely consistent with large drops in asset supply (negative shifts in asset supply curves) and large increases in asset demand (positive shifts in asset demand curves) during recessions. In fact, these shocks, which exacerbate asset shortages (net excess asset demand at a given interest rate), are one of the main reasons why the economy might end up in a liquidity trap.

This logic rests on the following assumptions, which we maintain throughout: $\delta\theta/\rho < 1$, $\delta^*\theta/\rho < 1$,$1/\theta > d > 0$ and $1/\theta > d^* > 0$. To understand the role of these, note that a recession endogenously reduces asset demand because it lowers the income of newborns. Further, the recession reduces the dividend paid out on Lucas trees, which lowers the value of the trees and hence private asset supply. The assumptions that $\delta\theta/\rho < 1$ and $\delta^*\theta/\rho < 1$ guarantee that a recession endogenously reduces net private asset demand.

The assumptions that $d > 0$ and $d^* > 0$ ensure that part of the asset supply (public asset supply) is *not* affected by the recession (a sort of "safe debt"). The recession resolves the asset shortage because equilibrium in the global asset market requires net private asset demand for public assets to equal public asset supply. The assumptions that $d < 1/\theta$ and $d^* < 1/\theta$ ensure that debt can be sustained in both countries even under financial autarky.

Equilibrium equations. The equilibrium equations are similar to those in the previous case except for the zero interest rates and endogenous output at Home and Foreign (ξ, ξ^*), where we have already replaced taxes at Home and Foreign using the government budget constraints $\tau\,(1-\delta)\,\xi X = -gD$ and $\tau^*\,(1-\delta)\,\xi^* X^* = -gD^*$:

$$0 = -\rho V + \delta\xi X, \tag{8a}$$

$$0 = -\rho V^* + \delta^*\xi^* X^*, \tag{8b}$$

$$gW = -\theta W + (1-\delta)\xi X + gD + (\rho+g)V, \tag{8c}$$

$$gW^* = -\theta W^* + (1-\delta^*)\xi^* X^* + gD^* + (\rho+g)V^*, \tag{8d}$$

$$x\theta(W+EW^*) = \xi X, \tag{8e}$$

$$(1-x)\theta(W+EW^*) = E\xi^* X^*. \tag{8f}$$

As before, the first two lines correspond to the asset pricing equations (for Home and Foreign), the next two lines characterize wealth dynamics, and the last two lines represent the market clearing conditions. The global asset market clearing condition $(V+D)+E(V^*+D^*) = W+EW^*$ can be omitted by Walras' Law.

Solving for the equilibrium. To solve for the equilibrium, we proceed as in the case with no liquidity trap. We first note that the home and foreign goods market clearing conditions (8e) and (8f) imply that the equilibrium nominal exchange rate is:

$$E = \frac{\xi}{\xi^*}. \tag{9}$$

The nominal exchange rate is the *ratio of Home and Foreign's outputs.* This simple expression is a direct consequence of the assumption of a unit elasticity of substitution between home and foreign goods, and the fact that there is no home bias in preferences (we relax these assumptions in appendices A.3 and A.4). Given that home and foreign prices are constant (in their own currency), a more depreciated nominal exchange rate implies a more depreciated real exchange rate, which shifts relative demand toward the home good. Since output is demand determined in the global liquidity trap, this expenditure switching effect requires a smaller recession at Home relative to Foreign.

We can combine home and foreign equations (8a)-(8d) to derive the asset pricing equation for global private assets (in home currency) $V^w = V+EV^*$ and the evolution of global wealth (in home currency) $W^w = W + EW^*$:

$$0 = -\rho V^w + \delta\xi X + \delta^* E\xi^* X^*, \tag{10a}$$

$$gW^w = -\theta W^w + (1-\delta)\xi X + (1-\delta^*)E\xi^* X^* + gD^w + (\rho+g)V^w, \tag{10b}$$

where $D^w = D + ED^*$ is global public debt in home currency. In addition, equilibrium in goods markets then requires:

$$\theta W^w = \xi X + E\xi^* X^*. \tag{11}$$

This is a system of *four* equations (9)-(11), in *five* unknowns V^w, W^w, ξ, ξ^*, and E. That is, there is a *degree of indeterminacy.* This indeterminacy is related to the seminal result by Kareken and Wallace (1981) that the exchange rate is indeterminate with pure interest rate targets, which is *de facto* the case when both countries are at the ZLB. An important difference here is that money is *not* neutral, and therefore different values of the exchange rate correspond to different levels of output at Home and in Foreign, as prescribed by equation (9). In other words, while global output needs to decline to restore equilibrium on asset markets, different combinations of domestic and foreign output—corresponding to different values of the exchange rate—are possible.[6,7]

[6] This indeterminacy result is due to the assumption that the liquidity trap is permanent. In Appendix A.6 we extend the model to consider the possibility of exit at some Poisson stopping time τ. The exchange rate post exit E_τ is determinate, and so is the exchange rate $E = E_\tau$ pre exit through a UIP logic, and so this form of indeterminacy à la Kareken and Wallace (1981) disappears. But even though this indeterminacy result literally requires the liquidity trap to be permanent, perhaps a natural practical interpretation is that the exchange rate is less anchored by fundamentals when the liquidity trap is expected to last for a long time—the longer the trap lasts, the more dubious the rational expectation logic that pins down the exchange rate in the liquidity by backward induction from its value after the trap.

In any case, with the possibility of exit, another form of indeterminacy emerges due to the interaction of portfolio effects and home bias. As long as some agents are risk neutral and hence feature a form of portfolio indifference, we can have equilibria with different values of $E = E_\tau$, exactly as in this section, with similar implications in terms of relative outputs and "currency wars"—lower values of E are associated with higher values of ξ and lower values of ξ^*. Interestingly, this logic can be more extreme in that we can also have equilibria with asymmetric liquidity traps where there is a liquidity trap in one country but not in the other. For example, Home can be in a liquidity trap with $r = 0$ and $\xi < 1$ while Foreign is not: $r^* > 0$ and $\xi^* = 1$. In this case, going back to the UIP equation, the exchange rate appreciates when the Poisson shock occurs $E > E_\tau$.

[7] When there is a possibility of exit as in Appendix A.6, and in the absence of home bias or of perfectly risk neutral agents—so that the other form of indeterminacy due to the interaction of portfolio effects and home bias is not present (see the previous footnote)—devaluations require a form of forward guidance that represents a deviation from the simple Taylor rules that we have imposed, as well as the possibility for output to be above potential after the exit: Forward guidance, by lowering interest rates below what the Taylor rule

From now on, we index the solution by the exchange rate E, and solve for the remaining equations:

$$\xi = 1 + \frac{1-\theta\bar{d}}{1-\frac{\bar{\delta}\theta}{\rho}}\frac{r^{w,n}}{\rho} + \frac{(1-x)d^{*}\theta(E-1)}{1-\frac{\bar{\delta}\theta}{\rho}}, \tag{12a}$$

$$\xi^{*} = 1 + \frac{1-\theta\bar{d}}{1-\frac{\bar{\delta}\theta}{\rho}}\frac{r^{w,n}}{\rho} + \frac{xd\theta(\frac{1}{E}-1)}{1-\frac{\bar{\delta}\theta}{\rho}}. \tag{12b}$$

It follows that both home and foreign outputs ξ and ξ^{*} are increasing in the world natural interest rate $r^{w,n}$, and home (foreign) output is increasing (decreasing) in the exchange rate E. The former is natural: The more acute the global asset shortage, the lower the world natural interest rate $r^{w,n}$, and the larger the required endogenous reduction in output (the lower ξ and ξ^{*}) to restore asset market equilibrium. The latter is intuitive since, as explained above, a depreciation in the home exchange rate stimulates the home economy to the detriment of the foreign economy through an expenditure switching effect.

Finally, note that the indeterminacy is bounded as it only applies while *both* countries are in a liquidity trap. Concretely, E must be within a range $[\underline{E}, \overline{E}]$, with $\xi = 1$ for $E = \overline{E}$, and $\xi^{*} = 1$ for $E = \underline{E}$, where $\bar{E} = 1 - (1-\theta\bar{d})r^{w,n}/[(1-x)d^{*}\theta\rho] > 1$ and $\underline{E} = 1/[1-(1-\theta\bar{d})r^{w,n}/(xd\theta\rho)] < 1$. By depreciating (appreciating) the exchange rate sufficiently, Home (Foreign) can avoid suffering a recession altogether.[8]

would have required after the exit, depreciates the exchange rate post exit, and also pre exit through a UIP logic. There are now two effects pre exit: (i) The pre exit devaluation itself stimulates output pre exit in the undertaking country at the expense of the other country exactly as when the liquidity trap is permanent as in this section; (ii) The reduction in interest rates and the associated increase in total output post exit stimulates output for all countries pre exit. As long as the probability of exit is small enough, the former effect (i) dominates the latter (ii), and the logic of our "currency wars" results during the global liquidity trap still goes through: In a global liquidity trap, devaluations stimulate the output of the undertaking country at the expense of the other country.

[8]For a given exchange rate E we can also provide an equivalent representation of the equilibrium using an Aggregate Demand (AD)-Aggregate Supply (AS) diagram:

$$\xi = \frac{\theta}{g+\theta}[x\xi(1+\frac{g\delta}{\rho}) + (1-x)E\xi^{*}(1+\frac{g\delta^{*}}{\rho}) + xgd + (1-x)gd^{*}],$$
$$\xi^{*} = \frac{1}{E}\frac{\theta}{g+\theta}[x\xi(1+\frac{g\delta}{\rho}) + (1-x)E\xi^{*}(1+\frac{g\delta^{*}}{\rho}) + xgd + (1-x)gd^{*}].$$

This is a system of two equations in two unknowns ξ and ξ^{*}. The left-hand-side and right-hand-side of the first equation describe respectively the home AS and AD curves as a function of ξ for a given E and ξ^{*}. The second equation does the same for Foreign. These equations—akin to home and foreign versions of the "Keynesian cross"—illustrate equilibrium through the perspective of goods markets rather than assets

Financial autarky. Following similar steps, we can define *financial autarky output*, $\xi^{a,l}$ and $\xi^{a,l*}$, as the output that obtains when intertemporal trade is not allowed:

$$\xi^{a,l} = 1 + \frac{1-\theta d}{1-\frac{\delta\theta}{\rho}} \frac{r^{a,n}}{\rho}, \tag{14a}$$

$$\xi^{a,l*} = 1 + \frac{1-\theta d^*}{1-\frac{\delta^*\theta}{\rho}} \frac{r^{a,n*}}{\rho}. \tag{14b}$$

Under financial autarky, home and foreign equilibrium outputs satisfy:

$$\xi^a = \min\left\{\xi^{a,l}, 1\right\} \quad ; \quad \xi^{a*} = \min\left\{\xi^{a,l*}, 1\right\}.$$

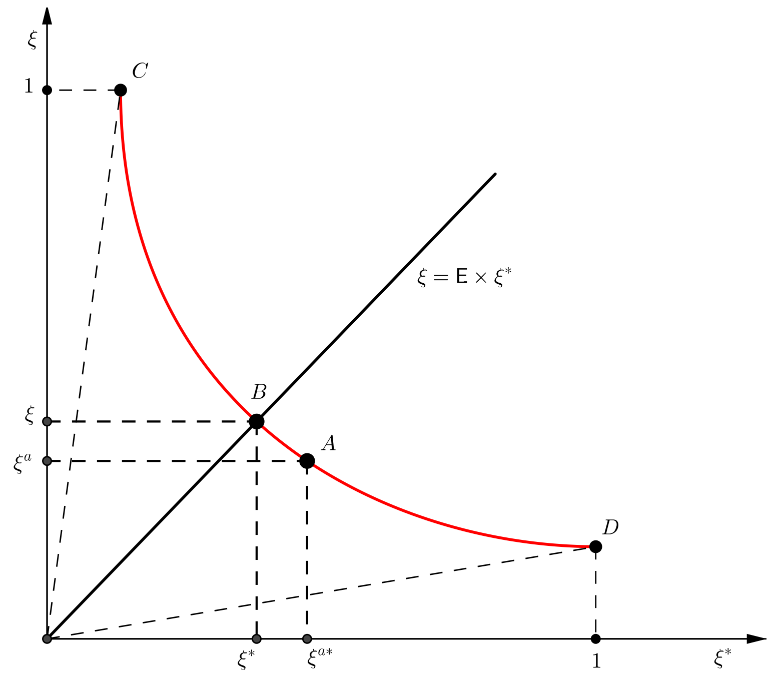
In particular, there is a liquidity trap at Home with $\xi^a < 1$ if and only if $r^{a,n} < 0$, and a liquidity trap in Foreign with $\xi^{a*} < 1$ if and only if $r^{a,n} < 0$, and the corresponding liquidity traps are deeper the more negative are the corresponding natural interest interest rates, i.e. the lower is financial capacity. These equations make clear that both at Home and in Foreign, the interest rate and outputs are entirely determined by domestic factors. Under financial autarky, and in contrast with the case of financial integration, each country's interest rate reflects its own asset scarcity. An asset shortage in one country cannot propagate to the another country when the capital account is closed.

Using the goods market clearing conditions, it follows that the *unique* equilibrium exchange rate under financial autarky satisfies:

$$E^a = \frac{\xi^a}{\xi^{a*}}, \tag{15}$$

which has the intuitive implication that if Home experiences a more severe liquidity trap (a lower ξ^a), it also has a more appreciated exchange rate. Unlike the financially integrated case, this is purely a goods market linkage, reflecting the relative scarcity of home goods.

markets. It is apparent from these equations that δ, δ^*, d and d^*, which all index global asset supply, act as positive aggregate demand shifters at Home and in Foreign. Similarly, θ, which is an inverse index of asset demand, acts as a positive aggregate demand shifter at Home and in Foreign. Finally, E and ξ^* act as positive aggregate demand shifters at Home, and $1/E$ and ξ act as positive aggregate demand shifters in Foreign.



The figure reports home (ξ) and foreign (ξ^*) output at the global ZLB, for different values of the exchange rate $E \in [\underline{E}, \bar{E}]$ when $\xi^a < 1$ and $\xi^{a*} < 1$. Point A denotes the autarky equilibrium ($E = E^a = \xi^a / \xi^{a*}$). When $E > E^a$, $\xi > \xi^a$ and $\xi^* < \xi^{a*}$ (point B). When $E = \bar{E}$, $\xi = 1$, Home escapes the ZLB and Foreign absorbs all the output loss (point C).

Figure 6: Output Determination in the Global ZLB

In the special case where both countries experience a liquidity trap under financial autarky (that is, when $r^{a,n} < 0$ and $r^{a,n*} < 0$), the equilibrium exchange rate simplifies to:

$$E^a = \frac{d}{d^*} \frac{1 - \frac{\delta^* \theta}{\rho}}{1 - \frac{\delta \theta}{\rho}}.$$

The country with larger asset scarcity (low d or low δ) has a lower output level and a stronger currency under financial autarky.

In that case, if $E = E^a$, the financial integration equilibrium coincides with the financial autarky equilibrium. For $E > E^a$, we have $\xi > \xi^a$ and $\xi^* < \xi^{a*}$, and vice versa for $E < E^a$. It follows that, by manipulating its exchange rate, a country can influence the relative size of its recession. This is summarized in Figure 6, which maps home and foreign output when the exchange rate varies between $\underline{E}$ and $\bar{E}$.

Net Foreign Assets, Current Accounts, and Metzler diagram in quantities. We now have all the ingredients to characterize Net Foreign Asset positions and Current Accounts, and to introduce one of our main analytical innovation, *the Metzler diagram in quantities*. Let's start by fixing the nominal exchange rate E. We can rewrite the home asset pricing and wealth accumulation equations (8a) and (8c) as:

$$V = \frac{\delta \xi X}{\rho}, \tag{16a}$$

$$W = \frac{\xi X + gD + g\frac{\delta \xi X}{\rho}}{g+\theta}, \tag{16b}$$

which implies:

$$\frac{NFA}{X} = \frac{W - (V+D)}{X} = \frac{\xi(1-\frac{\delta\theta}{\rho}) - \theta d}{g+\theta} = \frac{(1-\frac{\delta\theta}{\rho})(\xi - \xi^{a,l})}{g+\theta}, \tag{17a}$$

$$\frac{CA}{X} = g\frac{NFA}{X}. \tag{17b}$$

Equation (17a) has a similar interpretation as equation (6a): the home Net Foreign Asset and Current Account positions increase with home output ξ. Home is a net creditor (resp. debtor) if its output exceeds its financial autarky level: $\xi > \xi^{a,l}$ (resp. $\xi < \xi^{a,l}$).[9]

Similar equations hold for Foreign. In particular, we have:

$$\frac{NFA^*}{X^*} = \frac{\xi^*(1-\frac{\delta^*\theta}{\rho}) - \theta d^*}{g+\theta} = \frac{(1-\frac{\delta^*\theta}{\rho})(\xi^* - \xi^{a,l*})}{g+\theta},$$

which can be rewritten (replacing the exchange rate equation (9) into it) as:

$$\frac{NFA^*}{X^*} = \frac{\frac{\xi}{E}(1-\frac{\delta^*\theta}{\rho}) - \theta d^*}{g+\theta}. \tag{18}$$

Combining these equations with equilibrium in the world asset market expressed in the home currency

$$x\frac{NFA}{X} + (1-x)E\frac{NFA^*}{X^*} = 0, \tag{19}$$

[9] Observe that since $\xi \leq 1$, Home always runs a Current Account deficit when $\xi^{a,l} > 1$, i.e. when Home would escape the liquidity trap under financial autarky.

yields a simple re-derivation of the home recession as a function of the exchange rate E, equation (12a).

Given E, both the home and foreign Net Foreign Asset Positions are increasing in ξ. And given ξ, the foreign Net Foreign Asset position is decreasing in E. Both effects are intuitive.

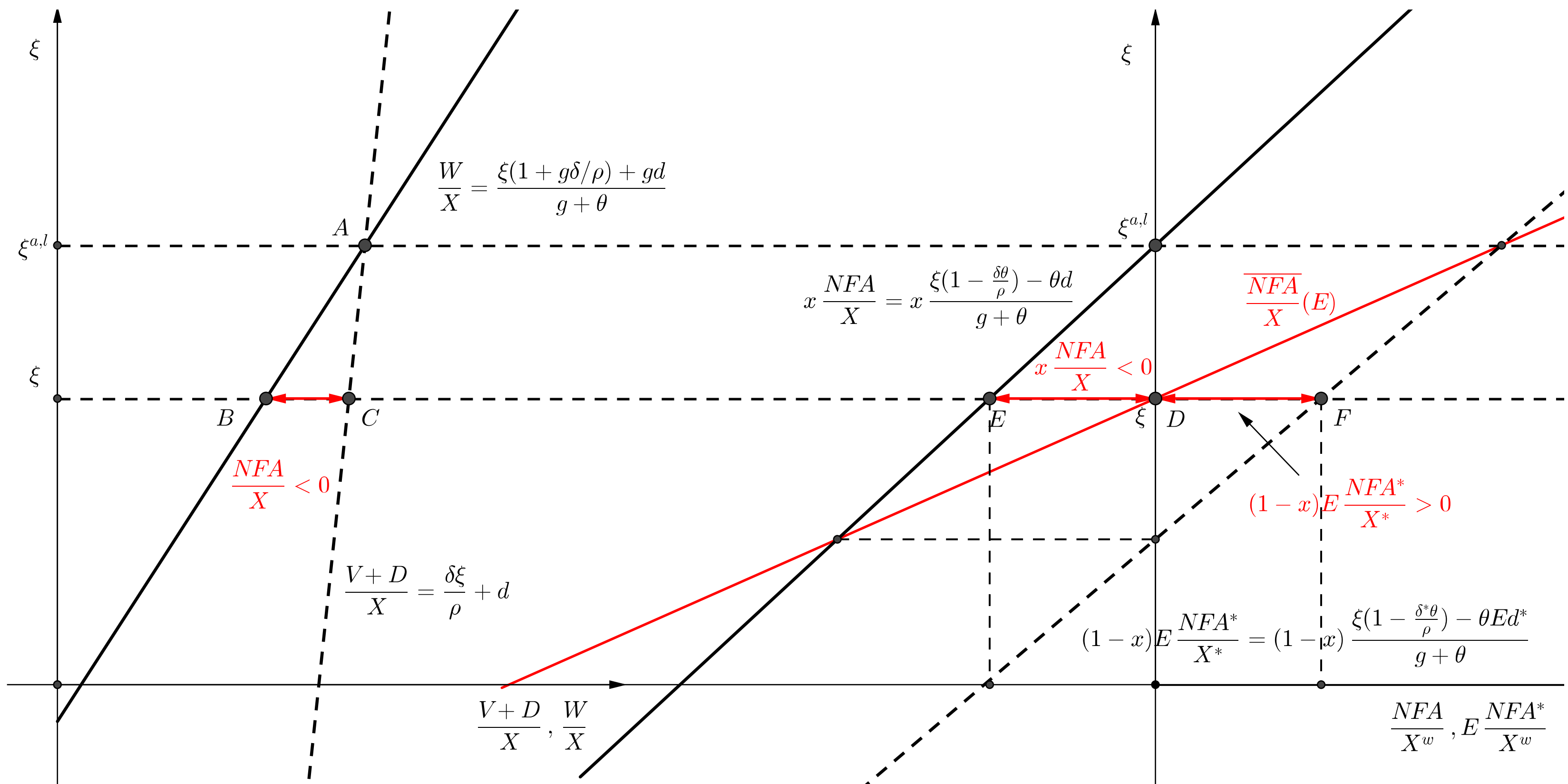
Indeed, given E, expressing all values in the home currency, an increase in ξ raises both home and foreign asset demands as well as the home and foreign supply of private assets, but leaves the home and foreign public supply of assets (public debt) unchanged. Similarly, given ξ, an increase in E increases foreign asset supply (foreign asset values in home currency) more than foreign asset demand (foreign wealth in home currency) because of the increased value of foreign public debt (in home currency). Taken together, this *Metzler diagram in quantities* immediately implies that ξ is increasing in E.

Panel (a) of Figure 7 reports home asset demand W (solid line) and home asset supply $V + D$ (dashed line) scaled by home potential output X, as a function of domestic output ξ (equations (16a) and (16b)). Both asset demand and asset supply are increasing in output, but the former increases faster than the latter. The two curves intersect at the financial autarky output $\xi^{a,l}$ (point A). For lower values of output, Home is a net debtor: $NFA/X < 0$. For higher values, it is a net creditor: $NFA/X > 0$. Panel (b) reports scaled home and foreign Net Foreign Asset position $NFA/(X + X^*)$ and $E \times NFA^*/(X + X^*)$, as a function of home output ξ (equations (17a) and (18)). The figure assumes that $\xi^{a,l*} < \xi^{a,l} < 1$ so that both countries are in a liquidity trap under financial autarky. Equilibrium home output ξ has to be such that global asset markets are in equilibrium, i.e. equation (19) holds (point D).

The Metzler diagram in quantities indicates that, under financial integration, domestic output is an average of the home and exchange-rate-weighted foreign financial autarky outputs. From equations (12a), (14a) and (14b), we obtain:

$$\xi = \frac{\theta \bar{d}(E)}{1 - \frac{\bar{\delta}\theta}{\rho}} = x \frac{1 - \frac{\delta\theta}{\rho}}{1 - \frac{\bar{\delta}\theta}{\rho}} \xi^{a,l} + (1 - x) \frac{1 - \frac{\delta^*\theta}{\rho}}{1 - \frac{\bar{\delta}\theta}{\rho}} E \xi^{a,l*}, \tag{20}$$

where $\bar{d}(E) = xd + (1 - x)Ed^*$ denotes the exchange rate-adjusted world public debt ratio, which increases with E since a depreciation of the home currency increases the value of



(a) Home Asset Demand and Supply

(b) Metzler Diagram when $\xi^{a,l*} < \xi^{a,l} < 1, E < E^a$ and $x = 0.5$

Panel (a) reports asset demand W/X (solid line) and asset supply $(V+D)/X$ (dashed line) as a function of home output ξ. The two lines intersect at the autarky level of output $\xi^{a,l}$ (point A). Panel (b) reports home (solid line) and foreign (dashed line) Net Foreign Assets scaled by world potential output, $xNFA/X$ and $(1-x)ENFA^*/X^*$, in the home currency, as a function of home output ξ, for a given E, when $\xi a, l < 1$ and $\xi^{a,l*} < 1$. Given an exchange rate $E \in [\underline{E}, \bar{E}]$, Home output is such that Net Foreign Asset positions are equilibrated, or equivalently such that the world's NFA (red line) $\overline{NFA/X}(E) = xNFA/X + (1-x)ENFA^*/X^*$ is zero (point D). If $\xi < \xi^{a,l}$, Home is a net debtor ($NFA/X < 0$), and runs a Current Account deficit ($CA/X < 0$).

Figure 7: Recessions and Net Foreign Asset Positions in a Global Liquidity Trap: the Metzler Diagram in Quantities

foreign public debt (expressed in the home currency).

We can use equation (20) to rewrite the home Net Foreign Asset position and Current Account as:

$$\frac{NFA}{X} = \frac{(1-\frac{\delta\theta}{\rho})}{g+\theta}\left[\frac{\theta\bar{d}(E)}{1-\frac{\bar{\delta}\theta}{\rho}} - \frac{\theta d}{1-\frac{\delta\theta}{\rho}}\right],$$
$$\frac{CA}{X} = g\frac{NFA}{X}.$$

Clearly, the more depreciated is the exchange rate, the greater is the home Net Foreign Asset position and so is its Current Account, allowing Home to export more of its recession abroad. It is apparent in these expressions that the sign and size of the home Net Foreign Asset position and its Current Account is determined by the gap between the exchange rate-adjusted world index of world asset supply $\theta\bar{d}(E)/(1-\bar{\delta}\theta/\rho)$, and the home index of asset supply $\theta d/(1-\delta\theta/\rho)$. Depending on the value of the exchange rate E, Home can be a surplus country, or a deficit country.[10]

When both countries are in a liquidity trap under financial autarky, we can express the Net Foreign Asset position and Current Account directly as a function of the exchange rate E, relative to the autarky exchange rate E^a. Substituting the expression for the exchange rate-adjusted financial capacity, we obtain:

$$\frac{NFA}{X} = \frac{1-\frac{\delta\theta}{\rho}}{1-\frac{\bar{\delta}\theta}{\rho}}\frac{(1-x)\theta d^*(E-E^a)}{g+\theta},$$
$$\frac{CA}{X} = g\frac{NFA}{X}.$$

We can now connect back with the financial autarky results. In the latter, the exchange rate is determinate precisely because the capital account is closed. In the case where both countries are in a liquidity trap under financial autarky, $\xi^a = \xi^{a,l} < 1$, $\xi^{a*} = \xi^{a,l*} < 1$ and $E^a = \xi^{a,l}/\xi^{a,l*}$. Then for $E = E^a$, the financial integration equilibrium coincides with the financial autarky equilibrium. For $E > E^a$, we have $\xi > \xi^a$, $\xi^* < \xi^{a*}$, and $NFA/X > 0$,

[10]It follows that in a global liquidity trap, there can be global imbalances even though the two countries are identical, which could never happen outside of a global liquidity trap. In this case, when $E > 1$, Home has a lower recession than Foreign and runs a Current Account Surplus, and vice versa if $E < 1$.

and vice versa for $E < E^a$. It follows that by depreciating its exchange rate and running a Current Account surplus, a country can reduce the size of its recession.

In order for a global liquidity trap to emerge under financial integration, it must be the case that at least one of the two regions is in a liquidity trap under financial autarky, in the sense that $r^{a,n} < 0$ or $r^{a,n*} < 0$. This does not, however, require *both* countries to experience a liquidity trap under financial autarky. Hence, it is perfectly possible for financial integration *per se* to drag a country into a global liquidity trap. This happens for Home if $r^{a,n} > 0$ but $r^{a,n*} < 0$ and $r^{w,n} < 0$. In that case, the preceding discussion indicates that Home must run a Current Account deficit and have a negative Net Foreign Asset position.

Secular Stagnation Hypothesis. Our model is consistent with the Secular Stagnation Hypothesis, put forward by Hansen (1939) and recently revived by Summers (2014) and Summers (2015a). Each economy could find itself in a permanent liquidity trap, with a deficient aggregate demand. The model offers a natural way of connecting the active debate, most recently illustrated by the exchange between Bernanke (2015) and Summers (2015b), surrounding secular stagnation and global imbalances. In particular, our model highlights that secular stagnation can be exported from one country to the other through Current Account surpluses in the origin country and Current Account deficits in the destination country. In other words, a "global savings glut" or a "global asset shortage", as discussed by Bernanke (2005) and Caballero et al. (2008a), can contribute to pushing the world economy into a secular stagnation equilibrium. Unlike the analysis in the benchmark case, where global imbalances affect the equilibrium real interest rate but are otherwise relatively benign, in an environment with very low autarky real interest rates, global imbalances may now contribute toward pushing the world economy into a global liquidity trap. See also Eggertsson et al. (2015) for a related analysis.

"Currency wars" and "reserve currency paradox". Outside the global liquidity trap, the exchange rate is pinned down ($E = 1$), output in each country is at its potential ($\xi = \xi^* = 1$) and the real interest rate is equal to its Wicksellian natural counterpart ($r = r^* = r^{w,n}$). It follows that nothing can be gained by a country's attempt to manipulate its exchange rate.

In the global liquidity trap, the global asset shortage cannot be offset by lower world interest rates and a world recession occurs. This global recession is propagated by global imbalances, with surplus countries pushing world output down and exerting a strong negative effect on the world economy.

Even though in this global liquidity trap regime the exchange rate is indeterminate, it is in principle possible for the home monetary authority to peg the exchange rate at any level E (within the indeterminacy region $[\underline{E}, \bar{E}]$) it sees fit by simply standing ready to buy and sell the home currency for the foreign currency at the exchange rate E. By choosing a sufficiently depreciated exchange rate, Home is able to partly export its recession abroad by running a Current Account surplus. That is, once interest rates are at the ZLB, our model indicates that exchange rate policies generate powerful beggar-thy-neighbor effects on output. This zero-sum logic resonates with current concerns regarding "currency wars": In the global stagnation equilibrium, attempts to depreciate one's currency affect one for one relative outputs, according to equation (9).[11,12]

Of course, if both countries attempt to simultaneously depreciate their currency, these efforts cancel out, and the exchange rate remains a pure matter of coordination. Moreover, if agents coordinate on an equilibrium where the home exchange rate is appreciated, as could

[11]Different authors take "currency wars" to mean different things. Our interpretation is that it corresponds to a situation where there is a conflict between the two countries on the desired level of the exchange rate in a zero-sum game: A devaluation improves the fate of one country at the expense of the other. A different perspective can be found in Korinek (2015), who emphasizes that negative spillovers from one country to the other are not necessarily inefficient—they can be thought as movements along a constrained Pareto efficient frontier—and hence do not necessarily build a case for international policy coordination. This is the case in our model as changes in the exchange rate devaluations do not generate Pareto improvements but movements along the constrained Pareto efficient frontier—which as explained above, we take to be precisely the meaning of "currency wars".

[12]For tractability, our baseline model assumes a unitary elasticity of substitution between home and foreign goods. Because of this assumption, the relative value of home vs. foreign output $\xi/(E\xi^*)$ is invariant to the exchange rate E because of perfectly offsetting price and quantity effects. Similarly, the dependence of the real consumption of home agents $\theta x^x(1-x)^{1-x}W/E^{1-x}$ on the exchange rate E depends on the relative strengths of offsetting effects of devaluations on home wealth W and on the relative price of foreign goods E. In Appendix A.3, we relax the unitary elasticity assumption. We consider arbitrary elasticities of substitution σ between home and foreign goods, and show that the main results of the model hold. As long as $\sigma > 1$, the relative value of home vs. foreign output $\xi/(E\xi^*)$ increases with E, so that devaluations of the domestic currency are associated in increases in the relative value of home vs. foreign output. The higher σ, the more domestic devaluations increase the real consumption of home agents $\theta W/\left[x+(1-x)E^{1-\sigma}\right]^{1/(1-\sigma)}$ and reduce that of foreign agents.

be the case if the home currency were perceived to be a "reserve currency," then this would worsen the recession at Home. In other words, while the reserve currency status may be beneficial outside a liquidity trap as it increases purchasing power and lowers funding costs, it exacerbates the domestic recession in a global liquidity trap. We dub this effect the "paradox of the reserve currency". This mechanism captures a dimension of the appreciation struggles of Switzerland during the recent European turmoil, and of Japan before the implementation of Abenomics. Similarly, it helps us understand some of the difficulties faced by the U.S. in normalizing its monetary policy.

3 Inflation

So far, we have assumed that prices are fully rigid. In this section, we relax this assumption and allow for *some* price adjustment through a Phillips curve.

This extension gives us the opportunity to reiterate some well-known insights about the economics of liquidity traps, and to obtain some new ones. The former are that credibly higher inflation targets reduce the severity of a liquidity trap, that more (downward) price flexibility can exacerbate the severity of the trap as the economy may fall into a deflationary spiral. The less known one is that in a *global* liquidity trap, it is the *more rigid* country that experiences the worst trap (note the contrast between this relative rigidity and the aggregate rigidity implication). Moreover, it is now possible for some regions of the world to escape the liquidity trap if their inflation expectations are sufficiently high.

3.1 Extending the Model

Phillips curve. We wish to capture the idea that wages, or prices, are rigid downwards, but not upwards. We follow the literature and assume that prices and wages cannot fall faster than a certain limit pace, perhaps determined by a "social norm" and that this limit pace is faster if there is more slack in the economy:[13]

$$\pi_{H,t} \geq -\kappa_0 - \kappa_1(1-\xi_t),$$
$$\pi^*_{F,t} \geq -\kappa^*_0 - \kappa^*_1(1-\xi^*_t),$$

where $\pi_{H,t} = \dot{P}_{H,t}/P_{H,t}$ (resp. $\pi^*_{F,t} = \dot{P}^*_{F,t}/P^*_{F,t}$) denotes the *domestic* (resp. foreign) inflation rate, and where $\kappa_1 \geq 0$ and $\kappa^*_1 \geq 0$. Moreover, we assume that if there is slack in the economy, prices or wages fall as fast as they can: $\xi_t < 1$ implies that $\pi_{H,t} = -\kappa_0 - \kappa_1(1-\xi_t)$ and $\xi^*_t < 1$ implies that $\pi^*_{F,t} = -\kappa^*_0 - \kappa^*_1(1-\xi^*_t)$. We capture this requirement with the complementary slackness conditions $[\pi_{H,t} + \kappa_0 + \kappa_1(1-\xi_t)](1-\xi_t) = 0$ and $[\pi^*_{F,t} + \kappa^*_0 + \kappa^*_1(1-\xi^*_t)](1-\xi^*_t) = 0$.

To summarize, there are two Phillips curves, one for Home and one for Foreign. The home Phillips curve traces out an increasing curve in the $(\pi_{H,t}, \xi_t)$ space, which becomes vertical at $\xi_t = 1$. The foreign Phillips curve is similar.

Monetary policy. We assume that monetary policy is conducted according to simple truncated Taylor rules, where the nominal interest rate responds to domestic inflation:

$$i_t = \max\{r^n_t + \bar{\pi} + \psi_\pi(\pi_{H,t} - \bar{\pi}), 0\},$$
$$i^*_t = \max\{r^{n*}_t + \bar{\pi}^* + \psi^*_\pi(\pi^*_{F,t} - \bar{\pi}^*), 0\}.$$

In these equations r^n_t and r^{n*}_t are the relevant natural interest rates at Home and in Foreign, which depend on whether we analyze the financial integration equilibrium or the financial autarky equilibrium. We denote by $\bar{\pi} \geq \max\{-\kappa_0, 0\}$ and $\bar{\pi}^* \geq \max\{-\kappa^*_0, 0\}$ the home and foreign inflation targets, and $\psi_\pi > 1$ and $\psi^*_\pi > 1$ are Taylor rule coefficients.

For simplicity, we take the limit of large Taylor rule coefficients $\psi_\pi \to \infty$ and $\psi^*_\pi \to \infty$. This specification of monetary policy implies that inflation in any given country is equal to its target and that there is no recession as long as the country's interest rate is positive. For example, for Home, either $\pi_{H,t} = \bar{\pi}$, $\xi_t = 1$, and $i_t = r^n_t + \bar{\pi} \geq 0$ or $\pi_{H,t} \leq -\kappa_0 \leq \bar{\pi}$, $\xi_t \leq 1$, and $i_t = 0$. The same holds for Foreign.

[13] The introduction of this kind of Phillips curves borrows heavily from Eggertsson and Mehrotra (2014) and Caballero and Farhi (2015).

3.2 Equilibria

We assume that the world natural interest rate $r^{w,n} = -\rho + \bar{\delta}\theta/(1-\bar{d}\theta) < 0$ is low enough that $r^{w,n} < \min\{\kappa_0, \kappa_0^*\}$, which yields the existence of a *global* liquidity trap equilibrium. We show that in this case, there are *several* possible equilibrium configurations once inflation considerations are added. First, there can be equilibria with no liquidity traps either at Home or in Foreign. Second, there can be equilibria with a symmetic global liquidity trap both at Home and in Foreign. Third, there can be asymmetric liquidity trap equilibria with a liquidity trap only in one country. We treat each in turn.

No liquidity trap equilibrium. We solve for the no-liquidity trap case. This equilibrium is such that $\xi = 1$, $\xi^* = 1$, $\pi_H = \bar{\pi}$, $\pi_F^* = \bar{\pi}^*$, $i = r^{w,n} + \bar{\pi}$, and $i^* = r^{w,n} + \bar{\pi}^*$.

It is straightforward to show that the terms of trade $S_t = E_t P_{F,t}^*/P_{H,t}$ is constant at $S_t = 1$ which implies that $\dot{E}_t/E_t = \pi_H - \pi_F^* = \bar{\pi} - \bar{\pi}^*$. The condition for this equilibrium to exist is that $i \geq 0$ and $i^* \geq 0$, i.e. $\min\{r^{w,n} + \bar{\pi}, r^{w,n} + \bar{\pi}^*\} \geq 0$. This condition shows that *the no-liquidity trap equilibrium exists if and only if the inflation targets $\bar{\pi}$ and $\bar{\pi}^*$ in both countries are high enough.*

Note, however, that this is an existence, not a uniqueness result. In fact, as we shall see next, other equilibria exist even if inflation targets are high enough to make the no-liquidity trap equilibrium feasible.

Symmetric global liquidity trap equilibrium. Let us now focus on the other extreme and solve for the symmetric global liquidity trap case.

Observe that in a stationary equilibrium the terms of trade $S_t = E_t P_{F,t}^*/P_{H,t}$ must be constant at $S_t = \xi/\xi^*$, so that $\dot{E}_t/E_t = \pi_H - \pi_F^*$. Uncovered Interest Parity then requires that $i = i^* + \dot{E}_t/E_t$, which combined with $i = i^* = 0$ implies that $\dot{E}_t/E_t = 0$ and hence $\pi_F^* = \pi_H = \pi^w$. That is, *in a global liquidity trap, inflation rates are equal across countries,* hence real interest rates are equalized, $r = r^* = -\pi^w$.

In Appendix A.2, we provide a detailed exposition of the equilibrium equations. We can represent the equilibrium as an Aggregate Demand (AD)-Aggregate Supply (AS) diagram which constitutes a system of four equations in four unknowns π_H, π_F^*, ξ, and ξ^*. The home and foreign AD curves are given by:

$$\xi = \frac{\frac{1-\frac{\pi_H}{\rho}}{1-\frac{\bar{\delta}\theta}{\rho}-\frac{\pi_H}{\rho}} x\theta d}{1-\frac{1-\frac{\pi_H}{\rho}}{1-\frac{\bar{\delta}\theta}{\rho}-\frac{\pi_H}{\rho}}\frac{1-x}{\xi^*}\theta d^*} \quad ; \quad \xi^* = \frac{\frac{1-\frac{\pi_F^*}{\rho}}{1-\frac{\bar{\delta}\theta}{\rho}-\frac{\pi_F^*}{\rho}}(1-x)\theta d^*}{1-\frac{1-\frac{\pi_F^*}{\rho}}{1-\frac{\bar{\delta}\theta}{\rho}-\frac{\pi_F^*}{\rho}}\frac{x}{\xi}\theta d}.$$

The home and foreign AS curves are given by:

$$\pi_H = -\kappa_0 - \kappa_1(1-\xi) \quad ; \quad \pi_F^* = -\kappa_0^* - \kappa_1^*(1-\xi^*)$$

as long as $\xi < 1$ and $\xi^* < 1$, and become vertical at $\xi = 1$ and $\xi^* = 1$.

It can be verified that the home and foreign AD equations imply $\pi_H = \pi_F^* = \pi^w$. If $\kappa_0 = \kappa_0^*$, this implies that

$$\frac{1-\xi^*}{1-\xi} = \frac{\kappa_1}{\kappa_1^*},$$

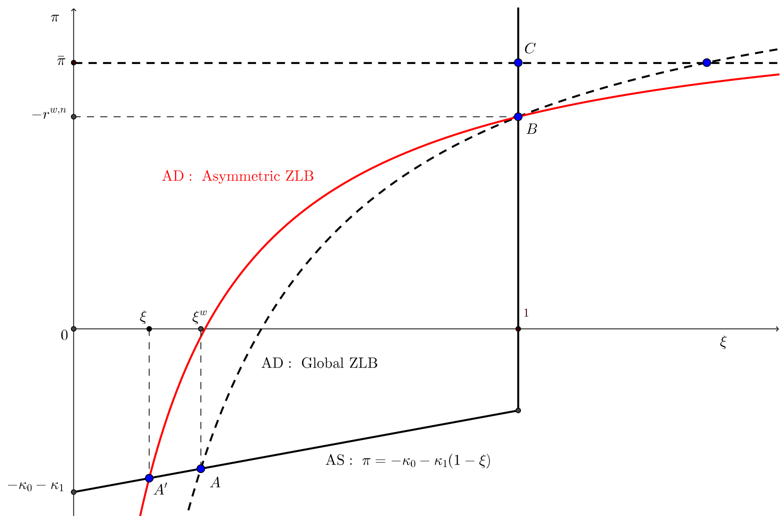
so that *Home has a smaller recession than Foreign,* $\xi > \xi^*$, *if and only if home prices or wages are more flexible than foreign prices or wages:* $\kappa_1 > \kappa_1^*$. More (downward) price or wage flexibility reduces the size of the recession at Home relative to Foreign because it depreciates the domestic terms of trade. In a stationary equilibrium, deflation rates are equalized across countries so relatively more wage flexibility implies a relatively smaller recession.

The rest of the equilibrium simplifies greatly when the Phillips curves are identical in both countries so that $\kappa_0^* = \kappa_0$ and $\kappa_1^* = \kappa_1$. Indeed, this requires that the recession is identical at Home and in Foreign: $\xi = \xi^* = \xi^w$, and $S = 1$. Moreover, in this case, we have the following simpler *global* AD-AS representation:

$$\xi^w = \frac{1-\frac{\pi^w}{\rho}}{1-\frac{\bar{\delta}\theta}{\rho}-\frac{\pi^w}{\rho}}\theta\bar{d},$$

$$\pi^w = -\kappa_0 - \kappa_1(1-\xi^w).$$

This representation makes clear that compared with the case with no inflation, *there is now a negative feedback loop between the global recession and inflation.* A larger recession reduces inflation, which in turn raises the real interest rate, causing a further recession etc. *ad*



The figure reports Aggregate Supply (solid black line) and Aggregate Demand (dashed black line) in a symmetric liquidity trap equilibrium (point A) and in a no liquidity trap equilibrium (point C), when $\kappa_0^* = \kappa_0$, $\kappa_1^* = \kappa_1$, and $\bar{\pi}^* = \bar{\pi}$. The red solid line represents the home AD curve in the asymmetric equilibrium where Foreign is out of the liquidity trap (point A').

Figure 8: Aggregate Demand and Aggregate Supply in a symmetric and asymmetric liquidity trap equilibria.

infinitum. This *feedback loop is stronger, the more flexible prices and wages are*, as captured by the slope of the Phillips curve κ_1. That is, wage flexibility plays out differently across countries and at the global level: Countries with more price flexibility bear a smaller share of the global recession than countries with less wage flexibility; but at the global level, more wage flexibility exacerbates the global recession.

The equilibrium is guaranteed to exist under some technical conditions on the Phillips curves parameters κ_0 and κ_1, which ensure that the feedback loop is not so powerful to lead to a total collapse of the economy.[14]

Figure 8 reports the global AD-AS diagram and displays both the no liquidity trap equilibrium (if it exists) and the symmetric liquidity trap equilibrium. For simplicity the figure is drawn in the case where Philips curves and inflation targets are identical in both countries so that $\kappa_0^* = \kappa_0$ and $\kappa_1^* = \kappa_1$, $\bar{\pi}^* = \bar{\pi}$.

We focus on the no liquidity trap equilibrium and the symmetric liquidity trap equilibrium

[14] For $\xi^w = 1^-$, the AD curve has $\pi^w = -r^{w,n}$, while the AS curve has $\pi^w = -\kappa_0 < -r^{w,n}$. For $\xi^w = 0$, the AD curve has $\pi^w = \rho$, while the AS curve has $\pi^w = -(\kappa_0 + \kappa_1)$. A sufficient condition for a unique intersection is that $\kappa_0 + \kappa_1 \leq -\rho$.

for now. The AS curve (black solid line) slopes upwards, then becomes vertical at $\xi = \xi^w = 1$: A smaller recession is associated with less deflation, until full employment is achieved. At the ZLB, the global AD curve (black dashed line) also slopes upwards since an increase in inflation reduces the real interest rate, which increases output. Away from the ZLB, the AD curve becomes horizontal at $\bar{\pi}$. We always assume that the upward sloping part of the AD curve is steeper than the non-vertical part of the AS curve and that they intersect at one point, A. The AD and AS schedules intersect at either exactly point A, or at three points, A, B, and C. Point A is the symmetric liquidity trap equilibrium: $i = 0$, $\pi^w = -\kappa_0 - \kappa_1(1 - \xi^w) < \bar{\pi}$, and $\xi^w < 1$. Point C, if it exists, corresponds to the no liquidity trap equilibrium with $i = i^* = \bar{\pi} > 0$, $\pi^w = \bar{\pi}$, and $\xi = \xi^w = 1$. Point B, if it exists, is unstable, and so we ignore it.

Asymmetric liquidity trap equilibria. Can we have an asymmetric equilibrium where one country is in a liquidity trap but not the other? As we shall see, it is *always possible.* These asymmetric liquidity trap equilibria are associated with different values of the real exchange rate, and are a manifestation of the same fundamental indeterminacy that we identified in the case with no inflation.

Suppose that one country is in a liquidity trap (say Home) but not the other (say Foreign). Then because the terms of trade must be constant at $S_t = \xi$, we must have $i = 0$, $i^* = i - \dot{E}_t/E_t = \pi_F^* - \pi_H > 0$, $\xi < 1$, $\xi^* = 1$, $\pi_F^* = \bar{\pi}^*$, and $\pi_H + \kappa_0 + \kappa_1(1 - \xi) = 0$. In Appendix A.2, we provide a detailed exposition of the equilibrium equations. We find:

$$\xi = \frac{x \frac{1 - \frac{\pi_H}{\rho}}{1 - \frac{\delta\theta}{\rho} - \frac{\pi_H}{\rho}} \theta d}{1 - (1 - x) \frac{1 - \frac{\pi_H}{\rho}}{1 - \frac{\delta\theta}{\rho} - \frac{\pi_H}{\rho}} \theta d^*},$$

$$\pi_H = -\kappa_0 - \kappa_1(1 - \xi).$$

The equilibrium is guaranteed to exist under the same technical conditions on Phillips curves that the ones derived above.

It is easy to see that *the home recession is larger and home inflation is lower in this asymmetric liquidity trap equilibrium where only Home is in a liquidity trap, than in the* *symmetric equilibrium where both Home and Foreign are in a liquidity trap.* In Figure 8, the red solid line reports the Home AD curve in the asymmetric equilibrium when Foreign is not in a liquidity trap. Point A' is the corresponding equilibrium. We can verify immediately that $\xi < \xi^w$, that is: The recession is more severe for the country that remains in the trap.

Inflation, exchange rates, and the structure of equilibria. Let us take stock and summarize the structure of equilibria when $r^{w,n} < \min\{\kappa_0, \kappa_0^*\}$. There may exist an equilibrium with no liquidity trap, which occurs if and only if $\min\{r^{w,n} + \bar{\pi}, r^{w,n} + \bar{\pi}^*\} \geq 0$. But there always exists a symmetric global liquidity trap equilibrium, as well as two asymmetric liquidity trap equilibria where only one country is in a liquidity trap. These symmetric and asymmetric liquidity trap equilibria are associated with different values of the real exchange rate and this multiplicity is a manifestation of the same fundamental indeterminacy that we identified in the case with no inflation. Indeed, it is immediate to see that terms of trade S are the most depreciated in the asymmetric liquidity trap equilibrium where Home is not in a liquidity trap but Foreign is, the most appreciated in the asymmetric liquidity trap equilibrium where Home is in a liquidity trap but Foreign is not, and intermediate between these two values in the symmetric liquidity trap equilibrium where both Home and Foreign are in a liquidity trap. The severity of the recession at Home is directly commensurate with the degree of appreciation of the terms of trade S.

"Currency wars". Suppose that $\min\{r^{w,n} + \bar{\pi}, r^{w,n} + \bar{\pi}^*\} < 0$. A country (say Home) can target its exchange rate by standing ready to exchange unlimited quantities of home currency for foreign currency at a given crawling exchange rate. Doing so can in effect rule out both the symmetric liquidity trap equilibrium and the asymmetric liquidity trap equilibrium where it is in a liquidity trap. Home can therefore always guarantee that it will not be in a liquidity trap, and avoid a recession by shifting it entirely to Foreign, which then experiences a deeper recessions.[15]

[15]In Appendix A.2, we characterize Net Foreign Asset positions and Current Accounts in all the equilibria described above. In the no liquidity trap equilibrium, these quantities are given by exactly the same formula as in the case with no inflation and can be represented in a Metzler diagram. In a symmetric global liquidity trap equilibrium instead, they are given by a Metzler diagram in quantities augmented with a global AS curve. The qualitative effects are essentially similar to the no inflation case.

4 Public Debt, Helicopter Drops, and Fiscal Policy

In a liquidity trap, public debt, helicopter drops, and fiscal policy have special roles to play. They all have the potential to stimulate the economy by alleviating the excess demand for financial assets and the corresponding excess supply of goods that materialize when interest rates are zero and output is at potential, and which result in equilibrium in a recession with output below potential.

4.1 Public Debt

In the interest of space, we only consider the case of a global liquidity trap. In the base model with rigid prices, we have

$$\begin{aligned}
\xi &= \frac{\theta \bar{d}(E)}{1-\frac{\bar{\delta}\theta}{\rho}}, \\
\xi^* &= \frac{1}{E}\frac{\theta \bar{d}(E)}{1-\frac{\bar{\delta}\theta}{\rho}}, \\
\frac{NFA}{X} &= \frac{(1-\frac{\delta\theta}{\rho})}{g+\theta}\left[\frac{\theta \bar{d}(E)}{1-\frac{\bar{\delta}\theta}{\rho}} - \frac{\theta d}{1-\frac{\delta\theta}{\rho}}\right], \\
\frac{CA}{X} &= g\frac{NFA}{X}.
\end{aligned}$$

These equations make apparent that for a given exchange rate E, an increase in debt at Home D or in Foreign D^* increases world net asset supply and reduces the world asset shortage. As a result home and foreign outputs ξ and ξ^* increase. An increase in debt at Home decreases the home Net Foreign Asset position and pushes the home Current Account toward a deficit.

Similar conclusions emerge in the extended model with inflation of Section 3, where we have

$$
\begin{aligned}
\xi^w &= \frac{1-\frac{\pi^w}{\rho}}{1-\frac{\bar{\delta}\theta}{\rho}-\frac{\pi^w}{\rho}}\theta\bar{d}, \\
\pi^w &= -\kappa_0-\kappa_1(1-\xi^w), \\
\frac{NFA}{X} &= \frac{(1-\frac{\delta\theta}{\rho}-\frac{\pi^w}{\rho})}{g+\theta+\pi^w}\left[\frac{\theta\bar{d}}{1-\frac{\bar{\delta}\theta}{\rho}-\frac{\pi^w}{\rho}}-\frac{\theta d}{1-\frac{\delta\theta}{\rho}-\frac{\pi^w}{\rho}}\right], \\
\frac{CA}{X} &= g\frac{NFA}{X}.
\end{aligned}
$$

The effect of public debt on output gains an extra kick through the feedback loop between output and inflation. The increase in output increases inflation, reducing real interest rates, further increasing output etc. ad infinitum. This boosts the Keynesian output multiplier associated with public debt issuance.

It is important to note that in a liquidity trap, we necessarily have $r^w \leq g$ since $r^w = 0$ and $g \geq 0$. This implies that the government does not need to levy taxes to sustain debt, and in fact can afford to rebate some tax revenues to households. Fiscal capacity is therefore not a constraint on the use of debt as an instrument to stimulate the economy. This stark conclusion rests on the assumption that the trap is permanent. If the trap were only temporary (as in the model with exit in Appendix A.6), the results could be different, depending on whether the post-exit economy is dynamically efficient or not. If the post-exit economy is dynamically inefficient, then the conclusion above still holds. But if the post-exit economy is dynamically efficient, then fiscal capacity is eventually required to service debt after exit, constraining the use of debt issuance as a stimulus tool during the liquidity trap.[16]

[16]When the economy is dynamically inefficient with $r^w < g$, it is possible to reinterpret government debt as a pure bubble. The only difference is that the lump sum rebate to newborns takes the form of new bubbles, with the same value. For example, at Home, we would replace debt D by a bubble B, and rebate to newborns $-\tau(1-\delta)\xi X = -(r^w - g)B$ by new bubbles. Crucially, the requirement that the value of new bubbles be positive requires that the economy be dynamically inefficient with $r^w < g$.

This reinterpretation offers the following insights. Outside of a liquidity trap, world interest rates are increasing in home and foreign bubbles. In a liquidity trap, home and foreign output gaps are both increasing in home and foreign bubbles. In both cases, an increase in the bubble at Home decreases the home Net Foreign Asset position and pushes its Current Account toward a deficit.

4.2 Helicopter Drops

At the ZLB, public debt and money are perfect substitute (at the margin) zero interest rate government liabilities.[17] As a result, Issuing government bonds and issuing money as a helicopter drop are rigorously equivalent at the ZLB. Hence all our results in Section 4.1 regarding the issuance of public debt at the ZLB apply *identically* to the issuance of money. In both cases, if the liquidity trap were temporary, and if the economy were dynamically efficient after the exit of the trap, fiscal capacity would be needed either to soak up the extra money that has been issued at the ZLB, or to service the government bonds that has been issued at the ZLB.

4.3 Government Spending

We now introduce balanced budget government spending. At Home, government spending on home goods $\gamma_G X$ is financed by increasing the tax τ on the income of newborns $(1-\delta)\,\xi X$, for a constant level of public debt D/X. The same applies to Foreign where government spending $\gamma_G^* X^*$ is financed by increasing the tax τ^* on the income of newborns $(1-\delta^*)\,\xi^* X^*$, for a constant level of public debt D^*/X^*.

In the interest of space, we only consider the case of a global liquidity trap. In the base

[17] As explained in Section 2.1, we could introduce money in the model via a Cash-In-Advance (CIA) constraint requiring agents to hold cash (of their country of residence) in a proportion ϵ of their consumption spending. At the ZLB, the model with $\epsilon > 0$ delivers the same equilibrium allocations as the cashless limit $\epsilon \to 0$ model which we focus on. Indeed, even when $\epsilon > 0$, the CIA constraint is slack at the ZLB, and hence money and public debt are perfect substitutes at the margin since holding money doesn't bring any additional marginal liquidity benefit to agents over and above holding public debt.

model with perfectly rigid prices, we have

$$
\begin{aligned}
E &= \frac{\xi - \gamma_G}{\xi - \gamma_G^*}, \\
\xi - \gamma_G &= \frac{\theta \bar{d}(E) + \frac{\overline{\delta \gamma_G}(E)\theta}{\rho}}{1 - \frac{\bar{\delta}\theta}{\rho}}, \\
\xi - \gamma_G^* &= \frac{1}{E} \frac{\theta \bar{d}(E) + \frac{\overline{\delta \gamma_G}(E)\theta}{\rho}}{1 - \frac{\bar{\delta}\theta}{\rho}}, \\
\frac{NFA}{X} &= \frac{\xi(1 - \frac{\delta\theta}{\rho}) - \gamma_G - \theta \frac{D}{X}}{g + \theta} = \frac{(1 - \frac{\delta\theta}{\rho})[\frac{\theta \bar{d}(E) + \frac{\overline{\delta \gamma_G}(E)\theta}{\rho}}{1 - \frac{\bar{\delta}\theta}{\rho}} - \frac{\frac{\delta \gamma_G \theta}{\rho} + \theta d}{1 - \frac{\delta\theta}{\rho}}]}{g + \theta}, \\
\frac{CA}{X} &= g \frac{NFA}{X}.
\end{aligned}
$$

These equations make apparent that given the exchange rate E, home government spending stimulates home output more than one-for-one, i.e. with a Keynesian government spending multliplier

$$1 + \frac{\frac{x\delta\theta}{\rho}}{1 - \frac{\bar{\delta}\theta}{\rho}} > 1,$$

and it stimulates foreign output but less with a Keynesian government spending multiplier of

$$\frac{1}{E} \frac{\frac{x\delta\theta}{\rho}}{1 - \frac{\bar{\delta}\theta}{\rho}} > 0.$$

These two effects are intuitive given that government spending not only increases the demand for home goods and reduces the asset demand arising from home agents who must now pay extra taxes to finance the increase in government spending, but also indirectly increases asset supply by stimulating home output. This explains why the domestic government spending multiplier is greater than one, and why the effect on foreign output is positive. Moreover, and for the same reason, home government spending reduces the home Net Foreign Asset position and pushes the home Current Account toward a deficit. Similar effects apply for foreign government spending.

We stress that these results rely on the assumption of perfectly rigid prices. Important differences arise when nominal rigidities are less extreme and some price adjustment is possible, as in the model of Section 3. Focusing on the global liquidity trap equilibrium with identical Phillips curves ($\kappa_0^* = \kappa_0$ and $\kappa_1^* = \kappa_1$) so that $\xi = \xi^* = \xi^w$, we have

$$
\begin{aligned}
S &= \frac{\xi^w - \gamma_G}{\xi^w - \gamma_G^*} \\
\xi^w - \gamma_G &= \frac{x\theta d + (1-x)\frac{\xi^w - \gamma_G}{\xi^w - \gamma_G^*}\theta d^* + \frac{x\theta\delta\gamma_G + (1-x)\theta\delta^*\gamma_G^*\frac{\xi^w - \gamma_G}{\xi^w - \gamma_G^*}}{\rho - \pi_H}}{1 - \frac{\theta\bar{\delta}}{\rho - \pi_H}}, \\
\pi^w &= -\kappa_0 - \kappa_1(1 - \xi^w), \\
\frac{NFA}{X} &= \frac{\xi^w(1 - \frac{\delta\theta}{\rho - \pi^w}) - \gamma_G - \theta d}{g + \theta + \pi^w}, \\
\frac{CA}{X} &= g\frac{NFA}{X}.
\end{aligned}
$$

For a given E, in response to an increase in home government spending, a transition to a new steady state where the home terms of trade is more appreciated takes place over time, during which home inflation runs higher than foreign inflation. In the short run, home output increases more than one-for-one i.e. with a Keynesian government spending multiplier greater than one, and foreign output increases, for the same reasons as above and for the additional reason that inflation increases, reducing the real interest rate, further stimulating output, further increasing inflation etc... ad infinitum. The home Net Foreign Asset position decreases, and the home Current Account is pushed toward a deficit.

In the long run home and foreign output increase by the same amount, because the appreciation of the home terms of trade rebalances demand toward foreign goods through an expenditure switching effect, and global output increases more than one-for-one (i.e. with a multiplier greater than one). The appreciation of the home terms of trade results in a further deterioration of the home Net Foreign Asset Position and a further increase in the home Current Account deficit.[18]

[18] These effects are similar to the ones derived in Farhi and Werning (2012) in the context of a standard open-economy New-Keynesian model of a currency union confronted with a temporary liquidity trap.

5 Safe Assets and Risk Premia

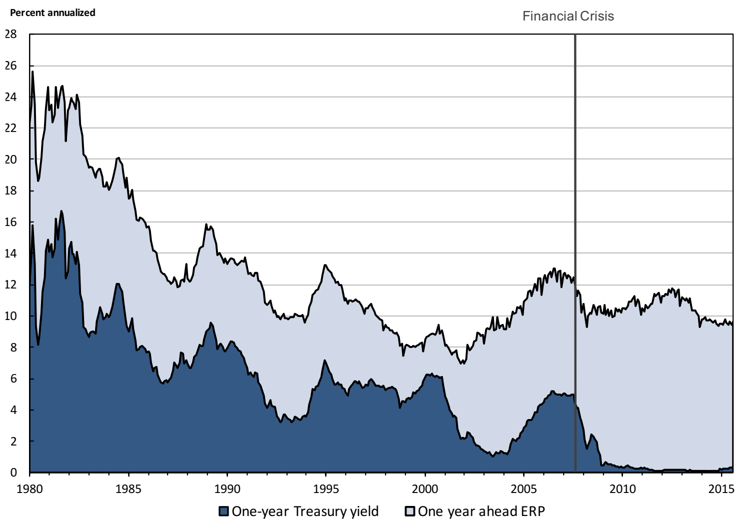
We now introduce a formal distinction between *safe assets* and *risky assets*, and analyze the implications of *safe* asset shortages rather than asset shortages in general. We do so by introducing risk and by allowing heterogeneity in risk aversion within and across countries.

This modification of the benchmark model allows us to address two important empirical observations. First, Figure 9 reports the one-year U.S. Treasury yield, together with the expected risk premium (ERP) from Duarte and Rosa (2015). The ERP is constructed as the first principal component of twenty models of the one-year ahead U.S. equity risk premium. The sum of the two components yields an estimate of expected U.S. equity returns. We observe two phases in this figure. From 1980 to roughly 2000, the ERP declines (from 11% to 2%), in line with the interest rate (from 16% to 6%). Since 2000, however, the ERP retraced its steps (from 2% to 9%), despite the continuing decline in interest rates (from 6% to 0%). The divergent behavior of the ERP and interest rates is particularly striking after 2009 when the U.S. enters the ZLB, and the risk premium *increases*, leaving expected equity returns largely unchanged.

Second, Figure 10 reports a crude illustration of the “Safe Asset Imbalances”. The figure reports the net safe asset position (as a fraction of world GDP) for each country or group of countries corresponding to Figure 1. The net safe asset position is constructed from Lane and Milesi-Ferretti (2007)’s External Wealth of Nation dataset, as the sum of Official Reserves (minus Gold), Portfolio Debt and Other Assets, minus Portfolio Debt and Other Liabilities.[19] The figure shows vividly that the net supply of safe assets originates largely with the U.S. and -to a smaller extent- the Eurozone. In 2011, the U.S. net supply of safe assets accounted for 9% of world GDP, up from 5% in 2000, while the Eurozone net supply accounted for 3% of world GDP. On the net demand side, we observe a large increase from China, mostly in the form of official reserves, from 0.8% of world GDP in 2000 to 4.5% in 2011, and a continued large absorption from Japan (around 3.8% of world GDP).

By introducing risk and heterogeneity in risk appetite, our model is able to account for

[19]This is a crude estimate of net safe asset positions since neither portfolio debt assets and liabilities or other assets and liabilities (mostly cross border bank loans) need be safe. Nevertheless, these holdings can be considered *safer* than portfolio equity and direct investment.

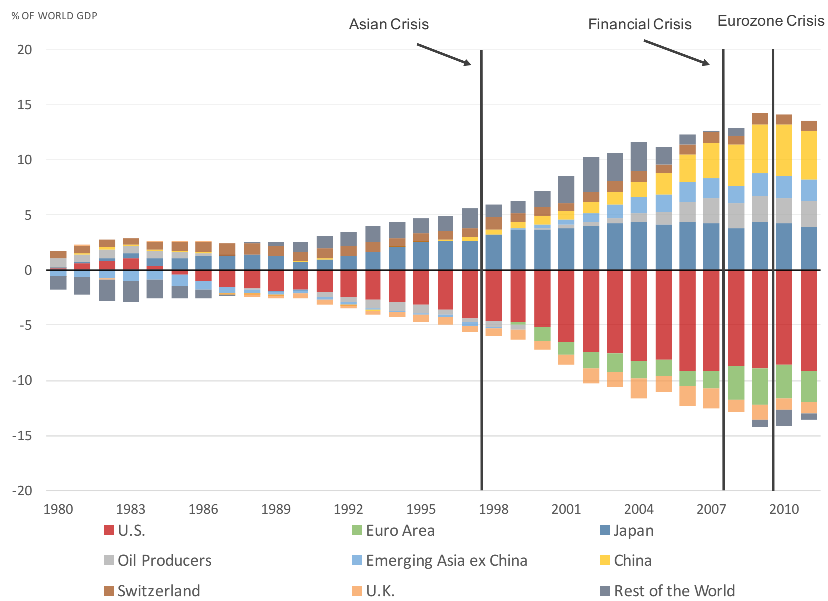


Note: The graph shows the one-year U.S. Treasury yield and the one-year expected risk premium (ERP), calculated as the first principal component of twenty models of the one-year-ahead equity risk premium. The figure shows that the equity risk premium has increased, especially since the Global Financial Crisis. Source: one-year Treasury yield: Federal Reserve H.15; ERP: Duarte and Rosa (2015).

Figure 9: U.S. Interest Rate and Expected Risk Premium

both sets of stylized facts. It also allows us to refine our view along three dimensions. First, asset shortages are concentrated in safe assets, giving a prominent role to a country's securitization and safe-asset tranching capacity. It also requires taking a more granular view of external accounts by disaggregating them by asset class, with the Net Foreign Asset positions and Current Accounts in safe assets playing the center stage in propagating recessions. Second, it leads to a possible rationalization of the "exorbitant privilege", whereby a country with a large securitization capacity runs a permanent negative Net Foreign Asset Position and a Current Account deficit (Gourinchas and Rey (2007)). Third, it gives rise to a *risk premium in UIP*, leading to the possibility of asymmetric safety traps equilibrium with *real interest rate differentials* and a new version of the "reserve currency paradox", whereby a country issuing a reserve currency which is expected to appreciate in bad times faces lower real interest rates and can hit the ZLB and enter a *safety trap* with zero nominal and real interest rates and a recession while other countries experience positive nominal and real interest rates and no recession.

For simplicity, we assume that prices are perfectly rigid and that there is no public debt



Note: The graph shows Net Safe positions as a fraction of world GDP. Net Safe positions are defined as the sum of Official Reserves (minus Gold), Portfolio Debt and Other Assets, minus Portfolio Debt and Other Liabilities. We observe that the net supply of safe assets originates largely with the U.S. and -to a smaller extent- the Eurozone. Source: Lane and Milesi-Ferretti (2007). Oil Producers: Bahrain, Canada, Iran, Iraq, Kuwait, Lybia, Mexico, Nigeria, Norway, Oman, Russia, Saudi Arabia, United Arab Emirates, Venezuela; Emerging Asia ex-China: India, Indonesia, Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand, Vietnam.

Figure 10: Safe Asset Imbalances

so that $D/X = D^*/X^* = 0$. We also assume that $\delta = \delta^*$ so that there are no differences between Home and Foreign in their ability to pledge future output into current assets. Instead we focus on a different dimension of financial development, the capacity to securitize assets into safe and risky tranches. We assume that this securitization capacities, denoted ϕ and ϕ^* and defined formally below, differs across countries.

Risk. We assume that a Poisson shock occurs with instantaneous probability λ. When the Poisson shock occurs, all uncertainty is resolved and output in both countries drops instantaneously and permanently by a factor $\mu < 1$. The possibility of an adverse future shock depresses the world natural interest rate before the Poisson shock below its value after the Poisson shock. We assume that the natural interest rate is positive after the Poisson shock $-\rho + \delta\theta > 0$, but the natural interest rate before the Poisson shock might be negative. This implies that the economy may be at the ZLB *before* the Poisson shock, but never *after* it. For simplicity, we study the limit $\lambda \to 0$. Because, as we shall see, some agents are risk averse, the Poisson shock matters even in the limit where its intensity becomes vanishingly small.

Neutrals and Knightians. Following the closed economy analysis in Caballero and Farhi (2015), we allow for a fraction α of agents in each country to be Knightian (infinitely risk averse over short time intervals). The remaining fraction $1-\alpha$ of agents is Neutral (risk neutral over short time intervals) as in the benchmark model. We assume that Knightians have full home bias: They only consume the goods of their own country. This implies that domestic Knightians only value financial assets whose payoffs are constant in the home good numeraire. By contrast, Neutrals have no home bias. The preferences of Knightians and Neutrals at Home are given by the following stochastic differential equations

$$
\begin{aligned}
U_t^K &= 1_{\{t-dt \le \tau_\theta < t\}} c_{H,t} + 1_{\{t \le \tau_\theta\}} \min{}_t \{U_{t+dt}^K\}. \\
U_t^N &= 1_{\{t-dt \le \tau_\theta < t\}} c_{H,t}^{x} c_{F,t}^{1-x} + 1_{\{t \le \tau_\theta\}} \mathbb{E}_t [U_{t+dt}^N],
\end{aligned}
$$

Other than that, a Neutral agent and a Knightian agent receive the same income $(1-\delta)\,\xi X$ at birth , and save it in its entirety until their death by investing in different portfolios (see below). New trees accrue only to Neutral newborns, an assumption which simplifies the analysis but does not matter for our substantive results. Similar assumptions hold for Foreign.

Tranching and securitization. Knightians shield themselves from aggregate risk, which is instead borne by Neutrals. Neutrals are of course compensated for the risk that they are bearing in the form of an *endogenous* positive risk premium. This allocation is achieved through an imperfect process of securitization of Lucas trees, as follows.

At any point in time, in each country, a fraction of the existing Lucas trees can be arbitrarily tranched into Arrow-Debreu securities which can then be arbitrarily traded and recombined. These Arrow-Debreu securities cannot be sold short. The remaining fraction of the trees can only be traded as a whole. Countries differ in their ability to generate tranched trees, and this is the only difference between the two counties. The fraction of tranched trees at Home is ϕ, and ϕ^* in Foreign.

At any point in time, Knightians invest all their wealth in safe assets, which they synthesize by constructing a portfolio with the right mix of Arrow-Debreu securities originating from the securitization of home and foreign tranched trees. Home (resp. foreign) Knightians synthesize home (resp. foreign) safe assets, i.e. assets that are riskless in the home (resp. foreign) good numeraire. At any point in time, Neutrals invest their wealth in portfolios of untranched trees and Arrow-Debreu securities originating in the securitization process of tranched trees.

It will prove convenient for our analysis to classify combinations of Arrow-Debreu securities into two categories. We use the term "macro puts" to denote combinations of Arrow-Debreu securities which pay off zero dividends until the Poisson shock realizes, and positive dividends after the Poisson shock realizes. Similarly, we use the term "macro calls" to denote Arrow-Debreu securities which only pay off positive dividends before the Poisson shock realizes, but zero dividends after the Poisson shock realizes. Macro puts can be combined with macro calls in different proportions to create home safe assets demanded by home Knightians and foreign safe assets demanded by foreign Knightians.

Equilibrium. We focus throughout on stochastic steady states *before* the Poisson shock. Denote by r^K and r^{K*} the risk free interest rates in the home and foreign numeraires, by r^w the risky rate of return, which is the same in the home and foreign numeraires (since we are working in the limit $\lambda \to 0$), and by E and E_τ the value of the exchange rate before and after the Poisson shock. The *endogenous* risk premia at Home and in Foreign are then given by $r^w - r^K$ and $r^w - r^{K,*}$. The equilibrium equations are described in detail in Appendix A.7. Here we only emphasize two key equations.

The first key equation is the global market clearing condition for macro puts, after the Poisson shock:

$$W^K + E_\tau W^{K*} \leq V^S + E_\tau V^{S*}, \tag{26}$$

where W^K and W^{K*} denote home and foreign Knightian wealth (in their respective currency), and V^S and V^{S*} denote the *payoffs* of home and foreign macro puts (in their respective currency), i.e. the value they promise to deliver if the Poisson shock materializes.[20] The payoffs V^S and V^{S*} are increasing in the securitization capacities ϕ and ϕ^* respectively, and increasing with the amount of macro safety μ.

The second key equation is a "modified UIP" equation for the exchange rate:

$$\frac{r^w - r^K}{r^w - r^{K*}} = \frac{E}{E_\tau}. \tag{27}$$

It illustrates that the exchange rate of the country with *the lowest safe interest rate* r^K, or the *highest risk premium* $r^w - r^K$, is expected to appreciate following the realization of the Poisson shock. One way to understand this equation is as follows: An investor can borrow one at r^K and invest at r^w, but that requires buying one unit worth of macro put payoff as "collateral". Similarly, an investor can borrow one at r^{K*} and invest at r^w, but that requires buying $\frac{E_\tau}{E}$ units worth of macro put payoff as collateral. Or in other words, an investor can borrow $\frac{E}{E_\tau}$ at r^{K*} and invest it at r^w, with one unit worth of macro put payoff. Both strategies require one unit worth of macro put payoff as collateral. They must net out the same return, which can be expressed as $\frac{E}{E_\tau}(r^w - r^{K*}) = r^w - r^K$.

In the simple case without a post-Poisson liquidity trap which we focus on here, the steady state of that phase is uniquely determined, and so are its dynamics from any initial position. By backward induction, this means that the exchange rate during the liquidity trap phase is also pinned down, conditional on the exchange rate E_τ that occurs at the time τ of the realization of the Poisson shock. This removes the indeterminacy in the nominal exchange rate à la Kareken and Wallace (1981) that we found in the previous sections: In fact, in equilibrium, we always have $E = E_\tau = 1$ and hence $r^K = r^{K*} = r^{K,w}$.[21] The *payoffs*

[20] The *payoffs* V^S and V^{S*} of home and foreign macro puts *after* the Poisson shock should not be confused with their *values* $\hat{V}^S$ and $\hat{V}^{S*}$ *before* the Poisson shock, which are derived in Appendix A.7. They should also in general be distinguished from the values of home and foreign safe assets. The latter is an ambiguous notion, since home macro puts can be used to create safe assets from the perspective of foreign Knightians and vice versa.

[21] This simple unique equilibrium is due to two assumptions, the relaxation of each of which would break it. First, as we mentioned in the main text, we have assumed that the economy is not a in a global liquidity trap after the Poisson shock. If we assume instead that the economy is in a liquidity trap after the Poisson shock, then an exchange rate indeterminacy à la Kareken and Wallace (1981) is reinstated. In this case, the exchange rate E_τ after the Poisson shock is indeterminate, and, from the "modified UIP condition", the exchange rate E before the Poisson shock inherits this indeterminacy.

Second, we have assumed no home bias for Neutrals. In Appendix A.7, we relax this assumption. An other form of indeterminacy appears, which we can also index by the exchange rate E_τ, because the in-of macro puts V^S and V^{S*} then coincide with the *values* of home and foreign safe assets with $V^S = \frac{\phi\mu X}{\theta}$ and $V^{S*} = \frac{\phi^*\mu X}{\theta}$, and home and foreign Knightians then perceive the same assets to be safe.

As explained in Caballero and Farhi (2015), there are different regimes in this model depending on whether equation (26) holds as a strict inequality or as an equality. In the first case, the marginal holder of a macro put is a Neutral (unconstrained regime) and there are no risk premia: $r^w = r^{K,w}$. In the second case, the marginal holder of macro puts is a Knightian, equation (26) holds with equality, and there are risk premia $r^w > r^{K,w}$. We assume throughout that we are in constrained regime, which occurs if α is large enough (so that the demand for macro puts is high enough), if μ is small enough or if ϕ and ϕ^* are small enough (so that the supply of macro puts is small enough).

Outside the safety trap. The natural allocation is such that

$$r^{K,w,n} = g + \delta\theta - (1-\delta)\theta\frac{\alpha - \bar{\phi}\mu}{\bar{\phi}\mu},$$

$$\frac{r^{w,n} - r^{K,w,n}}{r^{w,n}} = \frac{1}{\mu\bar{\phi}}\frac{g - r^{w,n}}{g - r^{w,n} + \rho}\left(1 - \frac{\delta\theta}{r^{w,n} + \rho}\right),$$

where $\bar{\phi} = x\phi + (1-x)\phi^*$ is the world average securitization capacity. The requirement that we are in the constrained regime is equivalent to $r^{w,n} > r^{K,w,n}$.

The natural allocation can be implemented by setting $r^K = r^{K*} = r^{K,w,n}$ as long as

ternational portfolios of Neutrals are indeterminate. Yet, a given portfolio allocation determines relative wealths immediately after the Poisson shock. In the presence of home bias in consumption, this pins down relative demands for home and foreign goods and therefore the nominal exchange rate E_τ. Conversely, for a given value E_τ, one can construct international portfolios that are consistent with this value of the exchange rate at the time of the Poisson shock. Note that this other form of indeterminacy in turn hinges on the assumption that some agents are risk neutral or that the probability of the bad Poisson shock is vanishingly small $\lambda \to 0$. If all agents where somewhat risk averse and if the probability of the bad Poisson shock were positive, then portfolios would be pinned down and this other form of indeterminacy would disappear.

Interestingly, relaxing either assumption leads to similar outcomes. In particular, in either case we can have an *asymmetric safety trap equilibrium* where there is a safety trap in one country but not in the other. For example, Home can be in a safety trap with $r^K = 0$ and $\xi < 1$ while Foreign is not: $r^{K*} > 0$ and $\xi^* = 1$. In this case, going back to the modified UIP equation (27), the exchange rate appreciates when the Poisson shock occurs $E > E_\tau$. This is another version of the "reserve currency paradox". If the home currency is a reserve currency, expected to appreciate in bad times, then the home risk free rate is lower, and Home can be in a safety trap even if Foreign is not. In this case, the more appreciated is the exchange rate after the bad Poisson shock (the lower is E_τ), the more appreciated is the exchange rate before the Poisson shock (the lower is E), and the deeper is the recession at Home, a version of our "currency wars" result.

$r^{K,w,n} > 0$. This happens when α, which indexes the demand for safe assets, is small enough compared to $\bar{\phi}\mu$, which indexes the supply for safe assets. We then have $r = r^* = r^{w,n}$, $\xi = \xi^* = 1$, and $E = E_\tau = 1$.

The safety trap. When $r^{K,w,n} < 0$, the natural allocation cannot be implemented. Instead, $r^K = r^{K*} = 0$, $\xi \leq 1$, and $\xi^* \leq 1$. We call this situation a *safety trap* rather than a liquidity trap to emphasize that its origin lies in the safe asset market. It follows that $r = r^* = r^w$, $E = E_\tau = 1$, and $\xi = \xi^* = \xi^w < 1$, where

$$\xi^w = 1 + r^{K,w,n} \frac{\bar{\phi}\mu}{(1-\delta)\,\alpha\theta},$$

$$1 = \frac{\xi^w}{\mu\bar{\phi}} \frac{r^w - g}{r^w - g - \rho}(1 - \frac{\delta\theta}{r^w + \rho}).$$

The requirement that we are in the constrained regime is equivalent to $r^w > 0$. Importantly, we see that, everything else equal, r^w is decreasing in ξ^w so that a deeper safety trap is associated with higher risk premia, a finding consistent with Figure 9.

In that regime, we also see that policies that support securitization in *any* country (bank recapitalizations, direct interventions in securitization markets, etc.) increase ϕ or ϕ^* and stimulate output and reduce risk premia in *all* countries.

Net Foreign Assets, Current Accounts, and the "Exorbitant Privilege". We can compute the home Net Foreign Asset Position and Current Account independently of wether Home, Foreign, or both are in a safety trap. We show in Appendix A.7 that both outside of a safety trap and in a safety trap, we have:

$$\begin{aligned} \frac{NFA}{X} &= \frac{(r^w + \rho - \theta)\frac{r^w - r^{K,w}}{r^w}\frac{\mu}{\theta}}{\theta + g - r^w}(\phi - \bar{\phi}), \\ \frac{CA}{X} &= g\frac{NFA}{X}. \end{aligned}$$

Suppose that Home has a larger securitization capacity than Foreign: $\phi > \phi^*$. In this case, we see that Home runs a negative Net Foreign Asset position and a Current Account deficit as long as $r^w + \rho - \theta < 0$, which is automatically verified in equilibrium.[22] Basically, Home's larger securitization capacity increases the value of its assets: Home is able to tranch out more "expensive" safe assets (high price, low rate of return) out of its risky assets than Foreign. Therefore, Home experiences a version of the "exorbitant privilege" documented by Gourinchas and Rey (2007): It is able to run a permanent negative Net Foreign Asset position and Current Account deficit because it pays a lower interest rates on its liabilities than on its assets.

Gross capital flows and Metzler diagram in safe assets. Both outside of a safety trap (when $r^{K,w,n} > 0$) and in a symmetric safety trap (when $r^{K,w,n} < 0$), we can represent the equilibrium determination of the safe interest rate $r^{K,w}$ and of the recession ξ^w through a *Metzler diagram in safe assets.* The key is to focus on the safe asset component CA^K of the Current Account, with corresponding safe asset component in Net Foreign Asset position NFA^K:

$$\begin{aligned}\frac{NFA^K}{X} &= \frac{W^K - \frac{\phi\mu X}{\theta}}{X} = \frac{\alpha(1-\delta)\xi^w}{\theta + g - r^{K,w}} - \frac{\phi\mu}{\theta},\\ \frac{CA^K}{X} &= g\frac{NFA^K}{X}.\end{aligned}$$

Similar equations hold for Foreign replacing NFA^K by NFA^{K*}, CA^K by CA^{K*}, W^K by W^{K*} and ϕ by ϕ^*.

We then have the following Metzler diagram representation

$$x\frac{NFA^K}{X} + (1-x)\frac{NFA^{K*}}{X} = 0.$$

If we are not in a safety trap with $\xi^w = 1$, this becomes a Metzler diagram for safe assets, which determines $r^{K,w} = r^{K,w,n} > 0$. If we are in a symmetric safety trap with $r^{K,w} = 0$,

[22] There are two opposing effects of a larger securitization capacity. First, it increases the value of home assets. Second, it means that the wealth of home agents accumulates faster because of the larger value of the sales of new securitized trees. The first effect worsens the Net Foreign Asset position and Current Account, while the second effect improves them. Since the strength of the second effect depends negatively on the propensity to consume θ and positively on the rate of depreciation ρ, the condition $r^w < \theta - \rho$ essentially bounds the strength of the second effect, and guarantees that the first effect dominates. It turns out that this condition is automatically verified in equilibrium.

this becomes a Metzler diagram for safe assets in quantities, which determines output ξ^w.

The Metzler diagram in safe asset implies that in the global equilibrium, countries that are net suppliers of safe assets experience a larger recession than under financial autarky. Figure 10 suggests that this is the case for the U.S. and -to a smaller extent- Europe. By contrast, Japan, China and oil producing economies, all net safe asset demanders, may experience less severe recessions.

6 Extensions

We present several extensions in the appendix, which we briefly summarize here.

Our baseline model features no home bias, a unitary trade elasticity (the elasticity of substitution σ between home and foreign goods), and only differences in financial development (asset supply) across countries. We relax these assumptions and analyze the effect of home bias (Appendix A.3), higher trade elasticities (Appendix A.4), and differences across countries in their propensities to save (asset demand), which we capture with a model featuring within-country heterogeneity between borrowing-constrained borrowers and savers (Appendix A.5).[23] A rough characterization of our results is that in a global liquidity trap, a high degree of home bias mitigates the impact of the exchange rate on the allocation of the global liquidity trap, Net Foreign Asset positions, and Current Accounts, while large trade elasticities exacerbate these impacts. Tighter credit constraints (because of lower financial development or an asymmetric deleveraging shock) or a smaller fraction of income accruing to borrowers (because of aging) in one country depress world interest rates, push toward Current Account surpluses in that country, and can send the global economy into a liquidity trap.

Our baseline model studies a stationary environment where the global economy can experience a permanent liquidity trap. We consider the effect of expected transitions out of

[23] As mentioned earlier, it is also possible to model differences in propensities to save across countries as differences in θ. Appendix A.5 instead introduces within country heterogeneity between borrowers and savers. The tightness of credit constraints reflects a country's financial development, and can be affected by deleveraging shocks, as in Eggertsson et al. (2015). Identifying borrowers with the young and savers with the middle-aged and the old, the relative importance of borrowers and savers can be used to capture a country's demographics. These features can generate differences in each country's propensity to save and in asset demand across countries, yet the model remains tractable.

the current liquidity trap into a good state (Appendix A.6). This allows us to discuss the role of *expected exchange rate movements* in creating *real interest rate differentials* already discussed in Section 5 but maintaining the assumption of risk neutrality. In the presence of home bias, this raises the possibility of a more asymmetric situation than the one encountered in the base model, where one country, the currency of which is expected to appreciate, is in a liquidity trap and has zero real interest rates, while the other is not in a liquidity trap and has positive real interest rates.

7 Final Remarks

World interest rates and global imbalances go hand in hand: Countries with large safe asset shortages run Current Account surpluses and push the world interest rate down. At the ZLB, the global asset market is in disequilibrium when output is at potential: There is a global safe asset shortage which cannot be resolved by lower world interest rates. It is instead dissipated by a world recession, which is propagated by global imbalances: Current Account surplus countries push world output down, exerting a negative effect on the world economy. Economic policy enters a regime of increased interdependence across the world, with either negative or positive spillovers depending on the policy instrument. Exchange rate policy becomes a zero-sum game of currency wars where each country can depreciate its exchange rate to stimulate its economy, at the expense of other countries. In contrast, safe public debt issuances, helicopter drops of money, increases in government spending, and support to private securitization, are positive-sum and stimulate output in all countries beyond the frontiers of the undertaking country. Our Metzler Diagram in Quantities is a powerful new tool to crystallize the economics of global imbalances and currency wars at the ZLB.

Unfortunately, this state of affairs is not likely to go away any time soon. In particular, there are no good substitutes in sight for the role played by US Treasuries in satisfying global safe asset demand. With mature US growing at rates lower than those of safe asset demander countries (as highlighted by The Economist, October 1, 2015), its debt and currency are likely to remain under upward pressure, dragging down (safe) interest rates and inflation, and therefore keeping the world economy (too) near the dangerous ZLB zone.

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A Appendix

A.1 New-Keynesian Microfoundations for Section 2.1

We provide one possible exact microfoundation for demand determined output in the presence of nominal rigidities in the model in Section 2.1. The microfoundation is in the New Keynesian tradition. We focus on the case of Home (the case of Foreign is identical). In a nutshell, domestic monopolistic firms produce imperfectly substitutable varieties of home intermediate goods and compete in prices. The firms' posted prices are rigid in the home currency, and that they accommodate demand at the posted price. The different varieties of the home intermediate goods are combined into a home final good by a competitive sector according to a Dixit Stiglitz aggregator. These assumptions are standard in the New Keynesian literature starting with Blanchard and Kiyotaki (1987).

Between t and $t + dt$, there is an endowment $X_t dt$ of each differentiated variety $i \in [0, 1]$ of non-traded input. Each variety i of non-traded input can be transformed into one unit of variety i of home intermediate good using a one-to-one linear technology by a monopolistic firm indexed by i which is owned and operated by the agents supplying variety i of the non-traded input, in proportion to their holdings of non-traded inputs.

The differentiated varieties of final home intermediate goods are then combined together into a home final good by a competitive sector according to a standard Dixit-Stiglitz aggregator

$$Y_t = \left(\int_0^1 X_{H,i,t}^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} dt,$$

where $X_{H,i,t}dt$ is the quantity of variety i of the final good. The price of the final home good is

$$P_{H,t} = \left(\int_0^1 p_{H,i,t}^{1-\sigma} di \right)^{\frac{1}{1-\sigma}},$$

where $p_{H,i,t}$ is the home currency price posted by monopolistic firm i for variety i of the home intermediate good. The resulting individual demand for each variety is given by

$$X_{H,i,t}dt = \left(\frac{p_{H,i,t}}{P_{H,t}} \right)^{-\sigma} Y_t dt.$$

Prices set by monopolistic firms are perfectly rigid in the home currency, equal to each other. We normalize these prices in the home currency to one

$$p_{H,i,t} = P_{H,t} = 1.$$

All the varieties of intermediate goods are then produced in the same amount

$$X_{H,i,t}dt = Y_t dt = \xi_t X_t dt.$$

Between t and $t + dt$, the varieties of non-traded inputs indexed by $i \in [\delta, 1]$, are distributed equally to the different agents who are born during that interval of time. The varieties of non-traded inputs indexed by $i \in [0, \delta]$ accrue equally as dividends on the different Lucas trees.

Real income (equal to real output) $\xi_t X_t dt$ is divided into an endowment $(1 - \delta)\xi_t X_t dt$ distributed equally to agents who are born during that interval of time, and the dividend $\delta \xi_t X_t dt$ of the Lucas trees. This provides an exact microfoundation for the model presented in Section 2.1.

A.2 Derivations for the Model with Inflation in Section 3

Global liquidity trap equilibrium equations. In a global liquidity trap equilibrium, the equilibrium values of $V^w = V + SV^*$, $W^w = W + SW^*$ (expressed in terms of the home good numeraire) and π_H, π_F^*, S, ξ, and ξ^* solve the following system of equations

$$
\begin{aligned}
S &= \frac{\xi}{\xi^*}, \\
\theta W^w &= \xi X + S\xi^* X^* \\
-\pi_H V^w &= -\rho V^w + \delta \xi X + \delta^* S \xi^* X^*, \\
g W^w &= -\theta W^w + (1-\delta)\xi X + (1-\delta^*) S\xi^* X^* + gD^w - \pi_H W^w + (\rho + g) V^w, \\
\pi_H &= -\kappa_0 - \kappa_1 (1-\xi), && \text{(A.1a)} \\
\pi_F^* &= -\kappa_0^* - \kappa_1^* (1-\xi^*) && \text{(A.1b)} \\
\pi_F^* &= \pi_H, && \text{(A.1c)}
\end{aligned}
$$

where $D^w = D + SD^*$. The first equation is the equation for the terms of trade. The second equation is the equation for total world wealth. Both result directly from combining the home and foreign goods market clearing conditions. The third equation is the asset pricing equation for world private assets. The fourth equation is the accumulation equation for world wealth, where we have used the government budget constraints to replace taxes as a function of public debt $\tau (1-\delta) \xi X = -gD$ and $\tau^* (1-\delta) \xi^* X^* = -gD^*$. The fifth and sixth equations are the home and foreign Phillips curves. The seventh equation represents the requirement derived above that the terms of trade be constant.

Asymmetric liquidity trap equilibrium equations. In an asymmetic liquidity trap equilibrium where one country (say Home) is in a liquidity trap but not the other (say Foreign), the equilibrium equations are instead given by:

$$
\begin{aligned}
S &= \xi, \\
\theta W^w &= \xi X + S X^* \\
-\pi_H V^w &= -\rho V^w + \delta \xi X + \delta^* S X^*, \\
g W^w &= -\theta W^w + (1-\delta)\xi X + (1-\delta^*) S X^* + gD^w - \pi_H W^w + (\rho + g) V^w, \\
\pi_H &= -\kappa_0 - \kappa_1 (1-\xi),
\end{aligned}
$$

and we have $i = 0$, $i^* = \bar{\pi}^* - \pi_H = i - \dot{E}_t / E_t > 0$.

Net Foreign Assets, Current Accounts, and Metzler Diagram in quantities. In this section, we characterize Net Foreign Asset positions and Current Accounts in the model with inflation of Section 3. We express these quantities in real terms in the home good numeraire. In the no liquidity trap equilibrium, these quantities are given by exactly the same formula as in the case with no inflation. In a symmetric global liquidity trap equilibrium, or in an asymmetric liquidity trap equilibrium, we have

$$
\begin{aligned}
\frac{NFA}{X} &= \frac{W - (V + D)}{X} = \frac{\xi (1 - \frac{\delta \theta}{r + \rho}) - \theta d}{g + \theta - r}, \\
\frac{CA}{X} &= g \frac{NFA}{X},
\end{aligned}
$$

where $\xi < 1$ and $r = -\pi_H$ if Home is in a liquidity trap and $\xi = 1$ and $r = -\pi_F^*$ if Home is not in a liquidity trap (but Foreign is).

The same forces that we identified in the model with no inflation are at play. For example, in a symmetric global liquidity trap equilibrium when the Phillips curves are identical across countries (so that $\kappa_0^* = \kappa_0$ and

$\kappa_1^* = \kappa_1$),

$$\begin{aligned}\frac{NFA}{X} &= \frac{W-(V+D)}{X} = \frac{(1-\frac{\delta\theta}{\rho}-\frac{\pi^w}{\rho})[\frac{\theta\bar{d}}{1-\frac{\delta\theta}{\rho}-\pi^w}-\frac{\theta d}{1-\frac{\delta\theta}{\rho}-\frac{\pi^w}{\rho}}]}{g+\theta+\pi^w},\\ \frac{CA}{X} &= g\frac{NFA}{X}.\end{aligned}$$

Hence to the extent that Home has a higher financial capacity than Foreign $\delta > \delta^*$, or a higher public debt ratio than Foreign $d > d^*$, then Home runs a negative Net Foreign Asset position and a Current Account deficit. We can also represent the equilibrium with a Metzler diagram in quantities augmented with a global AS curve. Indeed we have

$$\begin{aligned}\frac{NFA}{X} &= \frac{\xi^w(1-\frac{\frac{\delta\theta}{\rho}}{1-\frac{\pi^w}{\rho}})-\theta d}{g+\theta+\pi^w},\\ S\frac{NFA^*}{X^*} &= \frac{\xi^w(1-\frac{\frac{\delta^*\theta}{\rho}}{1-\frac{\pi^w}{\rho}})-\theta d^*}{g+\theta+\pi^w},\end{aligned}$$

and we must have

$$\begin{aligned}x\frac{NFA}{X}+(1-x)S\frac{NFA^*}{X^*} &= 0,\\ \pi^w+\kappa_0+\kappa_1(1-\xi^w) &= 0,\end{aligned}$$

with $S = 1$.

A.3 Home Bias

We assume that the spending share on home goods of home agents is $x + (1-x)\beta$, and similarly that the spending share on foreign goods of foreign agents is $x^* + (1-x^*)\beta$, where $x^* = 1-x$ and $\beta \in [0,1]$ indexes the degree of home bias. Full home bias corresponds to $\beta = 1$. The case of no home bias analyzed previously corresponds to $\beta = 0$.

With home bias in preferences, the good market clearing conditions (4a) and (4b) become:

$$[x+(1-x)\beta]\theta W + (1-x^*)(1-\beta)\theta W^* E = \xi X, \tag{A.3a}$$

$$(1-x)(1-\beta)\theta W + [x^*+(1-x^*)\beta]\theta W^* E = E\xi^* X^*. \tag{A.3b}$$

This applies both under financial integration and under financial autarky, whether Home is in a liquidity trap ($\xi < 1$) or not ($\xi = 1$), and similarly whether Foreign is in a liquidity trap ($\xi^* < 1$) or not ($\xi^* = 1$).

For conciseness, we only consider the case where there is a global liquidity trap under financial integration. In that case, just like in the case of no home bias, there is a degree of indeterminacy indexed by the exchange rate E.

The asset and wealth dynamic equations (8a)-(8d) are unchanged. After simple manipulations, we can express all equilibrium variables as a function of the nominal exchange rate:

$$
\begin{aligned}
\xi &= \frac{\theta \bar{d}^{\beta}(E)}{1-\frac{\bar{\delta}^{\beta}\theta}{\rho}}, \qquad \text{(A.4a)} \\
\frac{NFA}{X} &= \frac{(1-\frac{\delta\theta}{\rho})[\frac{\theta \bar{d}^{\beta}(E)}{1-\frac{\bar{\delta}^{\beta}\theta}{\rho}} - \frac{\theta d}{1-\frac{\delta\theta}{\rho}}]}{g+\theta} = \frac{(1-\frac{\delta\theta}{\rho})(\xi-\xi^{a,l})}{g+\theta}, \\
\frac{CA}{X} &= g\frac{NFA}{X},
\end{aligned}
$$

where we have defined the averages modified by home bias β as

$$
\bar{d}^{\beta}(E) = \frac{[\beta+(1-\beta)x\left(1+\frac{\frac{\delta^*\theta}{\rho}+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\right)]\theta d + (1-x)(1-\beta)\left(1+\frac{\frac{\delta^*\theta}{\rho}+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\right)E\theta d^*}{[\beta+(1-\beta)x\left(1+\frac{\frac{\delta^*\theta}{\rho}+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\right)] + (1-x)(1-\beta)\left(1+\frac{\frac{\delta^*\theta}{\rho}+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\right)},
$$

$$
\bar{\delta}^{\beta} = \frac{[\beta+(1-\beta)x\left(1+\frac{\frac{\delta^*\theta}{\rho}+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\right)]\left(1-\frac{\delta\theta}{\rho}\right) + (1-x)(1-\beta)\frac{1+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\left(1-\frac{\delta^*\theta}{\rho}\right)}{[\beta+(1-\beta)x\left(1+\frac{\frac{\delta^*\theta}{\rho}+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\right)] + (1-x)(1-\beta)\left(1+\frac{\frac{\delta^*\theta}{\rho}+\frac{\theta}{g}}{1-\frac{\delta^*\theta}{\rho}}\right)}.
$$

and where $\xi^{a,l}$ is defined exactly as in the case with no home bias, and given by the same formula, equation (14a). Equations (A.4a) and its equivalent for the foreign country show that, as before, home output ξ is increasing in the exchange rate E while foreign output ξ^* is decreasing in E. Finally, as before, the home Net Foreign Asset Position and Current Account are increasing in the gap between the domestic recession and the home financial autarky recession $\xi^{a,l}$. *The key difference introduced by home bias β is that the home and foreign outputs ξ and ξ^* become less responsive to the exchange rate E.* This can be seen directly by examining (A.4a) in the case of home bias ($\beta > 0$) and comparing to (12a) in the case with no home bias ($\beta = 0$). This effect is seen most transparently in the limit with full home bias ($\beta \to 1$) in which case the outputs ξ and ξ^* become completely insensitive to the exchange rate E.

Assume further that both countries are in a liquidity trap under financial autarky. Then, just like in the case with no home bias, the integrated equilibrium coincides with financial autarky when $E = E^a$. For $E > E^a$, we have $\xi > \xi^a$ and $\xi^* < \xi^a$ and vice versa for $E < E^a$.[24]

A.4 Trade Elasticities

We now assume away home bias and investigate instead the role of the elasticity of substitution σ between home and foreign goods. The main difference in the system of equilibrium equations is once again the goods market clearing conditions, which become

$$
\begin{aligned}
\frac{x}{x+E^{1-\sigma}(1-x)}(W+EW^*) &= \frac{\xi X}{\theta}, \\
\frac{(1-x)E^{1-\sigma}}{x+E^{1-\sigma}(1-x)}(W+EW^*) &= E\frac{\xi^* X^*}{\theta}.
\end{aligned}
$$

This applies both under financial integration and under financial autarky, whether Home is in a liquidity trap ($\xi < 1$) or not ($\xi = 1$), and similarly whether Foreign is in a liquidity trap ($\xi^* < 1$) or not ($\xi^* = 1$).

[24] One can readily check that the range $\left[\underline{E}, \bar{E}\right]$ increases with β, so that the model with home bias admits a larger range of indeterminacy. In the limit of full home bias, any value of the exchange rate is admissible.

This implies that we now have

$$E = \hat{E}^{\frac{1}{\sigma}}$$

where $\hat{E}$ is a renormalized exchange rate given by

$$\hat{E} = \frac{\xi}{\xi^*}.$$

The analysis under financial autarky is identical to the case $\sigma = 1$ except for the value of the financial autarky exchange rate. Unfortunately, the analysis under financial integration, although conceptually straightforward, leads to a nonlinear system of equations which is not amenable to a closed form solution.

Things simplify in the limit $\sigma \to \infty$, where the goods become perfect substitutes, to which we now turn. For conciseness, we only treat the case where there is a global liquidity trap under financial integration. As we take the limit $\sigma \to \infty$, we have $E = 1$, but there is still a degree of indeterminacy indexed by the renormalized exchange rate $\hat{E}$. Indeed, we can compute all the equilibrium variables as a function of $\hat{E}$:

$$\begin{aligned}
\xi &= \frac{x\theta d + (1-x)\theta d^*}{x(1-\frac{\delta\theta}{\rho}) + \frac{1}{\hat{E}}(1-x)(1-\frac{\delta^*\theta}{\rho})},\\
\frac{NFA}{X} &= \frac{(1-\frac{\delta\theta}{\rho})\xi - \theta d}{g+\theta} = \frac{(1-\frac{\delta\theta}{\rho})(\xi - \xi^{a,l})}{g+\theta},\\
\frac{CA}{X} &= g\frac{NFA}{X},
\end{aligned}$$

where $r^{w,n}$ and $\xi^{a,l}$ are defined exactly as in the unitary elasticity case, and are given by the same formulas. Home output ξ is increasing in the renormalized exchange rate $\hat{E}$, and foreign output is decreasing in the renormalized exchange rate $\hat{E}$. Finally, the home Net Foreign Asset Position is increasing in the gap between home output and home financial autarky output $\xi^{a,l}$ under zero home nominal interest rates. *The key difference introduced by $\sigma > 1$ over $\sigma = 1$ is that home and foreign outputs ξ and ξ^* become more responsive to the exchange rate E.* Indeed in the limit $\sigma \to \infty$, ξ and ξ^* become infinitely sensitive to the exchange rate E. In other words, larger trade elasticities magnify the stimulative effect of an exchange rate depreciation on the home recession.

Assume further that both countries are in a liquidity trap under financial autarky. Then, just like in the case with $\sigma = 1$, the financially integrated equilibrium coincides with financial autarky when $\hat{E} = \hat{E}^a$. For $\hat{E} > \hat{E}^a$, we have $\xi > \xi^a$ and $\xi^* < \xi^a$ and vice versa for $\hat{E} < \hat{E}^a$.

A.5 Within Country Heterogeneity: Borrowers and Savers

Here we work out a version of our model incorporating within country heterogeneity between borrowers and savers. For simplicity, we abstract away from public debt by setting $D/X = D^*/X^* = 0$.

We add a mass of borrowing constrained impatient borrowers (B) agents. The rest of the agents are savers (S) and are modeled as before. Borrowers consume as much as possible when they are born, and the rest when they die. They only get an endowment when they die, and they can only pledge a part of it. They must therefore borrow in order to consume when born. They then roll over their debt until they die, at which point they use their income to repay their debt and consume the remainder. In a small interval dt, a part $\eta\xi_t X_t dt$ of total income accrues to dying borrowers in the form of labor income. Because of the borrowing constraint, borrowers born in the interval dt can only consume $\chi X_t dt$, where we imagine that χ is small compared to η.[25] We assume that the new trees accrue to savers.

[25] Note that, as in Guerrieri and Lorenzoni (2011) and Eggertsson and Krugman (2012), the borrowing limit χX does not depend on whether the economy is in recession. This assumption is crucial to generate a liquidity trap, as it implies that the debt issued by borrowers does not scale with output, so asset demand declines faster than asset supply in the recession. While the assumption that the credit constraint is invariant to the recession is perhaps extreme, all that is needed for our result to go through is that the borrowing limit does not scale one for one with output.

Note that there is now a distinction between financial wealth and human wealth for borrowers. Indeed a borrower receives income when he dies. This future income is a form a human wealth and is not part of his financial wealth. When the borrower dies, this human wealth allows him to repay the debt that he has incurred to borrow when he was born and rolled over until his death (his financial wealth), and to consume the residual.

The evolution equations for the financial wealth of borrowers and savers are given by:[26,27]

$$\begin{aligned} gW^B &= -\theta W^B - \chi X + r^w W^B, \\ gW^S &= -\theta W^S + (1-\delta-\eta)\xi X + r^w W^S + (\rho+g)V, \\ gW^{B*} &= -\theta W^{B*} - \chi^* X^* + r^w W^{B*}, \\ gW^{S*} &= -\theta W^{S*} + (1-\delta-\eta)\xi^* X^* + r^w W^{S*} + (\rho+g)V^*. \end{aligned}$$

We continue to denote by $W = W^B + W^S$ total home wealth and by $W^* = W^{B*} + W^{S*}$ total foreign wealth and obtain the evolution equations for total wealth by aggregating the evolution equations for wealth by borrowers and savers in both countries:

$$\begin{aligned} gW &= -\theta W + (1-\delta-\eta)\xi X - \chi X + r^w W + (\rho+g)V, \\ gW^* &= -\theta W^* + (1-\delta^*-\eta^*)\xi^* X^* - \chi^* X + r^w W + (\rho+g)V^*. \end{aligned}$$

The good market clearing conditions are now given by:[28]

$$\begin{aligned} \xi X &= x(\theta(W+EW^*) + \eta\xi X + E\eta^*\xi^* X^* + \chi X + E\chi^* X^*) \\ E\xi^* X^* &= (1-x)(\theta(W+EW^*) + \eta\xi X + E\eta^*\xi^* X^* + \chi X + E\chi^* X^*). \end{aligned}$$

The asset pricing equations are unchanged:

$$\begin{aligned} r^w V &= -\rho V + \delta\xi X, \\ r^w V^* &= -\rho V^* + \delta^*\xi^* X^*. \end{aligned}$$

And we must still impose $r^w \geq 0$, $0 \leq \xi \leq 1$, $0 \leq \xi^* \leq 1$, and the complementary slackness conditions $r^w(1-\xi) = 0$ and $r^w(1-\xi^*) = 0$.

[26] Let us for example explain in details the wealth evolution equation for borrowers at Home. The wealth of borrowers is negative $W^B < 0$, it represents their debt. In an interval dt, the wealth of borrowers W^B changes because of because of dying borrowers repaying their debt ($-\theta W^B dt$), because of newborn borrowers taking on new debt ($-\chi X dt$), and because of the accumulation of interest ($r^w W^B$). In a steady state, the wealth of borrowers W^B must also change by $gW^B dt$. This gives the wealth evolution equation for borrowers.

[27] Note that the wealth of borrowers does not take into account the income of borrowers when they die, because it is not part of their financial wealth. But of course, the income of borrowers influences their consumption when they die. It therefore appears in the goods market clearing conditions. This explains the terms $\eta\xi X$ and $E\eta^*\xi^* X^*$ in the market clearing conditions at Home and in Foreign.

[28] For example, the home market clearing condition can be understood as follows. The demand arising from dying savers is given by $x\theta(W - W^B + EW^* - EW^{B*})$. The demand arising from newborn borrowers is given by $x(\chi X + E\chi^* X^*)$. And the demand arising from dying borrowers is given by $x(\eta\xi X + \theta W^B + E\eta^*\xi^* X^* + E\theta W^{B*})$.

In the interest of space, we only treat the liquidity trap case. We get:

$$\begin{aligned}
E &= \frac{\xi}{\xi^*}, \\
\xi &= \frac{\bar{\chi}(E)}{1-\bar{\eta}-\frac{\bar{\delta}\theta}{\rho}}, \\
\frac{NFA}{X} &= \frac{\frac{1-\eta-\frac{\delta\theta}{\rho}}{1-\bar{\eta}-\frac{\bar{\delta}\theta}{\rho}}\bar{\chi}(E)-\chi}{g+\theta}, \\
\frac{CA}{X} &= g\frac{NFA}{X}.
\end{aligned}$$

where for any variable z, we use the notation $\bar{z}(E) = xz(E) + (1-x)z^*(E)$.

The variable χ (χ^*) increases with home (foreign) financial development, and decreases with a home (foreign) deleveraging shock. Identifying the borrowers with the young and the savers with the middle-aged and the old, proportional decreases in the variables η and χ (η^* and χ^*) capture home (foreign) population aging.

These equations indicate that a deleveraging shock at Home (a decrease in χ) or in Foreign (a decrease in χ^*) can push the global economy into a liquidity trap. For a given exchange rate E, the larger the world deleveraging shock, the larger the recession in any given country. For a given exchange rate E and world deleveraging shock $\bar{\chi}(E)$, a larger home deleveraging shock (a lower χ) pushes the home Current Account towards a surplus.

Similarly, aging at Home (a proportional decrease in χ and η) or in Foreign (a proportional decrease in χ^* and η^*) can push the global economy in a liquidity trap. For a given exchange rate E, the larger the shock, the larger the recession in any given country. For a given exchange rate E, more aging at Home pushes the Home Current Account towards a surplus.

This analysis also shows how countries with tighter credit constraints or lower fraction of income accruing to borrowers act as if they had a larger asset demand (lower θ).

A.6 Recovery: Exchange Rates Movements and Interest Rates Differentials

We start with the model with permanently rigid prices, and consumption home bias of section A.3. For simplicity, we assume that there is no public debt so that $D/X = D^*/X^* = 0$.

We then assume that a Poisson shock occurs with instantaneous probability $\lambda > 0$. When the Poisson shock occurs, the fraction of output δ that accrues in the form of dividends jumps instantaneously and permanently by a factor $\nu > 1$ in both countries. This alleviates the asset shortage and increases the world natural interest rate. We assume that ν is large enough that upon the realization of the Poisson shock the world natural interest rate rises above zero: $-\rho + \nu\bar{\delta}\theta > 0$. This implies that the economy may experience a liquidity trap *before* the Poisson shock, but never *after* it.

The steady state of the post-Poisson shock economy is uniquely determined, and so are its dynamics from any initial position.[29] By backward induction, this means that the exchange rate during the liquidity trap phase is also pinned down, conditional on the exchange rate E_τ that occurs at the time τ of the realization of the Poisson shock. This removes the indeterminacy in the nominal exchange rate à la Kareken and Wallace (1981) that we found in our baseline model.[30]

[29]One can verify that the dynamics of the economy are saddle-path stable.

[30]This is because we have assumed that the economy is not a in a global liquidity trap after the Poisson shock. If we assume instead that the economy is in a liquidity trap after the Poisson shock (so that the recovery is only a partial recovery which doesn't lift the economy out of the ZLB), then even without home bias, the exchange rate indeterminacy à la Kareken and Wallace (1981) is reinstated. Indeed, in this case, the exchange rate E_τ after the Poisson shock is indeterminate. The exchange rate E before the Poisson shock, which depends on its value E_τ after the Poisson shock, inherits this indeterminacy. In the interest of

But another form of indeterminacy appears which we can index by the exchange rate E_τ. This is because, in our model, agents are risk neutral, so that international portfolios are indeterminate.[31] Yet, a given portfolio allocation will determine relative wealths immediately after the Poisson shock. In the presence of home bias in consumption, this pins down relative demands for Home and Foreign goods and therefore the nominal exchange rate E_τ. Conversely, for a given value E_τ, one can construct international portfolios that are consistent with this value of the exchange rate at the time of the Poisson shock. We summarize by writing domestic and foreign wealth and asset values at the time of the shock as $W_\tau = w_\tau X/\theta$, $W^*_\tau = w^*_\tau X^*/\theta$, $V_\tau = v_\tau X/\theta$, and $V^*_\tau = v^*_\tau X^*/\theta$ where it is understood that the coefficients w_τ,w^*_τ, v_τ and v^*_τ are functions of the exchange rate E_τ at the time of the shock.

We focus on the stochastic steady state before the Poisson shock. Because of the jump in the exchange rate at the time of the Poisson shock, Home and Foreign typically experience different real interest rates. This is in contrast to our baseline model where real interest rates are always equalized across countries. To see this most clearly, note that financial integration imposes that in the stochastic steady state prior to the Poisson shock, we have the following UIP equation:

$$r = r^* + \lambda(\frac{E_\tau}{E} - 1). \tag{A.7}$$

This implies that the home interest rate $r < r^*$ if the home currency is expected to appreciate after the Poisson shock $E_\tau/E < 1$.[32]

The asset pricing equations include news terms accounting for capital gains and losses triggered by the realization of the Poisson shock:

$$rV = -\rho V + \delta\xi X + \lambda\left(V_\tau - V\right),$$

$$r^*V^* = -\rho V^* + \delta^*\xi^* X^* + \lambda\left(V^*_\tau - V^*\right).$$

For example, a higher value of home assets V_τ after the Poisson shock increases the value of home assets V in the stochastic steady state before the Poisson shock.

The wealth accumulation equations include new terms accounting for the risk and return of each country's portfolio:

$$gW = -\theta W + (1-\delta)\,\xi X + rW + \lambda\left(W - W_\tau\right) + (g+\rho)\,V,$$

$$gW^* = -\theta W^* + (1-\delta)\,\xi^* X^* + r^*W^* + \lambda\left(W^* - W^*_\tau\right) + (g+\rho)\,V^*.$$

For example, a lower value of home wealth W_τ after the Poisson shock means that home agents have a riskier portfolio, and therefore collect higher returns as long as the Poisson shock does not materialize. This in turn increases home wealth W in the stochastic steady state before the Poisson shock.

The goods market clearing equations (A.3a) and (A.3b) are unchanged, and we must still impose $r \geq 0$, $r^* \geq 0$, $0 \leq \xi \leq 1$, $0 \leq \xi^* \leq 1$, and the complementary slackness conditions $r(1-\xi) = 0$ and $r^*(1-\xi^*) = 0$.

The jump in the exchange rate at the time of the Poisson shock opens the door to the possibility that Home and Foreign may not experience a liquidity trap simultaneously prior to the shock. Real interest rates can differ across countries, resulting in the possibility of more strongly asymmetric liquidity trap equilibria than those we have encountered so far, where one country has zero nominal interest rates, zero real interest rates and a recession, while the other country has positive nominal interest rates, positive real interest rates,

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space, we do not develop this model formally.

[31] This other form of indeterminacy hinges on our assumption that some (here all) agents are risk neutral. If all agents were somewhat risk averse, then portfolios would be pinned down and this other form of indeterminacy would disappear.

[32] We can also have equilibria with different values of $E = E_\tau$, with similar implications in terms of relative outputs and "currency wars" as in Section 2.3—lower values of $E = E_\tau$ are associated with higher values of ξ and lower values of ξ^*. Interestingly, But here, this logic can be more extreme in that we can also have equilibria with asymmetric liquidity traps where there is a liquidity trap in one country but not in the other. For example, Home can be in a liquidity trap with $r = 0$ and $\xi < 1$ while Foreign is not: $r^* > 0$ and $\xi^* = 1$. In this case, going back to the UIP equation, the exchange rate appreciates when the Poisson shock occurs $E > E_\tau$.

and no recession.

Going back to the UIP equation (A.7), we see that for Home to be the only country in a liquidity trap, we need $r = 0$, $\xi < 1$, $r^* > 0$, $\xi^* = 1$ and $\lambda\left(E_\tau/E - 1\right) = -r^* < 0$. This requires that the home exchange rate appreciate at the time of the shock, $E_\tau < E$. We focus on this configuration from here onwards.

Home output ξ is then given by

$$\xi = \frac{\beta \frac{g-\lambda}{g-\lambda+\theta} \frac{\lambda v_\tau - \frac{(\rho+\lambda)\lambda}{g-\lambda}(w_\tau - v_\tau)}{\rho+\lambda} + x^*(1-\beta)E}{[1 - \frac{\beta \frac{g-\lambda}{g-\lambda+\theta}}{\beta \frac{g-\lambda}{g-\lambda+\theta} + x^*(1-\beta)} \frac{\delta\theta}{\rho+\lambda}][\beta \frac{g-\lambda}{g-\lambda+\theta} + x^*\left(1-\beta\right)]}. \tag{A.8a}$$

This equation shows that everything else equal, as long as there is home bias $\beta > 0$, a higher value v_τ/θ of the home asset after the Poisson shock, and a lower value of the home Net Foreign Asset position after the Poisson shock $(w^*_\tau - v^*_\tau)/\theta$, contribute to a lower home output. Both increase the value of home wealth before the Poisson shock and, because of home bias, of the demand for home goods. The reason is that a higher value of v_τ/θ increases the value of new trees, and that a lower value of $(w^*_\tau - v^*_\tau)/\theta$ indicates that home agents take more risk, and are hence rewarded by a higher return before the Poisson shock.

The foreign interest rate r^* and the exchange rate are then given by the following system of nonlinear equations

$$0 = r^* + \lambda(\frac{E_\tau}{E} - 1),$$

$$1 - (\frac{\xi}{E} - 1)x\frac{1-\beta}{\beta} = \frac{\theta + \frac{g-\lambda-r^*}{\rho+\lambda+r^*}(\delta^*\theta + \lambda v^*_\tau) - \lambda\left(w^*_\tau - v^*_\tau\right)}{g - \lambda + \theta - r^*},$$

where we use the equation above to express ξ as a function of E. This is an equilibrium as long as $\xi < 1$ and $r^* \geq 0$.

We can also compute

$$\frac{NFA}{X} = \frac{\xi(1 - \frac{\delta\theta}{\rho+\lambda}) - \frac{\lambda v_\tau}{\rho+\lambda} - \lambda\frac{\theta}{g-\lambda}(w_\tau - v_\tau)}{g - \lambda + \theta} = \frac{1 - \frac{\delta\theta}{\rho+\lambda}}{g-\lambda+\theta}(\xi - \hat{\xi}^{a,l}),$$

$$\frac{CA}{X} = g\frac{NFA}{X}.$$

where $\hat{\xi}^{a,l}$ is home output in the equilibrium where Home is in financial autarky before the Poisson shock, but not after the Poisson shock (and where the equilibrium coincides with that under consideration after the Poisson shock).[33] Financial integration before the Poisson shock increases output $\xi \geq \hat{\xi}^{a,l}$ if and only if the exchange rate is more depreciated $E \geq \hat{E}^{a,l}$.[34]

A.7 Derivations for Section 5

In this section, we provide the derivations for Section 5. We generalize the model presented in the main text to allow Neutrals to have an arbitrary degree β of home bias as in Section A.3. To ease the task of the reader, we provide a self-contained exposition, with minimal reference to the main text, but with detailed derivations.

As in Section A.6, we assume that a Poisson shock occurs with instantaneous probability $\lambda > 0$ and we assume away public debt $D/X = D^*/X^* = 0$. However the nature of the shock is different. When the

[33] By financial autarky we mean that Net Foreign Asset positions at Home and in Foreign are equal to 0. We allow countries to trade actuarially fair insurance contracts on the realization of the Poisson shock. These contracts have zero ex-ante value for both home and foreign agents.

[34] The analysis simplifies drastically in the limit of full home bias ($\beta \to 1$). In this case, we have $\xi^a = \xi^{a,l}$, $w_\tau = v_\tau = w^*_\tau = v^*_\tau = 1$. This implies that ξ and r^* are given by their financial autarky values $\xi = \xi^{a,l}$, $r^* = r^{*a,n} = \delta^*\theta - \rho$, and Net Foreign Asset Positions and Current Accounts are zero $\frac{NFA}{X} = \frac{CA}{X} = 0$. This is an equilibrium if and only if $r^{*a,n} \geq 0$ and $r^{a,n} \leq 0$ (which is equivalent to $\xi^{a,l} \leq 1$).

Poisson shock occurs, output in both countries drops instantaneously and permanently by a factor $\mu < 1$. The possibility of an adverse future shock reduces the supply of assets, depressing the world natural interest rate before the Poisson shock below its value after the Poisson shock. We assume that $\delta = \delta^*$ so that there are no differences between Home and Foreign in their ability to pledge future output into current assets. Instead we focus on a different dimension of financial development, the capacity to securitize assets into safe and risky tranches. We assume that this securitization capacities, denoted ϕ and ϕ^* and defined formally below, differs across countries.

Neutrals and Knightians. Following Caballero and Farhi (2015), we allow for a fraction α of agents in each country to be Knightian (infinitely risk averse over short time intervals). The remaining fraction $1-\alpha$ of agents is Neutral (risk neutral over short time intervals) as in the benchmark model. We assume that Knightians have full home bias: They only consume the goods of their own country. This implies that domestic Knightians only value financial assets whose payoffs are constant in the Home good numeraire. By contrast, Neutrals have an interior degree of home bias indexed by β as in Section A.3. The preferences of Knightians and Neutrals at Home are given by the following stochastic differential equations

$$\begin{aligned} U_t^K &= 1_{\{t-dt \leq \tau_\theta < t\}} c_{H,t} + 1_{\{t \leq \tau_\theta\}} \min{}_t \{U_{t+dt}^K\}. \\ U_t^N &= 1_{\{t-dt \leq \tau_\theta < t\}} c_{H,t}^{\gamma} c_{F,t}^{1-\gamma} + 1_{\{t \leq \tau_\theta\}} \mathbb{E}_t[U_{t+dt}^N], \end{aligned}$$

where $\gamma = x + \beta(1-x)$. Similar equations hold for Foreign with $1-\gamma^* = x^* + \beta(1-x^*)$.

Tranching and securitization. In the presence of Knightians, equilibrium portfolios are no longer indeterminate. Knightians shield themselves from aggregate risk, which is instead borne by Neutrals. Neutrals are of course compensated for the risk that they are bearing in the form of a positive risk premium. This allocation is achieved through an imperfect process of securitization of Lucas trees, which takes the following form.

At any point in time, in each country, a fraction of the existing Lucas trees can be arbitrarily tranched into Arrow-Debreu securities which can then be arbitrarily traded and recombined. These Arrow-Debreu securities cannot be sold short. The remaining fraction of the trees cannot be tranched, and can only be traded as a whole. Countries differ in their ability to generate tranched trees, and this is the only difference between the two counties. The fraction of tranched trees at Home is ϕ, and it is ϕ^* in Foreign.

At any point in time, Knightians invest all their wealth in safe assets, which they synthesize by constructing a portfolio with the right mix of Arrow-Debreu securities originating from the securitization of home and foreign tranched trees. Home (resp. foreign) Knightians synthesize home (resp. foreign) safe assets, i.e. assets that are riskless in the home (resp. foreign) good numeraire. At any point in time, Neutrals invest their wealth in portfolios of untranched trees and Arrow-Debreu securities originating in the securitization process of tranched trees.

It will prove convenient for our analysis to classify combinations of Arrow-Debreu securities into two categories. We use the term macro puts to denote combinations of Arrow-Debreu securities which pay off zero dividends until the Poisson shock realizes, and positive dividends after the Poisson shock realizes. Similarly, we use the term macro calls to denote Arrow-Debreu securities which only pay off positive dividends before the Poisson shock realizes, but zero dividends after the Poisson shock realizes. Macro puts can be combined with macro calls in different proportions to create home safe assets demanded by home Knightians and foreign safe assets demanded by foreign Knightians.

The limit $\lambda \to 0$. For simplicity, we study the limit $\lambda \to 0$. Because of the presence of Knightians, the Poisson shock matters even in this limit where its intensity becomes vanishingly small. We also assume that new trees accrue only to Neutrals, an assumption which simplifies the analysis but does not matter for our substantive results.

Equilibrium equations. We focus on stochastic steady states throughout. The equilibrium variables are as follows. First, there are the risk free interest rates r^K and r^{K*} in the home and foreign numeraires. Second, there is the risky interest rate r^w which is the same in the home and foreign numeraires (since we are working in the limit $\lambda \to 0$). Third, there are the values of home and foreign macro puts $\hat{V}^S$ and $\hat{V}^{S*}$, and the values of home and foreign assets V and V^*. Fifth, there are the values of home and foreign Knightian wealth W^K and W^{K*}, as well as the value of home and foreign Neutrals wealth W^N and W^{N*}. Sixth, there are the home and foreign outputs ξ and ξ^*. We treat the value of the exchange rate E_τ after the Poisson shock as a parameter exactly as in Section A.6: Different values can be rationalized by different portfolios for Neutrals at Home and in Foreign.

The equilibrium equations are as follows. First, there are the asset pricing equations for home and foreign assets

$$V = \hat{V}^S + \frac{\delta \xi X}{r^w + \rho}, \tag{A.9a}$$

$$V^* = \hat{V}^{S*} + \frac{\delta \xi^* X^*}{r^w + \rho}, \tag{A.9b}$$

and the asset pricing equations of the macro puts

$$\hat{V}^S = \frac{r^w - r^K}{r^w} \mu \phi v_\tau \frac{X}{\theta}, \tag{A.10a}$$

$$\hat{V}^{S*} = \frac{r^w - r^{K*}}{r^w} \mu \phi^* v_\tau^* \frac{X^*}{\theta}, \tag{A.10b}$$

where the value of home and foreign assets *after* the Poisson shock is

$$V^S = v_\tau \frac{\mu X}{\theta}$$

and

$$V^{S*} = v_\tau^* \frac{\mu X^*}{\theta},$$

(where both v_τ and v_τ^* can be written as functions of E_τ as explained in Section A.6).

The logic behind the first two equations is as follows. Consider a particular date t. Home assets are composed of home macro puts, home macro calls, and untranched home trees. Home macro puts are worth V^S. macro calls constitute claims to a future stream of dividends $\phi \delta X e^{-\rho(s-t)} ds$ in any small interval ds until the Poisson shock realizes, and 0 after the Poisson shock realizes. They are worth $\phi \frac{\delta X}{r^w + \rho}$. Home trees that cannot be tranched constitute claims to a future stream of dividends $(1-\phi)\delta X e^{-\rho(s-t)} ds$ in any small interval ds until the Poisson shock realizes, and $(1-\phi)\mu\delta X e^{-\rho(s-t)} ds$ after the Poisson shock realizes. They are worth $(1-\phi)\frac{\delta X}{r^w+\rho}$.[35] The same applies to Foreign. Equations (A.9a) and (A.9b) follow.

The logic behind the last two equations is as follows. Consider a particular date t. Home macro puts can be combined with macro calls to create safe assets from the perspective of home Knightians worth $\mu \phi v_\tau \frac{X}{\theta}$—a fraction ϕ of the value $\mu v_\tau \frac{X}{\theta}$ of home assets after the Poisson shock. The required macro calls represent a constant future stream of dividends $r^K \mu \phi v_\tau \frac{X}{\theta} ds$ in any small time interval ds until the Poisson shock realizes. They are worth $\frac{r^K}{r^w} \mu \phi v_\tau \frac{X}{\theta}$. The value of home macro puts is the residual $\mu \phi v_\tau \frac{X}{\theta} - \frac{r^K}{r^w} \mu \phi v_\tau \frac{X}{\theta}$. The same applies to Foreign. Equations (A.10a) and (A.10b) follow.

Moreover, home macro puts can also be combined with macro calls to create safe assets from the perspective of foreign Knightians worth $\frac{E}{E_\tau} \mu \phi v_\tau \frac{X}{\theta}$. The required macro calls are worth $\frac{r^{K*}}{r^w} \frac{E}{E_\tau} \mu \phi v_\tau \frac{X}{\theta}$. The value of home macro puts is therefore also given by $\mu \phi v_\tau \frac{X}{\theta} - \frac{r^{K*}}{r^w} \frac{E}{E_\tau} \mu \phi v_\tau \frac{X}{\theta}$. This implies the following no-arbitrage condition

$$\frac{r^w - r^K}{r^w - r^{K*}} = \frac{E}{E_\tau}. \tag{A.11}$$

[35] The reason for this last statement is the following. Because these trees cannot be tranched, they are held by Neutrals, who do not value the associated dividends after the Poisson shock realizes because the intensity of the Poisson process λ is vanishingly small

Second, there are the wealth accumulation equations

$$\begin{aligned}
gW^K &= -\theta W^K + \alpha(1-\delta)\xi X + r^K W^K,\\
gW^{K*} &= -\theta W^{K*} + \alpha(1-\delta)\xi^* X^* + r^{K*} W^{K*},\\
gW^N &= -\theta W^N + (1-\alpha)(1-\delta)\xi X + r^w W^N + (\rho+g)V,\\
gW^{N*} &= -\theta W^{N*} + (1-\alpha)(1-\delta)\xi^* X^* + r^w W^N + (\rho+g)V^*.
\end{aligned}$$

Third, there are the market clearing conditions

$$\begin{aligned}
W^K + [x+\beta(1-x)]W^N + (1-x^*)(1-\beta)EW^{N*} &= \xi\frac{X}{\theta},\\
EW^{K*} + (1-x)(1-\beta)W^N + [x^* + (1-x^*)\beta]EW^{N*} &= E\xi^*\frac{X^*}{\theta},
\end{aligned}$$

Fourth, there is the condition that total Knightian wealth after the Poisson shock be less or equal than the total payoff of macro puts

$$W^K + E_\tau W^{K*} \leq [x\phi v_\tau + x^*\phi^* E_\tau v_\tau^*]\mu\frac{X+X^*}{\theta}.$$

Finally, we also have inequality requirements $r^w \geq \max\{r^K, r^{K*}\}$, $r^K \geq 0$, $r^{K*} \geq 0$, $0 \leq \xi \leq 1$, and $0 \leq \xi^* \leq 1$ together with the associated complementary slackness conditions.[36]

Unconstrained and constrained regimes. As explained in Caballero and Farhi (2015), there are different regimes in this model depending on whether the marginal holder of a macro put is a Neutral (unconstrained regime) or a Knightian (constrained regime). If it is a Neutral, then there are no risk premia $r^w = r^K = r^{K^*}$. If it is a Knightian, then there are risk premia $r^w > r^K$ and $r^w > r^{K*}$ and we have

$$W^K + E_\tau W^{K*} = [x\phi v_\tau + x^*\phi^* E_\tau v_\tau^*]\mu\frac{X+X^*}{\theta}.$$

We assume throughout that we are in the latter case, which always occurs if α is large enough, if μ is small enough or if ϕ and ϕ^* are small enough.[37]

A.7.1 Risk Premium in UIP and "Reserve Currency Paradox"

In this section, we zoom in on the exchange rate and characterize the deviation from UIP as a risk premium. We show that in a world of safe asset shortages, this can result in a "reserve currency paradox", whereby a country whose currency is expected to appreciate in bad times is more at risk of experiencing a safety trap.

Risk Premium in UIP. We call the no-arbitrage equation (A.11) the "modified UIP" equation. It illustrates that the country with *the lowest safe interest rate* has a depreciated real exchange rate. The exchange rate is the ratio of the risk premium at Home to the risk premium abroad: A country with a high risk premium has a depreciated exchange rate. Another way to understand this equation is as follows. An

[36] The complementary slackness conditions are

$$[[x\phi v_\tau + x^*\phi^* E_\tau v_\tau^*]\mu\frac{X+X^*}{\theta} - W^K - E_\tau W^{K*}][r^w - \max\{r^K, r^{K*}\}] = 0,$$

$$(1-\xi)r^K = 0, \quad (1-\xi^*)r^{K*} = 0.$$

[37] This is a valid equilibrium if untranched trees are worth more to Neutrals than to Knightians in either country (which is always verified if μ is small enough).

investor can borrow one at r^K and invest at r^w, but that requires buying one unit worth of macro put payoff as "collateral". Similarly, an investor can borrow one at r^{K*} and invest at r^w, but that requires $\frac{E_\tau}{E}$ units worth of macro put payoff as collateral. Or in other words, an investor can borrow $\frac{E}{E_\tau}$ at r^{K*} and invest it at r^w, with one unit worth of macro put payoff. Both strategies require one unit worth of macro put payoff as collateral. They must net out the same return, which can be expressed as $\frac{E}{E_\tau}(r^w - r^{K*}) = r^w - r^K$.

Yet another way to interpret this expression is that the modified UIP equation relates the steady state deviation from UIP in our model to the risk premium. Indeed, we have an endogenous risk premium ψ in the UIP equation so that

$$r^K = r^{K*} + \psi + \frac{\dot{E}}{E}$$

where (in the stochastic steady state prior to the shock)

$$\frac{\dot{E}}{E} = 0,$$

$$\psi = (1 - \frac{E}{E_\tau})(r^w - r^{K*}).$$

We have $\psi < 0$ if an only if $E > E_\tau$, i.e. if and only if the exchange rate of Home is expected to appreciate after the bad Poisson shock.

"Reserve currency paradox" and asymmetric liquidity traps. In general we can have a safety trap in one country but not in the other. For example, Home can be in a safety trap with $r^K = 0$ and $\xi < 1$ while Foreign is not: $r^{K*} > 0$ and $\xi^* = 1$. In this case, going back to the modified UIP equation, the risk premium in UIP is negative $\psi < 0$ and the exchange rate appreciates when the bad Poisson shock occurs $E > E_\tau$. This is another version of the "reserve currency paradox". If the home currency is a reserve currency, which is expected to appreciate in bad times, then the home risk free rate is lower, and Home can be in a safety trap even if Foreign is not.

A.7.2 Solving the Model with No Home Bias

The equilibrium equations can be boiled down to a system of nonlinear system of six equations in six unknowns E, r, r^K, r^{K*}, ξ, and ξ^*, which cannot be solved in closed form in general. This system is derived in Appendix A.7.3. Things drastically simplify when there is no home bias, i.e. $\beta = 0$. We therefore maintain the assumption that there is no home bias from now on, unless explicitly stated otherwise.

In the absence of home bias, we have $E_\tau = 1$, since the two economies are identical after the Poisson shock apart from their sizes (there is no more risk, and so the differences in securitization capacities become irrelevant). In that case, the economy jumps immediately to its long run steady state. We then have $E = 1$, $r^K = r^{K*} = r^{K,w}$, $\xi = \xi^* = \xi^w$, $v_\tau = v^*_\tau = 1$. The results in the main text of the paper follow easily (see Appendix A.7.3 below for the details).

A.7.3 Detailed Derivations

We can rewrite the system equilibrium equations as

$$x\frac{\alpha(1-\delta)\xi}{\theta + g - r^K} + (1-x)E^\mu \frac{\alpha(1-\delta)\xi^*}{\theta + g - r^{K*}} = [x\phi v(E^\mu) + (1-x)\phi^* E^\mu v^*(E^\mu)]\frac{\mu}{\theta},$$

$$\frac{r^w - r^K}{r^w - r^{K*}} = \frac{E}{E^\mu},$$

$$\frac{\alpha(1-\delta)\xi}{\theta+g-r^K}+[x+\beta(1-x)]\frac{(1-\alpha)(1-\delta)\xi+(g+\rho)[\frac{r^w-r^K}{r^w}\frac{\mu}{\theta}\phi v(E^\mu)+\frac{\delta\xi}{r^w+\rho}]}{\theta+g-r^w}$$
$$+(1-x)(1-\beta)E\frac{(1-\alpha)(1-\delta)\xi^*+(g+\rho)[\frac{r^w-r^{K*}}{r^w}\frac{\mu}{\theta}\phi^* v(E^\mu)+\frac{\delta\xi^*}{r^w+\rho}]}{\theta+g-r^w}=\frac{\xi}{\theta},$$

$$E\frac{\alpha(1-\delta)\xi^*}{\theta+g-r^{K*}}+x(1-\beta)\frac{(1-\alpha)(1-\delta)\xi+(g+\rho)[\frac{r^w-r^K}{r^w}\frac{\mu}{\theta}\phi v(E^\mu)+\frac{\delta\xi}{r^w+\rho}]}{\theta+g-r^w}$$
$$+[x^*+(1-x^*)\beta]E\frac{(1-\alpha)(1-\delta)\xi^*+(g+\rho)[\frac{r^w-r^{K*}}{r^w}\frac{\mu}{\theta}\phi^* v(E^\mu)+\frac{\delta\xi^*}{r^w+\rho}]}{\theta+g-r^w}=E\frac{\xi^*}{\theta},$$

$$r^K\geq 0,\quad 0\leq\xi\leq 1,\quad (1-\xi)r^K=0,$$
$$r^{K*}\geq 0,\quad 0\leq\xi^*\leq 1,\quad (1-\xi^*)r^{K*}=0.$$

With no home bias, we have $E=E^\mu=1$, $\xi=\xi^*=\xi^w$ and $r^K=r^{K*}=r^{K,w}$. We can solve the system and get

$$V^w=\frac{\xi^w X^w}{\theta},$$
$$W^{K,w}=\bar\phi\mu\frac{X^w}{\theta},$$
$$W^{N,w}=[\xi^w-\bar\phi\mu]\frac{X^w}{\theta},$$
$$r^{K,w}=\delta\theta+g-(1-\delta)\theta\frac{\alpha\xi^w-\bar\phi\mu}{\bar\phi\mu},$$
$$\frac{g-r^w+\rho}{g-r^w}\frac{r^w-r^{K,w}}{r^w}\mu\bar\phi=\xi^w(1-\frac{\delta\theta}{r^w+\rho}),$$
$$r^{K,w}\geq 0,\quad 0\leq\xi^w\leq 1,\quad (1-\xi^w)r^{K,w}=0.$$

In addition, we have

$$\frac{NFA}{X}=\frac{\bar\phi\mu}{\theta}+\frac{(1-\alpha)(1-\delta)\xi^w+(g+\rho)[\frac{r^w-r^{K,w}}{r^w}\frac{\mu}{\theta}\phi+\frac{\delta\xi^w}{r^w+\rho}]}{\theta+g-r^w}-[\frac{r^w-r^{K,w}}{r^w}\frac{\mu}{\theta}\phi+\frac{\delta\xi^w}{r^w+\rho}],$$

$$\frac{NFA^*}{X^*}=\frac{\bar\phi\mu}{\theta}+\frac{(1-\alpha)(1-\delta)\xi^w+(g+\rho)[\frac{r^w-r^{K,w}}{r^w}\frac{\mu}{\theta}\phi^*+\frac{\delta\xi^w}{r^w+\rho}]}{\theta+g-r^w}-[\frac{r^w-r^{K,w}}{r^w}\frac{\mu}{\theta}\phi^*+\frac{\delta\xi^w}{r^w+\rho}].$$

The requirement that

$$x\frac{NFA}{X}+(1-x)\frac{NFA^*}{X^*}=0$$

boils down to

$$0=\frac{\bar\phi\mu}{\theta}+\frac{(1-\alpha)(1-\delta)\xi^w+(g+\rho)[\frac{r^w-r^{K,w}}{r^w}\frac{\mu}{\theta}\bar\phi+\frac{\delta\xi^w}{r^w+\rho}]}{\theta+g-r^w}-[\frac{r^w-r^{K,w}}{r^w}\frac{\mu}{\theta}\bar\phi+\frac{\delta\xi^w}{r^w+\rho}].$$

This can be combined with the expression for $\frac{NFA}{X}$ above to yield

$$\frac{NFA}{X}=\frac{(r^w+\rho-\theta)\frac{r^w-r^{K,w}}{r^w}\frac{\mu}{\theta}}{\theta+g-r^w}(\phi-\bar\phi).$$