The Dollar and Global Financial Collapse

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Abstract

This paper explores the macroeconomic implications of the Fed acting as the international lender of last resort to foreign global banks during periods of crisis. To do so, I develop a stylized and tractable model that captures important features of the global financial system in the run up to the 2008 crisis, such as non-US global banks that invest in US assets but are exposed to dollar liquidity shortages. My model highlights the possibility of multiple equilibria, one of which resembles a global financial crisis with a sharp appreciation of the dollar, tighter financial conditions, weaker aggregate demand, and output losses. Moreover, these episodes may be self-fulfilling due to a feedback loop between the exchange rate and banks' capacity to raise funds. Given that global banks' liquidity needs are often denominated in dollars, the Fed is better equipped than other central banks to prevent the "bad" equilibrium when the dollar is strong. However, US incentives to intervene -through dollar swap lines- may not be aligned with the rest of the world.

Keywords: Exchange Rate, Swap Lines, Global Banks, Financial Crisis
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I. Introduction

Since the early 2000's, global banks -particularly in Europe- began accumulating large amounts of US assets[1]. These asset purchases were funded mostly by borrowing dollars in US short-term wholesale markets. As a result, global banks were exposed to liquidity shortages in dollars from financing long-dated and relatively illiquid assets with short-term liabilities.

When international interbank markets froze during the Global Financial Crisis (GFC), non-US banks struggled to roll over their outstanding dollar liabilities. Although both US and non-US banks faced liquidity shortages, the latter were hit harder since they lacked a large base of dollar deposits or easy access to dollar facilities from their domestic central banks. As a result, financial institutions were left "scrambling" for dollars, which led to an even more severe appreciation of the dollar and tighter financial conditions in international markets, further exacerbating the ongoing crisis. This narrative can be summarized in three key empirical facts that I document in detail in Section II:

1. The dollar appreciates and liquidity shortages arise during a crisis.
2. Non-US global banks have a large footprint in dollar banking.
3. Dollar funding of these banks is short-term and fragile, which exposes them to liquidity shortages.

In order to improve liquidity conditions in dollar funding markets in the US and abroad, the Federal Reserve acted unprecedentedly as the international lender of last resort providing dollar liquidity to the global financial system via bilateral swap lines[2] with several major central banks. Since then, swap lines have become a pillar of the international financial architecture (Bahaj and Reis, 2022*b*) and a key policy instrument during systemic financial stress episodes, such as the European sovereign debt crisis, Covid-19 pandemic, and the Silicon Valley Bank collapse.

The objective of this paper is to provide a theoretical framework that can rationalize the role of the Fed as the international lender of last resort and its macroeconomic implications. Even though recent studies highlight the effectiveness of the swap lines taking a micro-level empirical approach, there are still many open questions that are worth tackling from a macroeconomic perspective. In particular, this paper tries to answer three main questions. First, what is the impact of non-US global banks' imbalances on dollar fluctuations and the US economy during a crisis? Second, why are swap lines needed and why do foreign central banks rely on the Fed? Third, are the incentives of the US always aligned with those of the rest of the world?

[1]See Acharya and Schnabl (2010), Shin (2012), Broz (2015), among others. According to McGuire and von Peter (2012), the outstanding stock of BIS reporting banks' foreign claims grew from \$11 trillion at end-2000 to \$31 trillion by mid-2007.

[2]In short, a swap line is an agreement between two central banks to exchange currencies at a specific exchange rate, and for a short period of time. Section II provides more details about this instrument.

To answer these questions I develop a stylized and tractable model of the world economy that captures important features of the financial system in the wake of the GFC. As a first step, I use a two-period version of the model to illustrate how self-fulfilling global crises might occur by placing non-US global banks with maturity mismatches in dollars at the core of the international financial intermediation. This approach highlights the large spillovers that these banks can have on the US economy due to their significant holdings of US assets. Next, through the lens of this framework, I study the Fed's swap lines to foreign central banks, the incentives that triggered their implementation, the need for the intervention, and their implication for the world economy and for each country involved. Finally, I extend the baseline model to endogenize the investment and funding decisions of global banks, which allows me to study two additional aspects. On one hand, I analyze the conditions under which these banks decide to invest and fund themselves in dollars even though this exposes them to dollar shortages. Additionally, I show how the swap lines can influence their risk-taking behaviour, opening the door to potential moral hazard issues for the Fed.

In my framework, the world economy is exposed to self-fulfilling crises because of a feedback loop between the exchange rate and the capacity of non-US global banks to raise funds. This opens the door to multiple equilibria, in the spirit of Céspedes et al. (2017) and Bocola and Lorenzoni (2020). Due to the presence of financial frictions and maturity mismatches in dollars, an exchange rate depreciation (increase in the value of the dollar relative to other currencies) results in tighter market conditions for banks with short-term liabilities in dollars that need to be rolled-over. If households expect a significant depreciation, foreign banks may not receive the necessary funding to meet their obligations, leading to a banking crisis in their economy. As a consequence, aggregate demand in the affected country drops, and their exchange rate further depreciates, confirming households' pessimistic expectations.

The US is also affected by the potential collapse of these global banks, since they invest heavily in productive dollar-denominated assets that boost the economic activity in the US. Moreover, in a state of the world where the dollar is strong relative to other currencies, and given the size of global banks' balance sheets, non-US central banks without significant dollar reserves might lack the resources to eliminate the "bad" equilibrium. The Fed, on the other hand, can intervene by providing dollar liquidity directly. Nevertheless, its incentives to bail-out foreign global banks might not be necessarily in line with the interests of the rest of the world. The reason is that, during a global crisis, the US might benefit from a stronger dollar and cheaper sources of funding from abroad.

Equipped with this model, it is possible to see how changes in the fundamentals of the global economy (higher interest rates, balance sheet mismatches, investors' risk-aversion, etc.) might push the world in or out of the "safety zone" where financial crises are unlikely. The framework also highlights the mechanisms behind the dollar appreciation during a global crisis, its connection to tighter financial conditions, and how it ultimately reinforces the severity of the crisis.

Lastly, using a three-period version of the baseline model, I show how global banks do not necessarily have sufficient ex-ante incentives to reduce their exchange rate exposure, even if this maturity mismatch in dollars opens the door to a potential financial crisis. This happens because during "normal" times, dollar funding is relatively cheap, and the long-term investment opportunities in the US are attractive. If swap lines are anticipated, the reduction in perceived risk eases the financial constraint that banks face in period 0, and allows them to increase their positions and their exposure to dollar shortages. In this situation, the Fed faces a choice: should they announce the swap lines in advance, thereby benefiting from the global banks' intermediation services but risking the possibility of a crisis? Alternatively, they can opt for an unanticipated intervention, minimizing risk but also restricting investment opportunities in the US.

Overall, this paper contributes to our understanding of the fragility of dollar funding and the importance of global banks' imbalances in the international spillover of shocks[3]. It also emphasizes the critical role of the Fed's interventions in maintaining the stability of the global financial system.

Related Literature. This study relates to several broad strands of the literature. First, it is directly related to papers studying self-fulfilling crises in open economies, starting with Calvo (1988) and followed by Schmitt-Grohé and Uribe (2016), Obstfeld (1996), Cole and Kehoe (2000), and more recently by Céspedes et al. (2017), Aguiar et al. (2017), Farhi and Maggiori (2018), and Bocola and Lorenzoni (2020), among others. The feedback loop that drives the results in my framework works largely as in a "third-generation" currency crisis model (Krugman, 1999). These types of models have mostly been used to study emerging markets, and were particularly relevant to understanding the financial crises that they faced during the 90's. The novelty of this paper is that it focuses on global banks in a large economy such as the EU, which brings up two main differences with respect to traditional models. On the one hand, the liquidity shortages these banks face come from their maturity mismatches in dollars, rather than from currency mismatches, as in most emerging economies. Moreover, the collapse of these global intermediaries has significant spillovers to the international financial system, particularly to the US.

The focus on global banking of this paper is shared with a growing set of mostly empirical studies[4] (Cetorelli and Goldberg, 2012; Shin, 2012; Bräuning and Ivashina, 2020; Aldasoro et al., 2019). The behavior of global banks and their role in the transmission of crises are modelled in Kalemli-Ozcan et al. (2013), Ivashina et al. (2015) and Morelli et al. (2022). I follow a similar theoretical approach to Gabaix and Maggiori (2015) in building a minimalistic real model with two countries, financial frictions, and global financial intermediaries at the centre of the capital flows and the exchange rate determination. However, they do not consider potential imbalances in the balance sheet of the intermediaries, which in my model open the door to multiple equilibria and benefits from an international lender of last resort.

In this context, a key feature of this paper when assessing the role of global banks is the dollar

[3]See Shin (2012), Ivashina et al. (2015), Aldasoro et al. (2019), among others.

[4]Others include Acharya and Schnabl (2010), Correa et al. (2016), McGuire and von Peter (2012).

dominance. Recent studies that incorporate this characteristic, especially when focusing on exchange rate determination include Bruno and Shin (2015), Gourinchas et al. (2010), Maggiori (2017), Itskhoki and Mukhin (2021), Kekre and Lenel (2021), among others. Many of these studies focus on the US as the "World Banker", providing safe assets to the world. However, this traditional view predicts a dollar depreciation in times of crisis, which the authors try to challenge by incorporating *flight-to-safety* shocks (Kekre and Lenel, 2021) or exogenous trade costs that are linked to the banks' health (Maggiori, 2017), to mention a few. In contrast, this paper shifts the focus to non-US global banks, which played a crucial role in the intermediation of capital flows across developed countries in the run-up to the GFC. By doing so, the model is able to jointly explain the dollars' role as the reserve currency and its particular dynamics during a global crisis.

Finally, this paper also relates to the stream of literature on swap lines, most of which takes a micro-level empirical approach. From the studies focusing on this intervention[5] during the GFC, such as Baba and Packer (2009*b*), Baba and Packer (2009*a*), Moessner and Allen (2013), and Aizenman and Pasricha (2010), perhaps the most comprehensive study so far is Bahaj and Reis (2022*a*), who rely on a difference-in-difference identification to assess the effect of the Fed's swap lines on CIP deviations, portfolio flows, and the price of dollar-denominated corporate bonds. In a follow-up article (Bahaj and Reis, 2020), they study the impact on funding costs of the new swap lines introduced by the Fed as a response to shortages in the US dollar markets during the Covid-19 pandemic, similarly to Aizenman et al. (2021), Goldberg and Ravazzolo (2022), and Ferrara et al. (2022). Considering all these studies, the overall consensus points to the swap lines effectively helping to ease strains in US dollar funding markets and addressing sudden stop type episodes for banking systems.

On the theory side, the number of references is more limited. Bahaj and Reis (2022*a*) provide a model of the market for FX forwards into a small-scale general equilibrium model and find that the Fed swap lines reduce bank funding risk and increase the investment in dollar-denominated assets of non-US banks. Eguren-Martin (2020) and Cesa-Bianchi et al. (2022) on the other hand, propose a medium-scale DSGE model with a bank currency portfolio problem to assess the capacity of the swap lines to mitigate the impact of dollar-shortage shocks to the economy and financial system. Kekre and Lenel (2021) find that, in a business cycle model of the international monetary system, "flight-to-safety" shocks generate a dollar appreciation and a decline in global output, and show that dollar swap lines help to mitigate these effects. Contrary to the others listed here, my paper offers a tractable model of the global economy that features multiple equilibria. This allows me to study the intervention from the perspective of a lender of last resort[6] and as an instrument to prevent self-fulfilling crises.

[5]An older literature studied the swap lines that supported the Bretton Woods system as well as the Fed's reciprocal swap system between 1962 and 1998, when they were mainly used to finance foreign exchange rate interventions and keep currencies pegged to the dollar (e.g. Williamson, 1983; Obstfeld et al., 2009; McCauley and Schenk, 2020).

[6]Although in this paper the Fed acts as the international lender of last resort, the focus is on the macroeconomic aspect of a specific type of intervention (swap lines), and thus is different from the traditional lender of last resort literature, such as Bagehot (1873), Diamond and Dybvig (1983), or Rochet and Vives (2004).

The rest of the paper is organized as follows. Section II presents the three stylized facts that serve as the basis of the model. Section III describes the model. Next, Section IV discusses the multiple equilibria that might arise under this framework. The benefits of an international lender of last resort, as well as the trade-off they face, are presented in Section V, while Section VI extends the standard framework to discuss banks' optimal funding and investment decisions. Finally, Section VII concludes.

II. Stylized Facts

In this section I present three empirical facts that are distinctive features of the international financial system, and discuss briefly how I capture them in my model. Next, I elaborate on the usage and magnitude of the dollar swap lines, including the aspects of the intervention that I will highlight in the model.

Fact 1: The dollar appreciates and liquidity shortages arise during a crisis.

As shown in Figure 1, the dollar appreciated both during the global financial crisis and the Covid-19 crisis. This is a well-documented fact that traditional macro-finance models fail to capture and that is known as the reserve currency paradox (Maggiori, 2017; Chen, 2021). Moreover, dollar liquidity becomes scarce (Corsetti and Marin, 2020; Borio, 2020; FSB, 2020) as shown by the increase in the dollar funding costs in Figure 1. This reflects an increase in the demand for dollars in a context of high market volatility and risk aversion as market participants, who typically have a significant exposure to the dollar, hoard cash in anticipation of potential cash outflows to the real economy.

I introduce this fact in the model with a financial friction that limits the ability of global banks to raise funds. When these banks face maturity mismatches in foreign currency, a dollar appreciation can harm their net worth, increasing the level of risk that they pose to investors, and ultimately tightening the financial conditions they face.

Fact 2: Non-US global banks have a large footprint in dollar banking.

In the run-up to the GFC, the total dollar assets of banks outside the US reached \$10 trillion, and increased up to almost \$14 trillion in 2021. Surprisingly, this is comparable to the current size of the aggregate commercial banking sector in the US, as seen in Figure 2a. As mentioned in Shin (2012), it is as if an offshore banking sector of comparable size to the US banking sector is intermediating dollar claims and obligations[7]. From this offshore banking sector, EU-based banks were responsible for the largest share of these international funds. As shown in Figure 2b, the majority of their dollar assets were financed with equally large dollar liabilities. Regarding the type of assets they hold, Acharya

[7]To provide a clear idea of the extent of the intermediation activity conducted by non-US banks in the US, Figure A.1 shows that foreign claims of BIS reporting banks on US counterparties reached \$7.3 trillion by mid-2021.

and Schnabl (2009) and Shin (2012) report that European banks were sponsors for around 70% of the asset-backed commercial paper originated prior to the subprime crisis, and had large holdings on other US private label securities as well. Milesi-Ferretti (2009) draws on evidence from the US Treasury on foreign holdings of US securities to show that the bulk of non-government securities were held by European investors[8].

This phenomenon of non-US global banks playing an important role in the intermediation of dollar-denominated flows is an important feature of the international financial system in the run-up to the GFC. I incorporate this fact in my model by having global banks intermediating dollar funds from US households into productive long-term investments.

Fact 3: Dollar funding of these banks is short-term and fragile, which exposes them to liquidity shortages.

As mentioned before, the dollar-denominated asset purchases by global banks in the last two decades has been largely financed with dollar-denominated debt. Despite showing a combination of large gross dollar positions but small net positions, these banks were exposed to liquidity shortages given their reliance on short-term funding. McGuire and von Peter (2012) document that European banks' short term dollar funding gap (i.e. dollar roll-over needs) were at least 7% of US GDP at the onset of the GFC. Figure 3a shows that in 2007, their net short-term liabilities in dollars were around $1.4 trillion. This situation has not changed drastically in recent years, as non-US banks still tend to rely on short-term or wholesale US dollar funding. Figure 3b shows that only around 30% of their dollar liabilities comes from deposits -which is a relatively stable source of funding- compared to the 70% that deposits represent in their consolidated balance sheet[9].

Motivated by these characteristics, the model features global banks with short-term dollar liabilities that need to be rolled-over. Combined with the financial constraint discussed previously and the illiquidity of their assets, an exchange rate depreciation might prevent global banks from obtaining the funding needed to cover their dollar obligations, forcing them to shut down.

[8] Figure A.1 provides more evidence on this and shows that purchases of US assets by foreigners accounted for around 13% of US GDP in Q4-2007, and were focused mostly on MBS and corporate bonds, which tend to be long-term and relatively illiquid compared to treasuries, for example.

[9] Aldasoro et al. (2021) show that with around $1.4 trillion, US and offshore money market funds (MMFs) represented around 12% of the on-balance sheet dollar funding for non-US banks at end-2019. MMFs are a flighty funding source: Figure A.2 shows that non-US banks lost around $300 billion during the covid-19 turmoil, mostly from US markets.

(a) Global Financial Crisis (b) Covid-19 Crisis

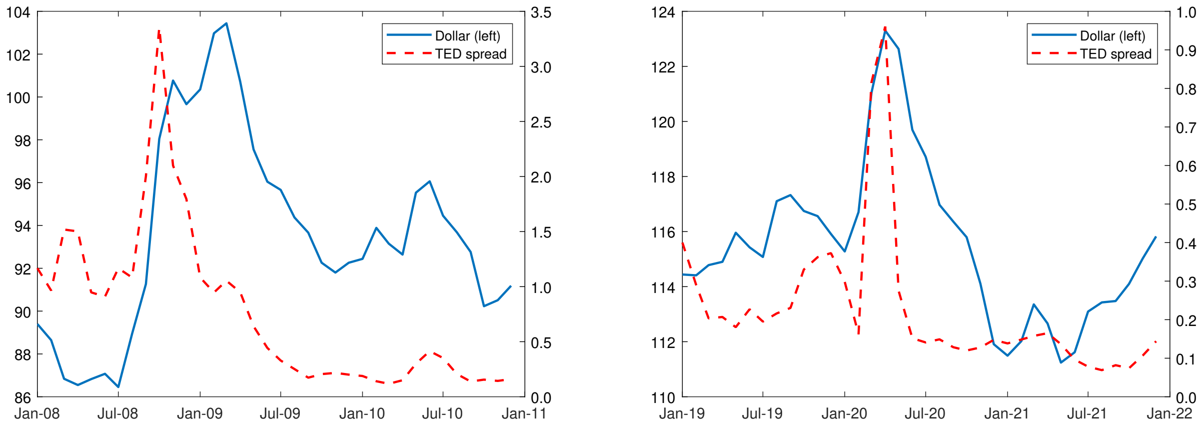


Figure 1: Dollar (index) and TED spread (%)

Note: The TED spread is defined as the difference between the 3-month LIBOR rate and the 3-month T-bill rate, thus it can be understood as the difference between the interest rate that investors demand from the government for investing in short-term Treasuries and the interest rate that investors charge large banks. A higher spread indicates that the cost of dollar funding for large banks increases, due to a higher perception of credit risk. ***Source:*** Fed.

(a) Dollar cross-border foreign currency claims and US banks' total assets ($ trillions)

(b) Dollar-denominated assets and liabilities of EU banks ($ trillions)

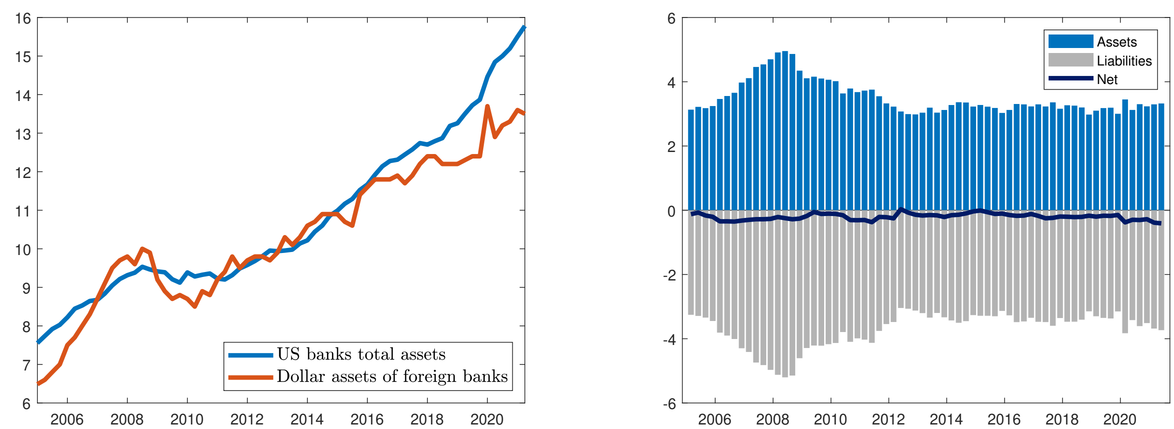


Figure 2: Dollar intermediation of non-US global banks

Note: In Panel (a), I consider US chartered commercial banks' total financial assets, and US dollar assets of banks outside the US. In Panel (b), estimates are constructed by aggregating the on-balance sheet cross-border and local positions reported by Belgian, Dutch, French, German, Italian and Spanish banks. ***Source:*** BIS, Flow of Funds, Fed.

(a) Net dollar positions of EU banks, by counterparty ($ trillions)

(b) Funding Structure in 2017 (% of total liabilities, by currency)

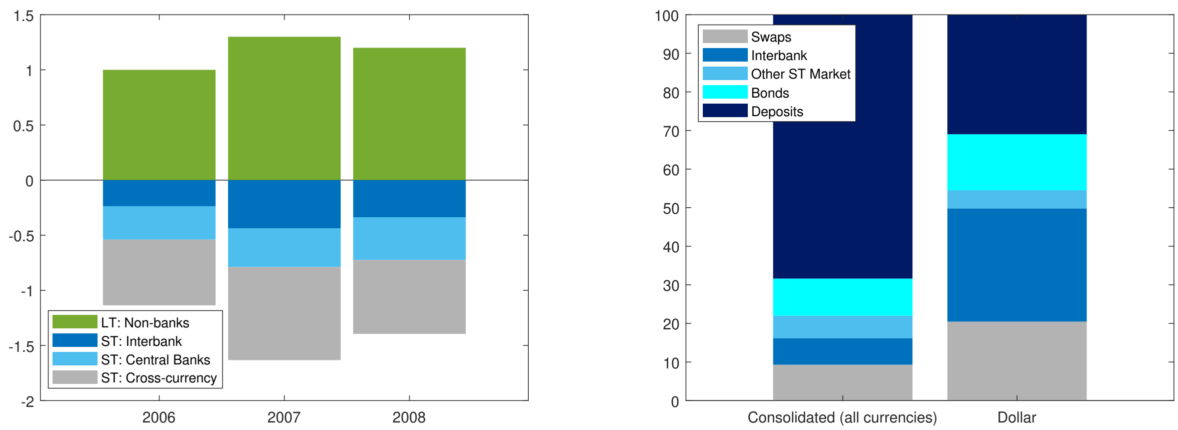


Figure 3: Dollar funding of non-US global banks

Note: In Panel (a), estimates are constructed by aggregating the on-balance sheet cross-border and local positions reported by Belgian, Dutch, French, German, Italian, Spanish, Swiss and UK banks' offices. An important assumption is that the positions with other banks, central banks, and cross-currency funding are mostly short-term. Panel (b) includes all BIS reporting banks, except those from the US. It includes their dollar positions outside the United States plus those in US branches, but excluding US subsidiaries. For more details on the methodology, see Online Annex 1.2 at www.imf.org/en/Publications/GFSRT. ***Source:*** BIS, IMF Global Financial Stability Report (2018), McGuire and von Peter (2012).

Swap Lines

In a nutshell, a swap line is an agreement between two central banks to exchange currencies at a specific exchange rate, and for a short period of time. The recipient central bank then lends the dollars out to eligible banks in its jurisdiction. From the perspective of the Fed, the end result is a loan of dollars to foreign banks, which is the approach that I will follow when discussing the model in this paper. Given that the terms and interest rate as a spread over the policy rate are set when the contract is signed, there is no exchange rate or interest rate risk for the Fed. Moreover, there is negligible credit risk, as the Fed deals only with selected foreign central banks, who guarantee these transactions[10].

The Fed's main objective during the crisis was to address liquidity shortages worldwide. In that sense, it provided liquidity to both domestic (via the Term Auction Facility) and foreign banks (via swap lines), as part of a far-reaching effort[11]. Based on minutes from the FOMC meetings, the Fed's intervention tried to i) prevent a risky US-dollar assets fire-sale, ii) prevent a run down lending of

[10] To consider a scenario in which the foreign central bank might default on the swap line is more complex and unlikely to happen in the short-term.

[11] In total, 14 foreign central banks have been benefited from access to the Fed's swap lines. Usage peaked at $450 billion in late May 2020 compared to $598 billion drawn during the GFC (Choi et al., 2021). The aggregate BOJ and ECB usage accounted for about 82% of the total peak.

EU banks in the US[12], and iii) calming the markets. According to Tooze (2018), the last point in the list might relate to the risk of the dollar losing its hegemony: it was key for the Fed to maintain the confidence in the dollar. In this paper I focus on the first two incentives.

III. Baseline model

This section describes a simple model of financial determination of exchange rates in imperfect financial markets. Time is discrete and there are three periods, $t = 0, 1, 2$, and two economies, the United States (US) and the Euro area (EU), each populated by a continuum of households. There are three goods: a non-tradable good in each economy, and one single tradable good, which is traded internationally. Both EU and US households invest with global banks in risk-free bonds denominated in their domestic currency[13]. Global banks are financially constrained, as will be discussed in detail later. At the end of period 2, all profits from global banks are transferred to EU households.

The model is built around three ingredients motivated by the empirical facts discussed earlier. First, banks start period 1 with short-term liabilities and illiquid long-term assets such that a maturity mismatch in dollars is formed. Second, they have to roll-over their initial debt in order to operate, but their ability to raise funds is limited. These two ingredients combined result in tighter financial conditions if the dollar appreciates in the short-run. Finally, although EU households own global banks, their operations have spillovers towards the US by boosting non-tradable output when their long-term assets mature. I now turn to a detailed description of the environment, including each of the model's actors, their optimization problems, and some simplifying assumptions.

A. Households

Euro area households derive utility from from consuming a consumption basket C defined as $C_t \equiv (C_t^N)^{1-\omega}(C_t^T)^{\omega}$, where C_t^T and C_t^N are the EU consumption of the tradable good and its non-tradable good, respectively. The parameter $0 < \omega < 1$ denotes their preference for the tradable good, while the non-tradable good is the numéraire in this economy. Consequently, the relative price of the tradable good with respect to the non-tradable good in the EU is simply denoted by p_t.

Households can trade tradable goods in a frictionless goods market across countries, but can only trade non-tradable goods within their domestic country. Financial markets are incomplete, and EU

[12] Besides the credit availability -especially related to mortgage-backed securities-, the Fed was also concerned about keeping mortgage rates low. In 2008, the Libor rate was relevant because it was the benchmark not only for US corporate loan contracts (among others), but also for the adjustable-rate household mortgages. Thus keeping offshore rates low was relevant for the Fed and the US economic recovery.

[13] This is in line with the empirical evidence provided -for example- by Maggiori et al. (2020), in which they establish that investor holdings are biased toward their own currencies to such an extent that countries typically hold most of the foreign debt securities denominated in their currency.

households trade a risk-free domestic currency bond with EU banks. The households' optimization problem is then

$$\max_{C_t} \quad U = \ln(C_1) + \beta \mathbb{E} \ln(C_2) \tag{1}$$

subject to the budget constraint in both periods,

$$Y_1^N + p_1 Y_1^T + L = C_1^N + p_1 C_1^T + B \tag{2}$$

$$\Pi + Y_2^N + p_2 Y_2^T + R \cdot B = C_2^N + p_2 C_2^T \ , \tag{3}$$

where Y_t^T and Y_t^N are the households' endowments of the tradable and non-tradable goods, respectively. On the other hand, Π represents the profits that banks transfer to EU households at the end of the first period. R is the gross interest rate paid by the euro-denominated bond (B). Finally, L is a pre-existing euro-denominated position with global banks that has to be repaid or claimed in period 1, but their actual value will depend on the banks' soundness, as will be discussed shortly.

The households' first-order conditions can be written as

$$p_2 C_2^T = \beta R p_1 C_1^T \tag{4}$$

$$C_t^N = \frac{1-\omega}{\omega} p_t C_t^T \tag{5}$$

Equation (4) is the Euler equation in terms of the tradable consumption and prices. Equation (5) determines the optimal allocation of consumption expenditure between tradable and non-tradable goods. It is straightforward to see from here that demand for non-tradables is increasing in the relative price of tradables and in C_t^T, due to households' desire to consume a balanced basket between tradable and non-tradable goods.

US households face a very similar optimization problem. The main differences with EU households is that they trade dollar-denominated bonds, and they hold pre-existing dollar-denominated positions L^* with global banks that have to be claimed in period 1. By analogy with the EU case, US households' optimization problem is

$$\max_{C_t^*} \quad U^* = \ln(C_1^*) + \beta \mathbb{E} \ln(C_2^*) \tag{6}$$

subject to the budget constraint in both periods,

$$p_1^* Y_1^{*T} + Y_1^{*N} + L^* = p_1^* C_1^{*T} + C_1^{*N} + B^* \tag{7}$$

$$p_2^* Y_2^{*T} + Y_2^{*N} + R^* B^* = p_2^* C_1^{*T} + C_2^{*N} \ , \tag{8}$$

where starred variables denote US quantities and prices. R^* is the interest rate paid by the dollar-denominated bond. Households also receive endowments Y_t^{*T} and Y_t^{*N} in both periods. Their first-order conditions follow the same intuition as their EU counterpart, and are given by

$$p_2^* C_2^{*T} = \beta^* R^* p_1^* C_1^{*T} \tag{9}$$

$$C_t^{*N} = \frac{1-\omega^*}{\omega^*} p_t^* C_t^{*T} \ . \tag{10}$$

The key variable in this real model is the exchange rate e_t. Since there is no nominal side to the model, the words *dollar*- or *euro*-denominated mean values expressed in units of US and EU non-tradable goods, respectively. In that context, I follow Gabaix and Maggiori (2015) in defining the exchange rate as the relative price between the two non-tradable goods, or in other words, as the quantity of *euros* bought by one *dollar*. Consequently, e_t is a measure of the strength of the dollar, so that an increase represents a dollar appreciation. The law of one price holds, and thus $e_t p_t^* = p_t$ in every period.

B. Global Banks

Global banks are owned by EU households[14]. They start period 1 with assets and liabilities in both currencies, with different maturities. Short-term liabilities are given by L and L^*, and have to be repaid in period 1. Meanwhile, long-term assets[15] in euros and in dollars mature in period 2, and have a gross return of A and A^*, respectively. In order to operate and avoid shutting down, banks try to roll-over their debt by trading bonds with EU (B) and US (B^*) households in their corresponding currencies.

The long-term assets exhibit two important features. First, they have no value if liquidated[16] in period 1, therefore banks cannot cover their liquidity needs by selling part of their assets. Secondly, they yield positive returns only if banks operate[17], and zero otherwise. This implies that $A, A^* > 0$ if banks operate, and they are zero otherwise. Therefore, under normal circumstances, banks enjoy

[14]The reader can think of a US banking sector also operating in the background. In a more complex set up, these banks would intermediate the funds from US households, and then engage in cross-border operations with foreign banks. Since the model focuses on global banks and their balance sheet mismatches, the lending by US banks is immaterial to the results, so I leave it unspecified.

[15]Since they are denominated in non-tradable goods, these assets can be thought as an investment in the housing sector. They can also be interpreted as if banks were financing firms that invest in the non-tradable sector.

[16]This assumption is in line with traditional bank-run models such as Diamond and Dybvig (1983) and Allen and Gale (2009) in which liquidating an asset before maturity entails significant costs. In my model, the assumption can be motivated by the fact that, in the run up to the GFC, global banks' dollar assets were mostly risky mortgage-backed securities and corporate bonds, which eventually suffered from significant negative devaluations when the crisis hit. The model in Clayton and Schaab (2022) also features global banks investing in illiquid long-term projects.

[17]As explained in Brunnermeier and Sannikov (2014), many macro-finance models with financial frictions consider banks as experts with a superior ability or greater willingness to manage and invest in productive assets. In this case, when banks shut down, the otherwise productive investment lacks the necessary management to yield positive results.

positive profits in period 2 given by

$$\Pi = A + e_2 A^* - RB - e_2 R^* B^* \ . \tag{11}$$

This is the case if they raise enough funds to fully repay their outstanding obligations, i.e., if the following condition holds:

$$L + e_1 L^* \leq B + e_1 B^* \ . \tag{12}$$

If equation (12) is not met, banks shut down and lose all profits, hence $\Pi = 0$. This result comes from the fact that the long-term assets provide no returns $(A, A^* = 0)$ if banks go bust, and that the pre-existing positions with US and EU households are not repaid or claimed $(L, L^* = 0)$. This set up in which assets from global banks turn out to be worthless if the bank defaults, leaving them with no resources to pay any of its debts, is similar to Ivashina et al. (2015).

In a friction-less world, banks would always be able to operate. Nevertheless, I introduce a friction that limits their ability to raise the required funding. In each period, after taking positions, they can divert a fraction of the funds they intermediate. If they divert the funds, banks are unwound and the households that had lent to them in $t = 1$ recover a portion $1 - \gamma \geq 0$ of their credit position $B + e_1 B^*$. Since creditors -when lending to the banks- correctly anticipate their incentives to divert funds, banks are subject to a credit constraint of the form:

$$\frac{1}{R}\Pi \geq \gamma(B + e_1 B^*) \tag{13}$$

where $1/R$ comes from the EU households' stochastic discount factor.

Bankers choose B and B^* to maximize the expected profits in (11) subject to the liquidity needs in (12) and the financial constraint in (13). The optimization problem results in the following condition:

$$R = R^* \frac{e_2}{e_1} \tag{14}$$

which reflects that the uncovered interest parity (UIP) holds[18] when banks operate. In equilibrium, if equation (12) holds, it does so with equality, so that combining the two restrictions and the UIP condition yields the following expression for the financial constraint:

$$\frac{A}{R} + e_1 \frac{A^*}{R} \geq (1 + \gamma)(L + e_1 L^*) \ .$$

In this form, it is easier to see how the constraint depends on the exchange rate. However, the

[18]This no arbitrage condition arises from the fact that banks take R and R^* as given.

magnitude and the direction of this effect will depend on the initial mismatches in banks' balance sheets. In the next section I will explore the case when dollar-denominated liabilities are such that an increase in the exchange rate tightens the constraint, in line with the evidence presented in Section II, showing that a dollar appreciation and worse financial market conditions go hand in hand (Fact 1).

C. Market Clearing

Market clearing for the non-tradable consumption good requires that in every country consumption is equal to the endowment:

$$\begin{aligned} Y_1^N &= C_1^N & \qquad Y_1^{N*} &= C_1^{*N} \\ Y_2^N + A &= C_2^N & \qquad Y_2^{*N} + A^* &= C_2^{*N} \end{aligned} \tag{15}$$

where the last two equations reflect that the outcome of the long-term assets can increase the non-tradable output in both countries in $t = 2$, and thus could be interpreted as the result of a productive set of projects. On the other hand, the market clearing condition for the tradable good requires that the world's endowment is equal to the world's demand in both periods,

$$Y_t^T + Y_t^{*T} = C_t^T + C_t^{*T} \ . \tag{16}$$

Next, I will provide the definition of a competitive equilibrium in this model.

Definition 1 (Competitive Equilibrium)**.** *A competitive equilibrium is a path of real allocations* $\{C_t^T, C_t^N, C_t^{*T}, C_t^{*N}\}_t$ *and* $\{B, B^*\}$*, interest rates* R*,* R^* *and exchange rate* $\{e_t\}_t$*, satisfying the households' optimality conditions in* (2)*,* (3)*,* (4) *and* (5) *-plus their counterparts for the US economy-, the banks' optimality conditions in* (11)*,* (12) *and* (14)*, the market clearing conditions in* (15) *and* (16)*, given a path of endowments* $\{Y_t^T, Y_t^N, Y_t^{*T}, Y_t^{*N}\}_t$*, and initial conditions* $\{L, L^*, A, A^*\}$*.*

Some useful simplifying assumptions

To streamline the algebra and concentrate on the relevant economic content, assume for now that both countries have the same preferences for non-tradables and the same discount factors, therefore $\omega = \omega^*$ and $\beta = \beta^*$. Moreover, I will assume that $Y_1^N = Y_1^{*N}$ and normalize it to 1. Combining households' first order condition and the market clearing, the interest rates in both countries can be expressed as

$$R = \frac{A + Y_2^N}{\beta Y_1^N} \qquad \text{and} \qquad R^* = \frac{A^* + Y_2^{*N}}{\beta^* Y_1^N} \ ,$$

from where it can be seen that the interest rates depend on the realization of banks' investments, because they boost non-tradable output when they materialize. Besides the asymmetries related to bank profits and their initial portfolio, I will allow for different endowments of the tradable good in each country. Denote the share of the EU endowment of the tradable good in the world economy as

$$\eta_t \equiv \frac{Y_t^T}{Y_t^T + Y_t^{*T}} \ .$$

For simplicity, assume that $\eta_1 = \eta_2 = \eta$. In Section VI I provide a generalization of the model that relaxes these assumptions, maintaining the main results.

IV. Multiple equilibria and self-fulfilling crises

Exchange rates and the state of the economy

Before finding the equilibria of the model, it is necessary to discuss what determines the state of the financial system (with operating or collapsed banks). In Section III we conclude that banks operate when their expected profits are large enough, such that households are confident in providing the required funding to roll-over banks' short-term liabilities. In this paper I will follow the literature of bank runs, where financial intermediaries might face liquidity issues but are otherwise solvent. Particularly, I will focus on the case where banks are solvent in dollars, but exposed to *dollar liquidity shortages*, following the empirical evidence presented before. This can be captured in the model by assuming

$$\begin{aligned} \text{Dollar profitability:} \quad & \frac{A^*}{R^*} - L^* > 0 \\ \text{Dollar liquidity:} \quad & \frac{A^*}{R^*} - (1+\gamma)L^* < 0 \end{aligned}$$

The previous two inequalities reflect that the discounted dollar profits of global banks might be large compared to their current dollar liabilities. However, they might be insufficient to cover their short-term dollar needs, which are determined also by γ. It is possible to interpret this parameter as capturing the market's risk intolerance, so that liquidity needs are larger when this intolerance is higher. To further narrow the focus of the analysis to dollar shortages, I will assume for now that $L = 0$, so that no euro-denominated debt has to be rolled-over[19]. With these conditions, the incentive compatibility constraint in 13 can be rewritten in terms of the exchange rate, as

$$e_1 \leq \frac{A/R}{(1+\gamma)L^* - A^*/R^*} \equiv \overline{e} \ .$$

$\overline{e}$ is defined as the exchange rate that makes the constraint hold with equality. This shows that,

[19]This assumption will also be relaxed in Section VI where I present a more generalized version of the model.

although e_1 affects the return of dollar investments positively, it also increases the liabilities that banks need to roll-over, making diverting funds more appealing. Under the assumption that banks face a *dollar shortage*, the overall result is that market conditions become tighter the higher is the exchange rate. If the depreciation goes beyond the threshold $\bar{e}$, banks cannot roll-over their debt and go bust. In that case, their assets lose all value and liabilities are not repaid, thus their profits drop to zero. On the contrary, if $e_1 < \bar{e}$, banks operate normally.

To fully characterize the equilibrium of the model I will focus on two variables: the exchange rate and capital flows. The reason is that both variables play a key role in the occurrence of "sudden stops" and financial crises, and eventually will drive most of intuition behind the main results of the model. In particular, I will focus on the exchange rate in period 1, and on EU savings, B. Since this is a two-country model, EU savings are equivalent to capital flows to the US, so I will use both terms interchangeably.

A. Static determination of exchange rates and capital flows

First, I will analyze how capital flows affect the exchange rate in period 1. From the perspective of the EU, the trade balance -in euros- is defined as follows:

$$p_1(Y_1^T - C_1^T) = B \ ,$$

where B represents the net capital flows to the US. Focusing on the left-hand side of the previous expression, the households' optimality condition in (5) and the market clearing conditions for non-tradable goods tell us that their expenditure in tradables is fixed, so that $p_1 C_1^T = \frac{\omega}{1-\omega} Y_1^N = \frac{\omega}{1-\omega}$. Furthermore, simple derivations presented in the appendix show that tradable market clearing (16) and utility maximization imply that

$$p_1 = \frac{\omega}{1-\omega} \frac{1}{Y_1^T + Y_1^{*T}} (1 + e_1) \ ,$$

reflecting the fact that, when a country's exchange rate depreciates, consuming tradable goods becomes more expensive. Finally, rearranging the equations above to express e_1 as a function of B yields:

$$e_1 = \underbrace{\frac{1-\eta}{\eta}}_{\substack{\text{Endowment}\\ \text{component}}} + \underbrace{B \cdot \frac{1-\omega}{\omega} \cdot \frac{1}{\eta}}_{\substack{\text{Capital flows}\\ \text{component}}} \ . \tag{17}$$

This equation describes a very intuitive result. The first component shows that, absent capital flows, the exchange rate is determined simply by the relative endowment of tradable goods in each economy. More interestingly, the second component captures the idea that the larger the capital outflows towards the US (EU savings), the larger the trade balance that the EU needs in period 1 to cover those outflows. Ultimately, a stronger trade balance is achieved by a euro depreciation ($\uparrow e_1$). Another way to look at this idea is that a weaker euro makes EU exports more attractive in markets abroad.

B. Intertemporal determination of exchange rates and capital flows

Now let us consider how the exchange rate in period 2 affects capital flows. I will divide the analysis into two cases - depending on if banks operate or not. First, if they operate, households maintain access to bonds in order to smooth consumption over time. In this line, the gross returns from EU savings covers any excess in expenditure in period 2, such that

$$R \cdot B = p_2(C_2^T - Y_2^T) + C_2^N - Y_2^N - \Pi \ .$$

Following a similar procedure as for the trade balance in period 1, it is possible to rewrite the expenditure in tradables as $p_2 C_2^T = \frac{\omega}{1-\omega} C_2^N$ and the price of tradables as

$$p_2 = \frac{\omega}{1-\omega} \frac{1}{Y_2^T + Y_2^{*T}} (C_2^N + e_2 C_2^{*N}).$$

Simple derivations described in the appendix show that the previous equation can be written in terms of e_1 by using the expressions for both interest rates, the UIP condition $e_2 = e_1 \dfrac{R}{R^*}$, and the market clearing conditions for non-tradable goods, $C_2^N = Y_2^N + A$ and $C_2^{*N} = Y_2^{*N} + A^*$. Moreover, banks' profits given by equation (11) can also be expressed in terms of e_1 by using the UIP condition and the liquidity condition in (12), so that $\Pi = R\Big[e_1\Big(\frac{A^*}{R^*} - L^*\Big) + \frac{A}{R}\Big]$. Finally, combining all these expressions, the previous equation can be rewritten as

$$B = \beta \frac{\omega}{1-\omega}\Big(1 - \eta\Big(1 + e_1\Big)\Big) - e_1 \underbrace{\left(\frac{A^*}{R^*} - L^*\right)}_{\text{Dollar profits}} \ . \tag{18}$$

Equation (18) highlights the importance of wealth effects in determining capital flows and the exchange rates. The first term on the right-hand side shows that an exchange rate appreciation ($\downarrow e_2$) in the EU represents a drop in relative prices in that economy in period 2, which pushes EU households to save more (or borrow less) in period 1 and thus capital outflows increase. This can be thought in terms of e_1 as well, since in a context where UIP holds, variations in the exchange rate are permanent (e_1 and e_2 move in the same direction). The last term on the right-hand side shows that a dollar appreciation in $t = 2$ represents a positive wealth shock for EU households through the profits they receive from banks, which reinforces the mechanism just discussed. This comes from the fact that banks' profits are partly denominated in dollars, thus a dollar appreciation results in higher benefits when converting them to euros. Finally, this positive wealth effect leads to fewer capital outflows in

$t = 1$, as EU households require less savings.

Now let us consider the scenario where global banks do not operate, which happens when $e_1 > \overline{e}$. In this context, there are two distinct forces at play that will determine the relationship between the exchange rate and capital flows. First, when banks go bust, their profits collapse to $\Pi = 0$ for the reasons discussed in Section III. This represents a negative wealth effect for EU households in period 2, leading them to demand more savings (fewer capital outflows) and consume less in period 1. On the other hand, given that in this simple model the only financial intermediation between countries is done by global banks, savings in both countries will correspond to the scenario of financial autarky[20]. In that case,

$$B = 0 \ . \tag{19}$$

C. Multiple equilibria

Considering the relations described previously, the dynamics between capital flows and the exchange rate can be summarized using the following two schedules,

$$e_1 = e(B) = \frac{1-\eta}{\eta} + B \cdot \frac{1-\omega}{\omega}\frac{1}{\eta}$$

$$B = \mathcal{B}(e_1) = \begin{cases} \frac{\omega}{1-\omega}\beta\Big(1-\eta\Big(1+e_1\Big)\Big) - e_1\Big(\frac{A^*}{R^*} - L^*\Big) & \text{if } e_1 < \overline{e} \\ 0 & \text{if } e_1 > \overline{e} \end{cases}$$

An equilibrium can be found looking for pairs $(\hat{e}_1,\ \hat{B})$ that satisfy $\hat{B} = \mathcal{B}(\hat{e}_1)$ and $\hat{e}_1 = e(\hat{B})$. Without any loss of generality, I will normalize the equilibrium when the exchange rate in period 1 is below $\overline{e}$ to $e_1^L < 1$, and that when it is above $\overline{e}$ to $e_1^H > 1$. This can achieved by imposing limits on η, the share of tradable endowment owned by the EU. Using the properties of the two schedules, the next proposition collects these results[21].

Proposition 1. *Suppose the simplifying assumptions described in the previous section hold, and let $\overline{e}$ be the value of e_1 that makes the IC constraint of banks hold with equality. If banks operate, i.e. if $e_1 < \overline{e}$, the equilibrium exchange rate is $e_1^L < 1$. If banks go bust, i.e. if $e_1 > \overline{e}$, the equilibrium exchange rate is $e_1^H > 1$. Both equilibria co-exist if the parameters are such that $e_1^H > \overline{e} > e_1^L$. One way to achieve this in a simple way is to set $\overline{e} = 1$ by adjusting the fraction that creditors can recover when banks collapse to $\gamma = (\frac{A}{R} + \frac{A^*}{R^*})/L^*$.*

[20]This is by no means needed for the main mechanism in the model. C presents an extension in which, even in the absence of global banks, households can trade dollar bonds, but at a cost to EU households.

[21]Specifically, I assume that $\frac{1}{2} > \eta > \frac{1}{2} - \frac{\phi}{2(1+\beta)}$, where $\phi \equiv [\frac{A^*}{R^*} - L^*]\frac{1-\omega}{\omega}\frac{1}{Y^N}$. Appendix B contains all the proofs.

Figure 4 plots an example of the schedules derived previously. As explained before, $e(B)$ is increasing in B from a trade balance perspective. An increase in capital outflows towards the US has to be compensated by a stronger trade balance, which is achieved by a euro depreciation. On the other hand, $\mathcal{B}(e_1)$ is usually decreasing in e_1. Under normal circumstances, a dollar appreciation represents a positive wealth shock to EU households via banks' profits, which leads them to demand fewer savings in period 1. Nevertheless, if the dollar appreciates beyond a certain threshold, the market conditions tighten to the point where banks do not operate and capital flows are reversed to their autarky levels. Whenever multiple equilibria are possible -as in this example- I interpret the "bad" equilibrium with a strong dollar and collapsed banks as a financial crisis, and obtain a number of predictions about the behavior of consumption, output, the exchange rate, and capital flows during those events. The next proposition collects these predictions.

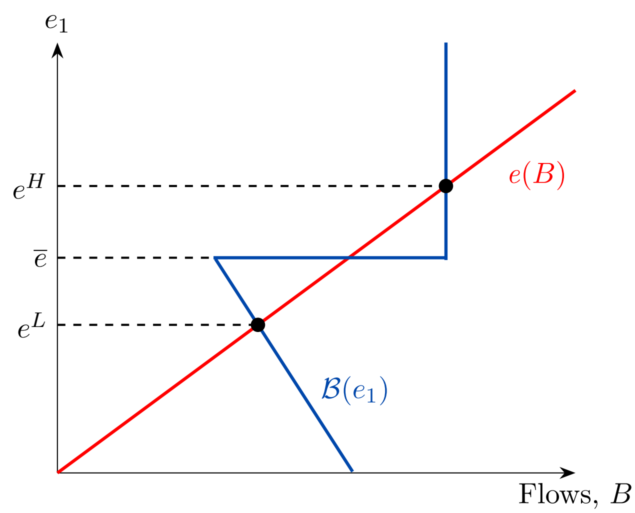


Figure 4: Exchange rate and Capital Flows

Proposition 2. *If there are three equilibria and we compare the two stable ones, we obtain the following predictions about the crisis equilibrium with respect to the standard equilibrium:*

i. The dollar is more appreciated;

ii. Banks face tighter financial conditions and struggle to roll over their debt;

iii. Global output and wealth in the EU are lower;

iv. Net capital flows to the US are larger.

These results are in line with the evidence provided in Section II and with other studies that rely on more complex models such as Kekre and Lenel (2021), Eguren-Martin (2020) and Maggiori (2017). A crucial element needed for this mechanism to work is that the exchange rate depreciates when global banks collapse. In the model, this happens because EU households suffer a "sudden stop" during a crisis, which ends up hurting their aggregate demand and eventually depreciating the euro. In that sense, capital flows to the US are given by $B < 0$ in "normal" times, meaning that EU households are borrowing from abroad. When banks collapse, $B = 0$ which represents an increase in the net flows to the US. In Appendix C I relax the assumption that households do not have access to other financial vehicles when banks collapse, so the dynamics behind the capital flows are more clear, but the results point towards the same direction.

In this context, expectations about e_1 -and the incentives of banks to divert funds- can become self-fulfilling. If households are pessimistic and expect a high exchange rate (e_1^H), they will not provide banks with the funding to roll-over their debt, leading to a banking crisis. Capital flows are then reversed back to autarky levels, which can be interpreted as a "sudden stop". In this scenario, EU households are forced to consume less given the lack of financial intermediation, leading to a euro depreciation, confirming the initial expectations of a high exchange rate. This result is reinforced by the negative wealth shock to EU households coming from the loss of banks' profits in $t = 2$. Overall, this mechanism works because agents are atomistic and ignore the consequences that their actions have on aggregate outcomes[22], as it is common in the literature studying self-fulfilling crises.

Importance of fundamentals

Notice that the existence of multiple equilibria depends on the fundamentals of the global economy. For example, when agents are impatient (low β), banks are more likely to divert funds, so that the required dollar appreciation that makes banks collapse is even lower. Likewise, if the initial dollar short-term liabilities (L^*) are high, banks are more exposed to fluctuations in the exchange rate. Financial conditions also play a role: if they are tighter (high γ), the impact of an exchange rate depreciation on banks soundness is amplified, making multiple equilibria more possible. To illustrate this, Figure 5 shows two cases when the model features only a unique equilibrium. In panel (a), the "good" equilibrium is the only one possible. On the contrary, in panel (b) only the "bad" equilibrium can materialize. Such a situation is likely if, for example, γ is particularly high and thus $\bar{e}$ shrinks, making global banks less resilient to exchange rate depreciations.

For completeness, panel (a) in Figure 6 shows how different values of γ give rise to the three potential scenarios for the economy. Recall that this parameter can be interpreted as the risk aversion of investors, thus $\bar{e}$ is decreasing in γ, but the values of the exchange rate in equilibrium are unchanged (e^L and e^H). The interesting case that this paper focuses on is one in which $\gamma' < \gamma < \gamma''$ so that the correspondence $\mathcal{C}^e$, which captures the potential values of e_1 in equilibrium, accepts both e^L and e^H as solutions. Panel (b) on the other hand, highlights the role of A^* and L^* on determining the equilibrium. A drop in A^* or an increase in L^* have similar effects: everything else constant, they

[22] The importance of lenders' expectations for global banks is also highlighted in Ivashina et al. (2015), where they can have a significant impact on foreign banks that depend on unsecured short-term dollar funding, in the presence of frictions in the FX forward markets.

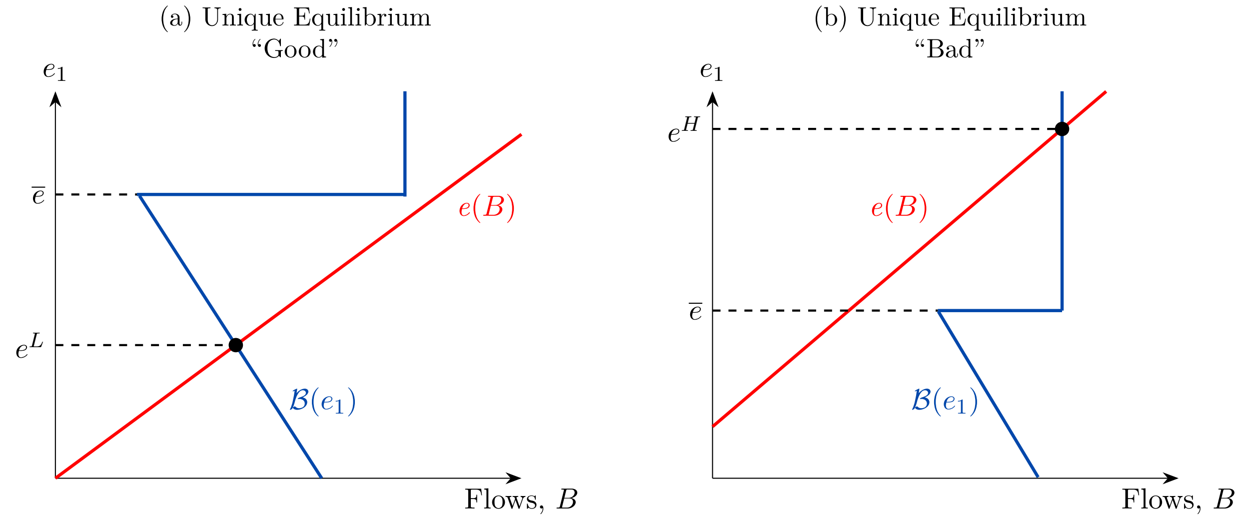


Figure 5: Exchange rate and Capital Flows

lower $\overline{e}$ because of the increase in the dollar liquidity needs, and in addition, they increase e^L because of the lower profits of global banks and thus weaker demand from EU households. As a result, γ' and γ'' drop, reducing the zone in which only the "good" equilibrium and multiple equilibria can happen, and making the "bad" equilibrium more likely.

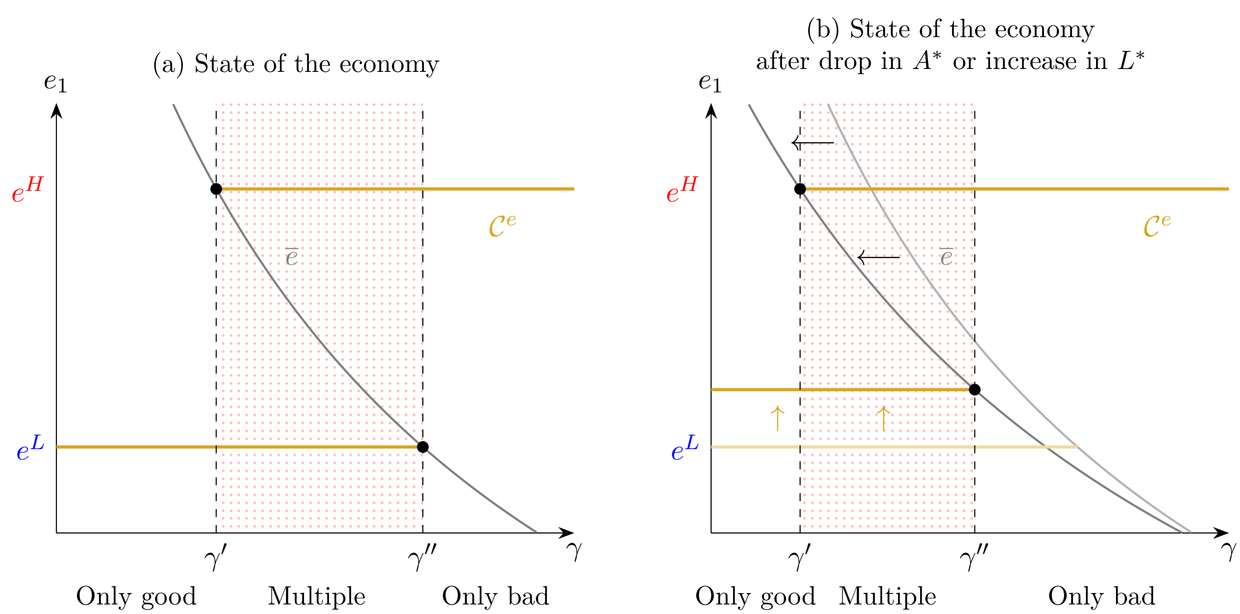


Figure 6: Exchange rate and severity of the financial friction

V. Lending of Last Resort

In this section I introduce a government that intervenes in financial markets in period 1, discuss the motives behind these interventions, and find under what conditions governments can prevent the collapse of global banks.

An economy that is exposed to a "bad" equilibrium driven by pessimistic expectations could usually benefit from the intervention of a benevolent government, a social planner, or in this case, a lender of last resort. I follow Bocola and Lorenzoni (2020) and Gertler and Kiyotaki (2015) in modelling the lender of last resort and introduce a government that can make a transfer S to global banks in period $t = 1$. This transfer is financed by imposing a tax τ on consumers' endowment of non-tradables Y_1^N, which is later transferred back to the households with interests R^S (non-distortionary tax).

Intuitively, the intervention is successful if the lender of last resort has the capacity to provide the liquidity that banks need, so that households rule out the possibility of a banking collapse from their expectations, and are willing to provide banks with deposits. As it is common in these type of models, the intervention might not need to materialize, as long as the government can convince the markets that its commitment to prevent the collapse scenario is credible (Céspedes et al., 2017). Naturally, the credibility of this claim depends on the resources that the government can access.

A. Intervention by the ECB

Consider first the case where the central bank in the EU (ECB) acts as the lender of last resort to global banks. This is a starting scenario, where a central bank tries to bail out domestic banks and avoid a collapse of the domestic financial system. For now, I will not motivate this intervention with potential welfare gains, but assume that it is part of the central bank mandate to avoid a financial crisis.

Recall that for simplicity, I set $L = 0$ so that all the initial debt held by banks is denominated in dollars (L^*). The ECB then sets R^S and transfers S to banks such that their profits are

$$\Pi = e_2 A^* + A - R^S S \ ,$$

meaning that the full amount of the initial liabilities in dollars is covered with the transfer in euros,

$$e_1 L^* = S \ , \quad \text{where } S = \tau Y_1^N \tag{20}$$

Finally, equation (20) can be written in terms of the tax rate, so that $\tau = e_1 \frac{L^*}{Y_1^N}$. Note that in this case, τ is a function of the exchange rate: a stronger dollar relative to the euro means that a higher tax rate is needed to cover the initial liabilities from banks. Naturally, the intervention is limited by the amount of resources in the economy, which in this case is given by Y_1^N. On top of that, I follow Bocola and Lorenzoni (2020) and introduce limited fiscal capacity[23] in the form of an upper bound on the tax rate,

$$\tau \leq \overline{\tau} \ .$$

As I mentioned previously, in order for the intervention to be successful, agents must believe that the lender of last resort has enough resources to prevent the "bad" equilibrium at all costs. In this framework, that means that the ECB must have enough tax income to cover the banks' dollar liabilities, even in the sate of the world where the dollar is largely appreciated (in other words, when the exchange rate is e_1^H). Considering equation (20) and the tax limit, the next proposition captures this insight.

Proposition 3. *Consider the ECB sets transfers S in euros to cover banks' dollar liabilities L^*. These transfers are financed with taxes on EU households' non-tradable endowment such that $S = \tau Y^N$. The intervention will eliminate the "bad" equilibrium if it is credible, which happens when the following condition holds:*

$$\overline{\tau} > e_1^H \frac{L^*}{Y^N} \equiv \tau^H \ .$$

Moreover, if the commitment to intervene is credible, the ECB would not have to intervene to prevent the collapse scenario.

A graphic illustration of the previous proposition is presented in Figure 7. If a fixed tax limit is considered, it is possible to analyze how the fundamentals of the global economy might give rise to unpreventable equilibria, from the perspective of the ECB. Denote $e^{\overline{\tau}}$ as the maximum exchange rate that the central bank can handle, given $\overline{\tau}$. Consider a "bad" equilibrium such as the one given by the blue and solid red line. Since the exchange rate during a collapse (e^H) is lower than $e^{\overline{\tau}}$, the ECB can effectively prevent the financial crisis from materializing, as shown by the dotted green. Now, for instance, if the endowment of tradables goods (η_1) in the EU is lower, relative prices in that economy will be higher, which leads to an increase in the exchange rate in both equilibria, as shown by the red dotted line. The limitations of the central bank makes a scenario with $e^{H'} > e^{\overline{\tau}}$ unpreventable.

B. Intervention from the Fed

Consider now the intervention from the Fed instead of the ECB. In the model, the motivation for the Fed to intervene will come mainly from preventing a collapse of productive investments in the US and a subsequent decline in US non-tradable output in period 2, but a more comprehensive analysis of

[23] This can be motivated in many ways. From the point of view of a central bank, this limit could represent a maximum level of inflation that can be tolerated given the massive liquidity injection, and upper bound to the potential losses that the bank can take given a (very) low default risk, or the cost of facing political pressure from helping foreign banks.

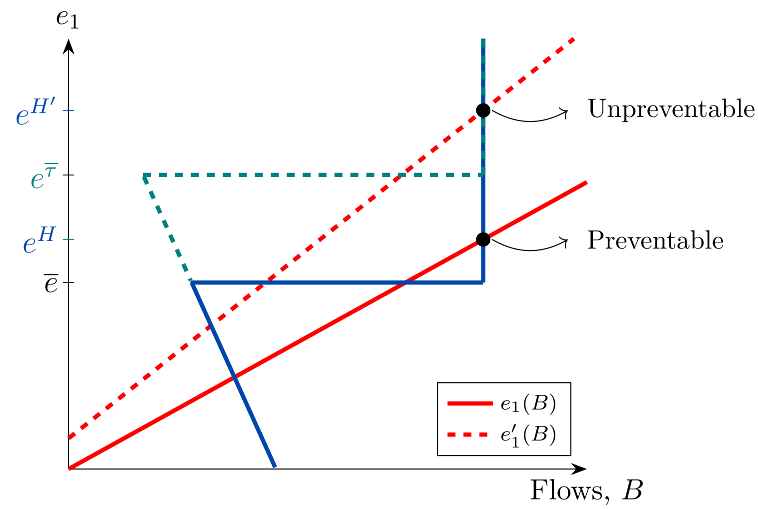


Figure 7: Intervention by the ECB and fundamentals

the welfare implications is left for the next section. The mechanism to intervene is the same as the one described before, but now the Fed is the one transferring resources S^* directly to global banks[24]. This transfer is financed with taxes τ^* on US households' non-tradable output (recall that $Y_1^N = Y_1^{*N}$). An important difference between these two central banks is that one provides euros (EU non-tradable goods), while the other provides dollars (US non-tradable goods). The Fed then transfers S^* dollars to cover banks' dollar liabilities, such that

$$L^* = S^* \ , \quad \text{where } S^* = \tau^* Y^N \ . \tag{21}$$

Equation (21) can be written in terms of the tax rate, thus $\tau^* = \dfrac{L^*}{Y_1^N}$. This expression shows that, unlike the case for the ECB, the tax rate needed to cover L^* does not depend on the exchange rate. To compare the Fed's and the ECB's interventions, assume that both governments face the same tax limit $\overline{\tau}$. When banks operate, we have that $e_1^L < 1$ so one unit of EU non-tradable goods has more value than one unit of US non-tradable goods, i.e. one *euro* is worth more than one *dollar*.

Nevertheless, during a financial crisis, the situation changes. Whenever banks go bust and the exchange rate appreciates to $e_1^H > 1$, the dollar is stronger than the euro. Again, this is consistent with the evidence shown in Section II suggesting a large appreciation of the dollar during a crisis, and is also in line with the *dash-for-dollars* (Cesa-Bianchi and Eguren-Martin, 2021) or *flight-to-safety* (Kekre and Lenel, 2021) phenomena, in which the demand for dollars increase during turbulent episodes. The implications of a "weak" euro for the ECB are that now the required intervention is larger than

[24]In practice the transfer from the Fed goes to the foreign central bank, which eventually distributes the resources to the domestic banks. However, in the absence of additional frictions, this would be equivalent to the Fed directly helping foreign banks.

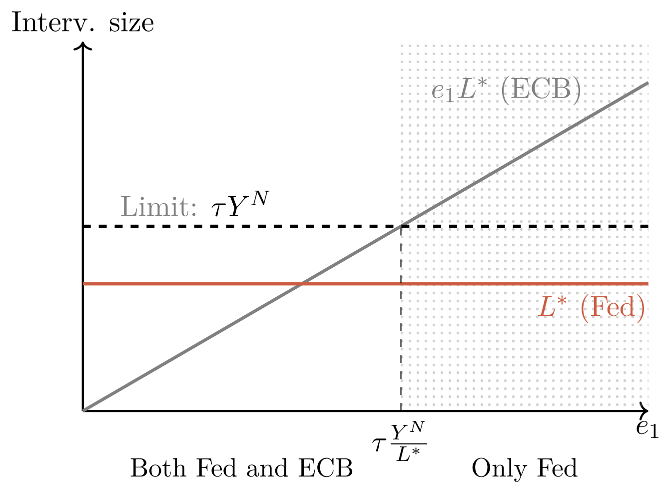
under "normal" times. Meanwhile, the required size of the Fed's intervention remains unchanged. Considering this, a very particular case might arise: one in which the Fed has the resources to engineer a credible intervention, while the ECB does not. The next proposition summarizes these results and the conditions for this to happen.

Proposition 4. *Consider that both countries face the same tax limit $\overline{\tau}$, receive similar non-tradable endowments, $Y_1^N = Y_1^{*N}$, and that the exchange rate during a financial crisis is $e_1^H > 1$. To be effective, the intervention from the ECB requires setting $\tau Y^N \equiv e_1^H L^*$, which is higher than the required tax rate that the Fed has to impose $\tau^* Y^N = L^*$. Moreover, only the Fed will be able to eliminate the "bad" equilibrium, if the following condition holds:*

$$\underbrace{e_1^H L^*}_{\substack{\textit{Liq. needs} \\ \textit{in euros}}} > \underbrace{\overline{\tau} Y^N}_{\substack{\textit{Maximum} \\ \textit{intervention}}} > \underbrace{L^*}_{\substack{\textit{Liq. needs} \\ \textit{in dollars}}}$$

A graphic illustration of this proposition is presented in Figure 8. It provides a theoretical explanation -in a very reduced form- as to why the Fed provided the required liquidity to non-US banks during the GFC and the Covid-19 crisis, and not the corresponding domestic central banks. It is also reasonable to think that an injection of euros from the ECB to bail-out the struggling banks could have triggered an even larger depreciation with respect to the dollar, amplifying the initial shock.

Figure 8: Intervention by Fed and ECB



C. Welfare analysis

So far, this paper has described the mechanism through which governments or central banks can provide liquidity to global banks, without much discussion about the incentives behind these interventions. I will shed light on this crucial aspect by focusing on the welfare implications from converging to each of the equilibria featured in the model.

Denote with a subscript "L" variables in the equilibrium with the low exchange rate, and with "H" to those in the equilibrium with the high exchange rate. Welfare losses from the collapse of global banks are given by

$$\text{EU:} \quad \Psi \equiv U_L - U_H = \underbrace{(1-\omega)\beta \ln\left(\frac{A+Y_2^N}{Y_2^N}\right)}_{\text{Loss from } \downarrow \text{ NT}} \underbrace{-\omega\left[\ln\left(\frac{C_{H,1}^T}{C_{L,1}^T}\right) + \beta \ln\left(\frac{C_{H,2}^T}{C_{L,2}^T}\right)\right]}_{\text{Loss from euro depreciation}} \tag{22}$$

$$\text{US:} \quad \Psi^* \equiv U_L^* - U_H^* = \underbrace{(1-\omega)\beta^* \ln\left(\frac{A^*+Y_2^{*N}}{Y_2^{*N}}\right)}_{\text{Loss from } \downarrow \text{ NT}} \underbrace{-\omega\left[\ln\left(\frac{C_{H,1}^{*T}}{C_{L,1}^{*T}}\right) + \beta^* \ln\left(\frac{C_{H,2}^{*T}}{C_{L,2}^{*T}}\right)\right]}_{\text{Gain from dollar appreciation}} \tag{23}$$

The effects of the collapse of global banks on welfare can be broken down into two. First, there are direct effects coming from the forced liquidation of US and EU long-term assets. Both countries suffer from the lose of productive investments that would otherwise boost the availability of non-tradable goods in period $t = 2$. In that sense, C_2^N and C_2^{*N} are reduced by A and A^*, respectively. These directs effects are captured by the first term in the welfare loss functions.

However, there is a second important welfare effect coming from general equilibrium forces. Notice that the distribution of the overall world endowment of tradables depends on the exchange rate. A stronger dollar ($\uparrow e_t$) increases $C_{L,t}^{*T}$ and consequently reduces $C_{L,t}^T$, as shown here:

$$C_{L,1}^{*T} = (Y_1^T + Y_1^{*T})\frac{e_1^L}{1+e_1^L} \qquad C_{L,2}^{*T} = (Y_2^T + Y_2^{*T})\frac{e_1^L}{\beta/\beta^* + e_1^L} \ .$$

In that sense, the effect coming from the tradable sector is captured by the second term in (22) and (23), but importantly, it is positive for the US and negative for the EU. This can be interpreted as follows. When a global crisis hits, net capital flows to the US increase given the drop in the aggregate demand from EU households, leading to an appreciation of the dollar. In turn, this means that relative prices $\frac{p_t}{p_t^*}$ in the US go down, allowing US households to consume a larger amount of tradable goods.

If we put these effects together, it is possible to draw some conclusions. On one hand, preventing the collapse of EU-owned global banks is always beneficial for the EU, since they consume fewer non-tradable and tradable goods in the "bad" equilibrium, compared to the "good" one. On the other hand, the US faces two opposite forces in different directions. US households lose from the loss of non-tradable goods, but this loss is smoothed by the benefit from cheaper access to funds from abroad and to tradable goods, coming from lower relative prices and a stronger dollar.

Whether US households experience an overall welfare gain or loss when global banks collapse will depend on the parameters of the model. The following proposition captures these results.

Proposition 5. *Comparing the utility obtained by households under the "good" and the "bad" equilibria,* *EU households always experience a welfare loss* ($\Psi > 0$) *due to lower supply of non-tradable goods and higher prices of the tradable good. On the contrary, US households might benefit from lower prices, but face lower consumption from non-tradable goods. The overall welfare outcome for these households is ambiguous* ($\Psi^* \lesseqgtr 0$) *and depends, among other things, on the magnitude of* A^**.*

This will depend, naturally, on the parameters of the model. Given the simplifying assumptions used so far, the Fed's decision whether to intervene or not will depend on the trade-off between losing future non-tradable output, or benefiting from lower prices due to a drop in the aggregate demand of the rest of the world. As long as the investment from foreign global banks in US assets A^* is large enough and provide a significant boost to the US economy, the Fed will have incentives to act as the international lender of last resort.

To give a better idea of this trade-off I provide a simple numerical example. I follow Gabaix and Maggiori (2015) in calibrating most of the parameters. It is straightforward to see that, for US households, the loss from the lower consumption of non-tradables is increasing in A^*. On the contrary, the benefits coming from lower prices are decreasing in A^* because of its effects on the equilibrium exchange rate[25]. These two effects drive the welfare loss for US households in opposite directions, as shown in Figure 9. In this numerical example, if A^* represents less than 15% of the non-tradable endowment in the US, then the Fed has no incentives to intervene.

D. Willingness and capacity to intervene

To finalize this section, I will jointly analyze the willingness (welfare-based) and the capacity (resource-based) to intervene in the financial markets, both from the perspective of the ECB and the Fed. As shown in the previous subsection, if the exchange rate is too high in the collapse scenario, the ECB might lack the resources to provide banks with the required liquidity. This is shown in Figure 10 by the tax limit $\overline{\tau}$ and the function $\tau = e_1 \frac{L^*}{Y^N}$ describing the required size of the intervention in euros, which intersect at $e^{\overline{\tau}}$. Therefore, any $e_1^H < e^{\overline{\tau}}$ will leave the EU in the safety zone so that the ECB is able to successfully eliminate the "bad" equilibrium from agents' expectations. For this example, I assume that $\tau^* < \overline{\tau}$ so that the Fed can always credibly intervene. If $e_1^H > e^{\overline{\tau}}$, two cases will arise depending on the Fed's willingness to intervene. First, if the welfare loss for US households Ψ^* is large enough, the Fed will provide the required liquidity to foreign global banks. Since an increase in the exchange rate represents lower relative prices of tradables for the US, the welfare loss will be decreasing in e_1^H. From Figure 10 the Fed will then intervene if $e_1^H < e^F$, where e^F is the exchange rate consistent with no welfare loss, $\Psi^* = 0$. If this condition holds, the EU is in the dependence zone.

[25]To see this, first note that given the simplifying assumptions I consider, we have that $\ln\left(\frac{p_1^{*H}}{p_1^{*L}}\right) = \ln\left(\frac{Y_2^{*N}+A^*}{Y_2^{*N}}\frac{p_2^{*H}}{p_2^{*L}}\right) = \ln\left(\frac{1+e^H}{e^H}\frac{e^L}{1+e^L}\right) < 0$. Since $\frac{\partial e^L}{\partial A^*} < 0$, finally $\partial \ln\left(\frac{1+e^H}{e^H}\frac{e^L}{1+e^L}\right)/\partial A^* < 0$.

(a) For the EU (b) For the US

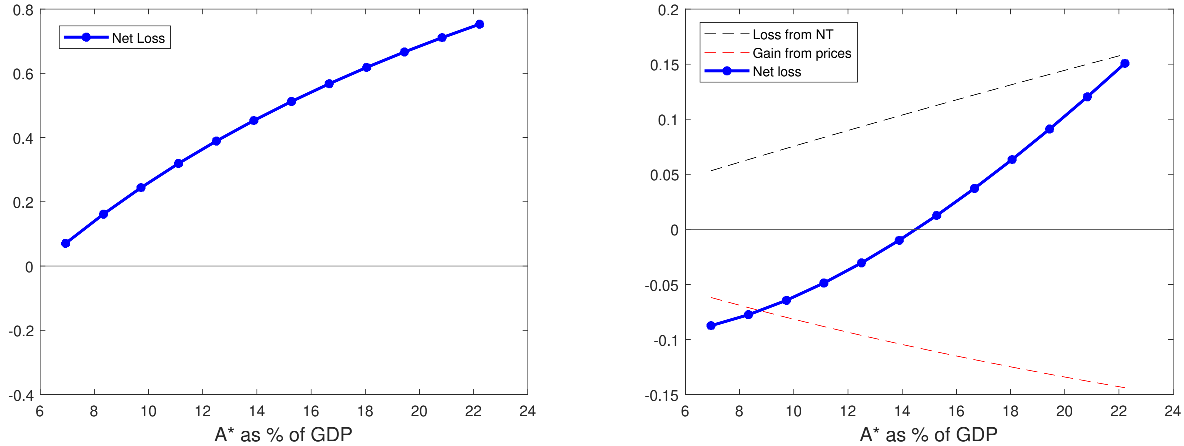
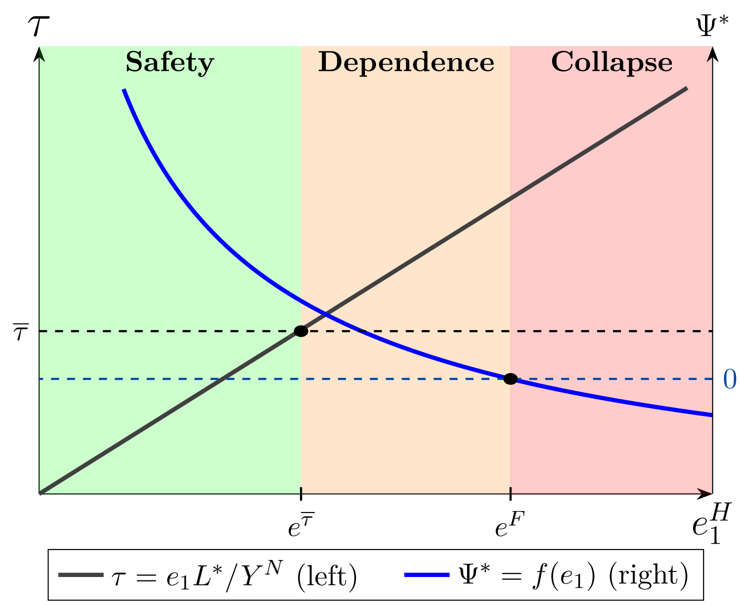


Figure 9: Welfare loss

Note: This example uses the following parameters: $L = 0, L^* = 1, \beta = .99, \omega = 0.2, Y_t^T + Y_t^{*T} = 2, \eta = .49, Y_t^N = 18$. The welfare loss was normalized by including a non-pecuniary cost for the benevolent government of intervening in a foreign market, which is proportional to the required size of the intervention, L^*.

Finally, if $e_1^H > e^F$, the Fed lacks the incentives to intervene, and global banks collapse.

Figure 10: Capacity and willingness to intervene



Note: Under this configuration, $\tau^* < \overline{\tau}$ so the Fed can always intervene. τ is the tax rate that the ECB needs to impose in order to cover the banks' liquidity needs. Ψ^* is the welfare loss/gain for US households from converging to the "bad" equilibrium ($\Psi^* > 0$ represents a welfare loss).

Despite the simplicity of this exercise, it provides a big picture of where the global financial system might be heading. In the last decade, the world economy has been operating in the dependence zone: foreign central banks have drawn a substantial amount of dollars from the Fed via central bank swap lines to alleviate the dollar funding pressure that their banks were facing during the GFC and the Covid-19 crisis. However, larger imbalances, less investment in productive US assets, or a further reduction in the US output as a share of the world's output might potentially push the global financial system to a collapse.

VI. Fragility and dollar funding

In this section I will extend the simple model presented in the previous sections for two main reasons. First, I will relax some of the simplifying assumptions imposed in the main body of the paper for tractability to show that the main results hold under a more general setting. Second, I want to study the equilibrium determination of banks' assets and liabilities, since this is key for the analysis of a global financial crisis. Similarly to Bocola and Lorenzoni (2020), my main objective here is to show that even though non-US global banks can choose ex-ante whether to denominate their debt in euros or in dollars, this does not rule out the possibility of multiple equilibria. In other words, despite a maturity mismatch in dollars opens the door to a "bad" equilibrium, banks do not necessarily have sufficient ex-ante incentives to reduce their exchange rate exposure.

In terms of the model, the idea of this section is to endogeneize key variables for the determination of the equilibria, such as the banks' liabilities L and L^*, and also their investments A and A^* in both currencies. Particularly, I want to show that -under certain circumstances- it is rational for banks to take dollar and euro positions such that

$$e_1^L \leq \underbrace{\frac{A/R-(1+\gamma)L}{(1+\gamma)L^*-A^*/R^*}}_{\overline{e}} \leq e_1^H \ , \tag{24}$$

which is the condition for the existence of multiple equilibria.

A. Extended model

The extended model features a very similar environment as the simple one, with a few important additions. There are now three periods, such that $t \in \{0,1,2\}$. In period 0, banks will face two decisions: how much to invest in EU (K) and in US (K^*) assets, and how to finance these investments, between euro (B_1) and dollar (B_1^*) bonds. Banks have access to a technology that transforms 1 unit of EU and US NT goods in period $t=0$ into r and r^* units in $t=2$, respectively.

An important difference with the simple model is that now I introduce a sunspot variable ξ that coordinates agents' expectations. It is realized at the beginning of $t = 1$, and take two values

$$\xi = \begin{cases} 1 & \text{with prob. } 1-\rho \\ 0 & \text{with prob. } \rho \end{cases}$$

If $\xi = 0$, agents have pessimistic expectations, households do not provide the required liquidity to banks, so they are unable to roll-over their debt and collapse. On the other hand, if $\xi = 1$, agents are optimistic and banks are able to raise the liquidity needed to operate. The probability ρ will be determined by banks' fragility, as will be discussed in the next section.

A.1. Households

Households now consume in $t = 0$ as well, and decide how much to save. They receive endowments of tradables and non-tradables as in the other periods. The budget constraint for EU households is

$$\begin{aligned} Y_0^N + p_0 Y_0^T &= p_0 C_0^T + C_0^N + B_1 \\ Y_1^N + p_1 Y_1^T + \mathcal{R}_0 B_1 &= C_1^N + p_1 C_1^T + B_2 \\ \Pi + Y_2^N + p_2 Y_2^T + R_1 B_2 &= C_2^N + p_2 C_2^T \ . \end{aligned}$$

Importantly, the interest rate on their euro bonds B_1 might take two values, depending on the sate of the economy. US households face a similar problem, and the interest rate on their dollar bonds B_1^* also depends on the state of the economy. We can express both conditions jointly as

$$\mathcal{R}_0 \ , \ \mathcal{R}_0^* = \begin{cases} R_0 \ , \ R_0^* & \text{with prob. } 1-\rho \\ \ 0 \quad , \ \ 0 & \text{with prob. } \rho \end{cases} \ .$$

To shed more light on the interest rates that will help pin down our variables of interest B_1 and B_1^*, we turn to the households' Euler equation. In addition to the ones presented in the previous section, the first order conditions in $t = 0$ show that

$$R_0 = \frac{1}{1-\rho} \frac{C_1^N}{\beta C_0^N} \qquad\qquad R_0^* = \frac{1}{1-\rho} \frac{C_1^{*N}}{\beta^* C_0^{*N}} \ .$$

The interest rates paid on the euro and dollar bonds are higher if the probability of a collapse is larger, showing that households are compensated for the risk they are taking. Finally, to highlight the connection with the simplified model described in the previous sections, this approach endogeneizes L and L^* as $\mathcal{R}_0 B_1 \equiv L$ and $\mathcal{R}_0^* B_1^* \equiv L^*$.

A.2. Banks

In the simplified version, banks only had to decide how to repay their initial short-term liabilities. Now, banks must also chose how much to invest in $t = 0$ and how to finance that initial investment. They maximize their expected profits given the sunspot variable ξ, and using the discount factor M_t:

$$\begin{aligned}
\text{Max} \quad & \mathbb{E}_0\left(\tfrac{1}{\mathcal{R}_0\mathcal{R}_1}\Pi\right) \equiv (1-\rho)\tfrac{1}{R_0 R_1}\Pi^G \\
\text{where} \quad & \Pi^G = e_2 r^* K^* + rK - e_2 R_1^* B_2^* - R_1 B_2 \quad \text{, s.t}
\end{aligned}$$

$$\begin{aligned}
&\text{(Initial investment)} && e_0 K^* + K = e_0 D_1^* + D_1 \\
&\text{(Roll-over needs)} && e_1 B_2^* + B_2 \geq e_1 \mathcal{R}_0^* B_1^* + \mathcal{R}_0 B_1 \\
&\text{(IC constraints)} && \mathbb{E}_0\left(\tfrac{1}{\mathcal{R}_0\mathcal{R}_1}\Pi\right) \geq \gamma(e_0 B_1^* + B_1) \quad \text{in } t = 0 \\
& && \mathbb{E}_0\left(\tfrac{1}{\mathcal{R}_1}\Pi\right) \geq \gamma \mathbb{E}_0(e_1 B_2^* + B_2) \quad \text{in } t = 1
\end{aligned}$$

where variables with the superscript ξ depend explicitly on the realization of the sunspot, and M_1 and M_2 are the 1- and 2-period discount factors that come from EU households' preferences. Note that since profits during a banking crisis are zero and they can be ignored, for ease of notation I will mostly refer to profits under the "normal" scenario as Π (same for the corresponding M_t). I will assume, without loss of generality, that the IC constraint in $t = 0$ binds so that banks' investment is limited. The first order conditions for this problem are intuitive,

$$\frac{\mathbb{E}(e_{t+1})}{e_t} = \frac{R_t}{R_t^*} \tag{25}$$

$$\frac{\mathbb{E}(e_2)}{e_0} = \frac{r}{r^*} \tag{26}$$

suggesting that UIP holds in every period as long as banks operate, and that the optimal choice of K and K^* requires that their returns are equalized, adjusting for the long-term exchange rate depreciation. Similarly to the case of the liabilities, this setup endogeneizes A and A^* from the simplified model as $rK \equiv A$ and $r^* K^* \equiv A^*$.

A.3. Market Clearing

Market clearing conditions for the EU non-tradable good are now

$$Y_0^N = C_0^N + K \tag{27}$$

$$Y_1^N = C_1^N \tag{28}$$

$$Y_2^N + rK = C_2^N \ , \tag{29}$$

and analogous for the US economy. The first equation show that the endowment of non-tradables in each economy is divided between consumption and investment. The last two equations follow the same logic as in the simple version of the model, where the outcome of the long-term assets can increase the non-tradable output in both countries in $t = 2$, and thus could be interpreted as the result of a productive set of projects. The market clearing conditions for the tradable good remains unchanged in every period.

B. Optimal Exposure

B.1. Determination of the imbalances

With the optimality conditions from households and banks, we can proceed to analyze the equilibrium values for K, K^*, B_1 and B_1^*. The optimal investment is constrained and given by

$$K = \frac{r\beta^2 \frac{(1-\rho)^2}{1-\rho+\gamma} Y_0^N - Y_2^N}{r\left(1 + \beta^2 \frac{(1-\rho)^2}{1-\rho+\gamma}\right)}$$

where K^* has an equivalent expression but with $(*)$. Importantly, K is affected by ρ in two ways. First, an increase in ρ increases the cost of funding, as households require higher interest rates to compensate for the additional risk. On the other hand, banks' expected profits drop if ρ increases, since the chances of a collapse -and thus obtaining no profits- are more likely. Overall, these two forces tighten the financial constraint, and thus reduce the amount of investment that banks can afford.

Next, to fully understand how the optimal exposure is determined in equilibrium, first we need to see how the exchange rate is affected by the probability of a bank run. Following similar steps when finding the equilibrium in section IV, we get that

$$e_0^L = \frac{(1-\eta)(1+(1-\rho)(\beta+\beta^2))}{\eta(1+(1-\rho)(\beta^*+\beta^{*2})) + \frac{\theta}{1-\theta}\frac{\gamma}{(1-\rho)}\frac{K^*}{Y_0^{*N}-K^*}} \cdot \frac{Y_0^N - K}{Y_0^{*N} - K^*}$$

where I have used $\eta_t \equiv \eta$ simply for ease of notation. Although the relation between e_0 and ρ is highly non-linear, a simple numerical exploration shows that for low values of ρ we have that the dollar appreciates when the probability of a bank run increases ($\partial e_0/\partial\rho > 0$). Intuitively, if a bank run is more likely, then the expected profits of banks drop given higher funding costs and limited investment capacity. This generates a negative wealth shock to EU households in the future, which eventually depreciates the euro.

Dollar liquidity shortages are also affected by ρ. Recall that for multiple equilibria to exist, banks must be exposed to dollar liquidity shortages, as in equation (24). We can re-express the threshold $\bar{e}$

from that condition as

$$\bar{e} \equiv \frac{rK/R_1 - R_0 D_1(1+\gamma)}{(1+\gamma)R_0^* B_1^* - r^* K^*/R_1^*} = f(\rho) \ , \tag{30}$$

which shows another non-linear link, this time between $\bar{e}$ and ρ. As in the case of e_0^L, a numerical exploration reveals some intuitive results. First, dollar liquidity shortages given by the numerator of the previous expression are negatively affected by an increase in the probability of a collapse. This follows the same logic as what happens with the exchange rate: more constrained banks are forced to shrink their expositions. Eventually, the effect of lower dollar shortages dominates and leads to an increase in $\bar{e}$, so that $\partial \bar{e}/\partial \rho > 0$. In other words, higher risk decreases banks' resiliance to dollar appreciations. A numerical example showing these relations is provided in Figure 11.

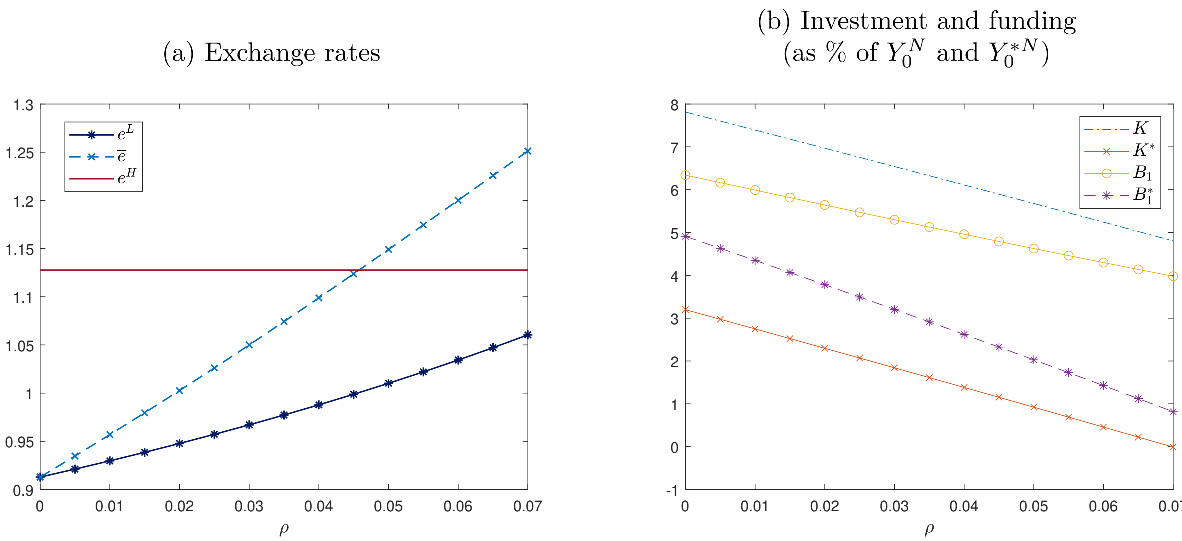


Figure 11: Impact of ρ on key variables

Note: For this illustrative example the parameters used were $r^* = 1.3$, $\beta^* = 0.91$, $Y_0^{*N}/Y_2^{*N} = 1.75$, $r = 1.2$, $\beta = 0.9$, $Y_0^N/Y_2^N = 2.3$, $Y_1^N = Y_1^{*N} = 2.5$, $\omega = \omega^* = 0.1$, $\gamma = 0.7$, $\eta_0 = 0.45$, $\eta_1 = 0.47$, $\eta_2 = 0.55$.

B.2. Determination of the probability of a crisis

The probability of a financial crisis should depend, at least partially, on the fragility of the banking sector. Even in my model, where there is an exogenous sunspot variable that coordinates households' expectations, rational expectations suggest that if there is no mismatch of any kind in banks' balance sheets, then agents should assign a zero probability to a crisis. The exact opposite extreme case occurs if the imbalances are so large that even if optimistic expectations are ruled out, a crisis is inevitable

($\rho = 1$). This relation can be expressed as

$$\rho = \begin{cases} \sim 1 & \text{if } \overline{e} < e_1^L < e_1^H \\ (0,1) & \text{if } e_1^L < \overline{e} < e_1^H \\ 0 & \text{if } e_1^L < e_1^H < \overline{e} \end{cases} \tag{31}$$

where the magnitude of $\overline{e}$ with respect to the exchange rate in both states of the world gives us a measure of banks' imbalances. Intuitively, if $\overline{e}$ is above e_1^H, banks can tolerate even a very sharp depreciation, thus a crisis is not possible and $\rho = 0$. On the other hand, if $\overline{e} < e_1^L$, then banks are too exposed to a dollar appreciation, to a point where a collapse is practically a certain event.

B.3. Multiple equilibria

The objective of this section is to show that even though non-US global banks can choose ex-ante whether to denominated their debt in euros or in dollars, this does not rule out the possibility of multiple equilibria. By combining (30) and (31) we can determine the ex-ante probability of a financial crisis ρ and global banks' imbalances $\overline{e}$ in $t = 0$. If in equilibrium $0 < \rho < 1$, then both "good" and "bad" equilibria are possible in $t = 1$.

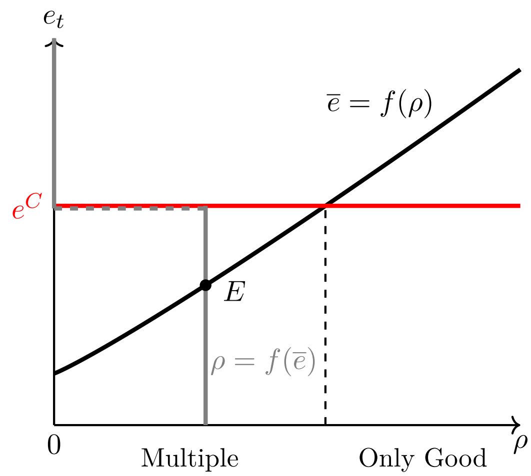
Before moving to the numerical exercise, I want to clarify the intuition behind these results using Figure 12. Start from a point where $\rho = 0$, so that banks face very little financial restrictions. In that case, it is optimal for them to take more debt to invest more. If the exchange rate is low enough, debt denominated in \$ is relatively cheap, so banks will be exposed to dollar liquidity shortages, and $e_1^L = \overline{e}$. Nevertheless, a financial crisis is a possibility whenever $e_1^L \leq \overline{e} < e_1^H$, thus we can conclude that in an equilibrium with certain parameters, $\rho > 0$. In other words, under certain fundamentals of the world economy -and without any kind of policy intervention- a financial crisis cannot be ruled out.

If on the contrary we start from a point where a financial crisis is almost certain ($\rho \sim 1$), banks face tight restrictions and can only take limited debt and thus invest less. Given their limited ability to invest and the higher cost of funding, their exposure to dollar liquidity shortages is relatively low. In other words, banks' profit maximization when $\rho \sim 1$ leads to smaller imbalances, so $\overline{e}$ is high. But when $e_1^H < \overline{e}$, it means that the exchange rate that forces banks to shut down is so high, that a collapse is not possible. Following this logic, it must be that $\rho < 1$ so that a financial crisis is not the only possible outcome in equilibrium.

C. Numerical example

I now present a numerical example of a world economy that is exposed endogenously to multiple equilibria. The idea is to quantify the effects of a financial crisis that is associated with dollar liquidity shortages using this simple model. I will calibrate most of the parameters to match evidence on output

Figure 12: Probability of a bank run and $\hat{e}$



losses for the US and the EU during a crisis, as well as the euro depreciation. On top of that, I will also match the the dollar liquidity shortages that banks were exposed to, and the interest rates in both currencies in the run up to the GFC.

One period corresponds to one quarter. The period I am particularly interested in modeling is Q4-2008, because this is when the US economy suffered its sharpest quarterly output decline since the late 50's, but the dollar rallied against most currencies, including the euro. Data for the US are retrieved from the U.S. Bureau of Economic Analysis and the Board of Governors of the Federal Reserve System, while data for the EU area comes from Eurostat. BIS is the source for the data on global banks.

The target pre-crisis annualized interest rates in the US and in the EU are 2.5% and 3.5%, respectively. This is meant to capture the low interest rate environment characterizing the world economy in the years preceding the start of the GFC. The quarterly output drop in the US during Q4-2008 was 2.18%, while it was 1.8% for the EU. Finally, the share of dollar liabilities in the total portfolio of global banks is 18%, which is the simplest way to capture dollar liquidity needs.

The parameters of the model are calibrated to match this data. I follow Gabaix and Maggiori (2015) in setting $\omega = \omega^* = 0.1$ so that non-tradables account for 90% of the consumption basket. I set $\beta = 0.89$ and $\beta^* = 0.9$, which are relevant to match the annualized interest rates of $R_0 = 1.025$ and $R_0^* = 1.035$. As for the productivity of US and EU investments, I set $r^* = 1.25$ and $r = 1.2$, reflecting that investment opportunities in the US were more attractive relative to those in the EU. In terms of output, I set $Y_0^{*N}/Y_2^{*N} = 1.9$ and $Y_0^N/Y_2^N = 2$ so that there are incentives to invest in both economies, but showing that the investment in the US is already partially covered, potentially by US banks intermediating some of it. The rest of the parameters are as follows: $\eta_0 = 0.5$, $\eta_1 = 0.488$, $\eta_2 = 0.5$, $1 - \omega = 0.9$, $\gamma = 0.8$, $Y_1^N = Y_1^{*N} = 2.6$.

Table 1: Parameters and targeted variables

Variable	Description	Target	Model
$\dfrac{r^*K^*}{r^*K^*+Y_2^{*N}}$	US output loss	2.2%	3.8%
$\dfrac{rK}{rK+Y_2^N}$	EU output loss	1.8%	1.8%
$\dfrac{e^H-e^L}{e^L}$	ER depreciation	12.5%	12.5%
	$ shortage as % of assets	18%	21%
R_0^*	US interest rate	1.025	1.025
R_0	EU interest rate	1.035	1.035
ρ	Prob. of crisis	-	2%

The results of this exercise are shown in Table 1. This simple model is able to perfectly match the behavior of key variables around the GFC, such as the output decline in the EU, the dollar appreciation with respect to the euro, and ex-ante interest rates in both economies. Other targeted variables such as the drop in US output and the magnitude of dollar shortages respond in the expected direction, but they react slightly more drastically in the model compared to what the data suggests. Perhaps introducing additional asymmetries between dollar and euro funding could close these gaps. Overall, this outcome with multiple equilibria is consistent with an ex-ante probability of a crisis of $\rho = 2\%$.

D. Anticipated vs Unanticipated interventions

[Work in Progress]

VII. Conclusions

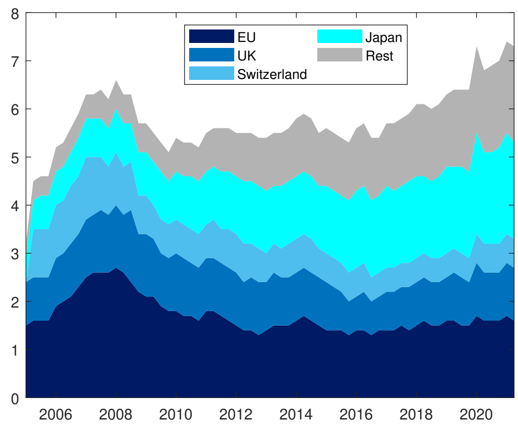
In this paper I provide a framework to study the global macroeconomic implications of the Fed's swap lines to foreign central banks in times of crisis. European banks were acting as "bankers of the world" by intermediating flows between US and EU households in their respective currencies, and investing in dollar-denominated assets in the United States. However, given preexisting balance sheet imbalances and volatile funding sources, they were largely exposed to exchange rate fluctuations: a significant dollar appreciation would force them to shut down. If EU global banks ultimately go bust, the drop in aggregate demand that accompanies the banking crisis would lead to a euro depreciation. I argue that this mechanism opens the door to self-fulfilling crises driven by pessimistic expectations.

In this context, the world economy can benefit from a lender of last resort. However, in a state of the world where the dollar is strong relative to other currencies, and given the size of the balance sheets of global banks, non-US central banks without significant dollar reserves might lack the resources to eliminate the “bad” equilibrium. The Fed, on the other hand, can intervene by providing dollar liquidity directly. Nevertheless, its incentives to bail-out foreign global banks might not be necessarily in line with the interests of the rest of the world. I believe this framework represents a useful starting point to think about the implications of the Fed as the international lender of last resort. In addition, it rationalizes the puzzling dollar appreciation during a global financial crises, which more traditional models in international macroeconomics fail to capture.

Appendix

A. Additional Stylized Facts

(a) Foreign claims of BIS reporting banks on US counterparties ($ trillion)



(b) Purchases of US assets by foreigners (% of GDP)

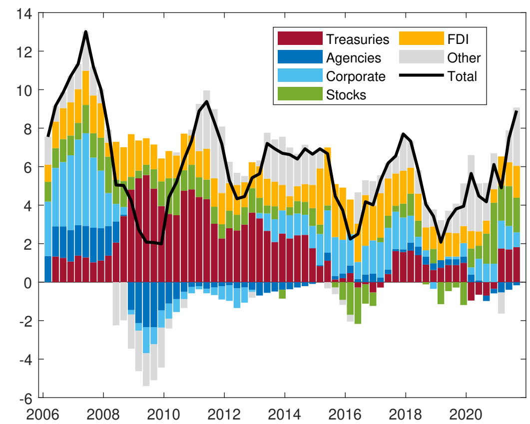
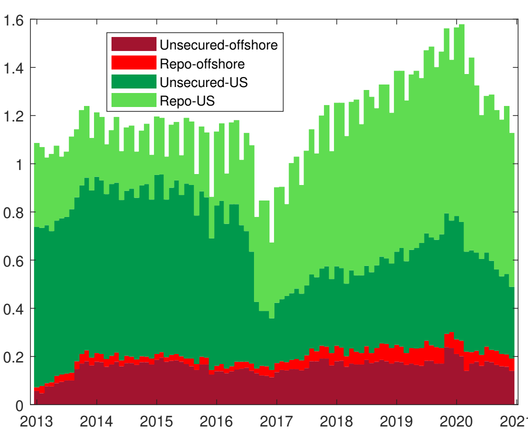


Figure A.1: Dollar assets of non-US banks

Note: For Panel (b), it is 4-quarter sums in % of GDP. As of April 2021, more than 90% of the Agency bonds are asset-backed securities. The large majority of US issuers of corporate bonds are non-financial organizations and financial organizations that are non-traditional depository institutions. ***Source:*** BIS, US Department of the Treasury.

Figure A.2: Money Market Funds funding ($ trillions)



Note: "Unsecured" refers to funding provided by prime funds, "repo" includes government and Treasury funds (which can only do repos), as well as repos by prime funds. For more details, see Aldasoro et al. (2021). ***Source:*** BIS, Aldasoro et al. (2021).

(a) Linear relation in first differences (2005-2020) (b) Dynamics around the GFC

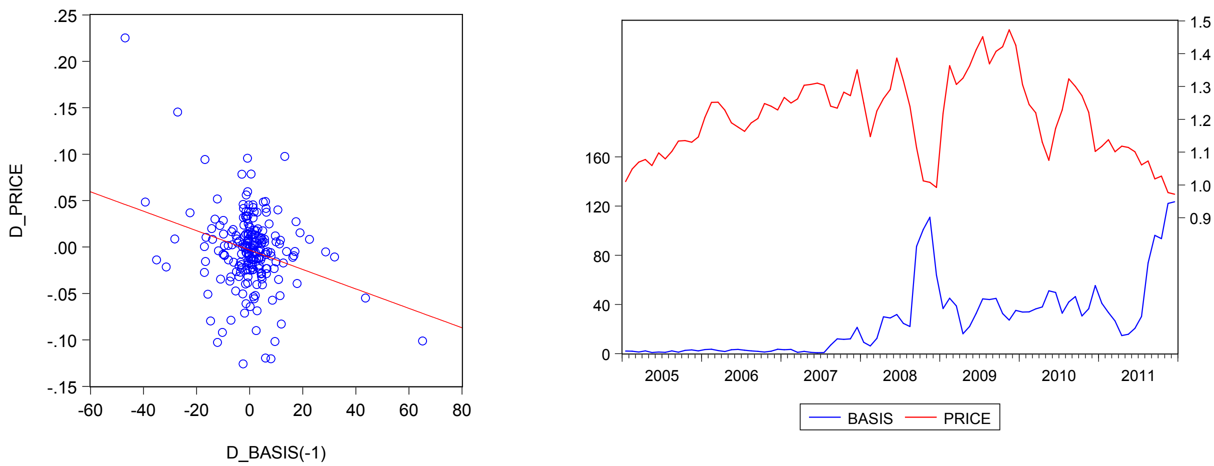


Figure A.3: Relative price of US/EU Banks and UIP deviations

Note: Considers the relative price of US/EU Global banks, and EUR/USD UIP deviations. ***Source:*** Bloomberg.

B. Proofs and derivations

B.1. Derivation of Equation 17

From the households' optimality conditions we obtain that $p_t C_t^T = \frac{\omega}{1-\omega} C_t^N$ and $p_t^* C_t^{*T} = \frac{\omega}{1-\omega} C_t^{*N}$. Now consider the tradable market clearing condition,

$$C_t^T + C_t^{*T} = Y_t^T + Y_t^{*T}$$

and multiply both sides of the equation by p_t. Combining all these expression, the market clearing condition for non-tradable goods, and the law of one price $e_t p_t^* = p_t$, we get the following expressions for the price of tradable goods in both periods:

$$p_1 = \tfrac{\omega}{1-\omega} \frac{Y^N}{Y_1^T + Y_1^{*T}} \left[e_1 + 1 \right] \tag{32}$$

$$p_2 = \tfrac{\omega}{1-\omega} \frac{Y^N}{Y_2^T + Y_2^{*T}} \left[e_2 \frac{Y^{*N} + A^*}{Y^N} + 1 \right] . \tag{33}$$

Finally, combining (32) with the households' optimality condition and the trade balance in period 1 given by $p_1(Y_1^T - C_1^T) = B$, we get

$$e_1 = \frac{1-\omega}{\omega} \frac{1}{Y^N \eta} B + \frac{1-\eta}{\eta} ,$$

where $\eta \equiv \frac{Y_t^T}{Y_t^T + Y_t^{*T}}$.

B.2. Proof of Proposition 1

Proposition 1. *Suppose the simplifying assumptions described in the previous section hold, and let $\bar{e}$ be the value of e_1 that makes the IC constraint of banks hold with equality. If banks operate, i.e. if $e_1 < \bar{e}$, the equilibrium exchange rate is $e_1^L < 1$. If banks go bust, i.e. if $e_1 > \bar{e}$, the equilibrium exchange rate is $e_1^H > 1$. Both equilibria co-exist if the parameters are such that $e_1^H > \bar{e} > e_1^L$. One way to achieve this in a simple way is to set $\bar{e} = 1$ by adjusting the fraction that creditors can recover when banks collapse to $\gamma = (\frac{A}{R} + \frac{A^*}{R^*})/L^*$.*

Proof. If banks operate, $e_1 < \bar{e}$ and the following two equations determine the exchange rate and capital flows in equilibrium:

$$e_1 = e(B) = \frac{1-\omega}{\omega}\frac{1}{Y_1^N \eta}B + \frac{1-\eta}{\eta}$$

$$B = \mathcal{B}(e_1) = \tfrac{\omega}{1-\omega}\beta Y_1^N(1-\eta(1+e_1)) - e_1\left(\frac{A^*}{R^*} - L^*\right)$$

Solving the previous system results in the following expression for e_1^L:

$$e_1^L = \frac{(1-\eta)(1+\beta)}{\eta(1+\beta) + \frac{1-\omega}{\omega}\frac{1}{Y^N}(\frac{A^*}{R^*} - L^*)} \;. \tag{34}$$

Denote $\phi \equiv [\frac{A^*}{R^*} - L^*]\frac{1-\omega}{\omega}\frac{1}{Y_1^N}$. In order to get $e_1^L < 1$, from (34) it must be that

$$\frac{1}{2} - \frac{\phi}{2(1+\beta)} < \eta \;. \tag{35}$$

When banks collapse, capital flows are given by $B = 0$ and thus it is straightforward to see, using $e(D)$, that the exchange rate in this equilibrium is

$$e_1^H = \frac{1-\eta}{\eta} \;,$$

where $e_1^H > 1$ if

$$\eta < \frac{1}{2} \;. \tag{36}$$

Finally, combining (35) and (36), $e_1^H > 1 > e_1^L$ if

$$\frac{1}{2} > \eta > \frac{1}{2} - \frac{\phi}{2(1+\beta)}$$

□

B.3. Proof of Proposition 2

Proposition 2. *If there are three equilibria and we compare the two stable ones, we obtain the following predictions about the crisis equilibrium with respect to the standard equilibrium:*

i. The dollar is more appreciated;

ii. Banks face tighter financial conditions and struggle to roll over their debt;

iii. Output in the US and wealth in the EU are lower;

iv. Net capital flows to the US are larger.

Proof. The proof for each item in the proposition will be provided separately.

i. Follows from the conditions in Proposition 1: $e_1^H > e_1^L$.

ii. Again from the previous proposition, $e_1^H > 1$. Furthermore, from the normalization of $\overline{e} = 1$, which can be achieved by setting $\gamma = (\frac{A}{R} + \frac{A^*}{R^*})/L^*$, it follows that $e_1^H > \overline{e}$, meaning that banks are considered risky and fail to receive the funding needed to cover their short-term liabilities.

iii. When banks do not operate, non-tradable output in the US is simply given by the endowments in both periods, $Y_1^{N*} + Y_2^{N*}$. On the contrary, if US assets owned by global banks materialize, non-tradable output in the US increases to $Y_1^{N*} + Y_2^{N*} + A^*$. Wealth in the EU is higher since we are assuming that $\Pi > 0$, which is lost if banks collapse.

iv. Under this simplified version, capital flows to the US (in euros) are given by

$$B = p_1(Y_1^T - C_1^T)$$

which can be re-expresed in terms of the exchange rate

$$B = \frac{\omega}{1-\omega} Y_1^N \left(\eta(1+e_1) - 1\right) \ .$$

From the previous equation, the upper bound imposed on η such that $\frac{1}{2} > \eta$ and the fact that $e_1^L < 1$, lead to $B < 0$ when $e_1 = e_1^L$. When banks collapse, however, household do not have access to any financial asset, thus $B = 0$ which represents an increase in the net flows to the US.

□

B.4. Proof of Proposition 3

Proposition 3. *Consider the ECB sets transfers S in euros to cover banks' dollar liabilities L^*. These transfers are financed with taxes on EU households' non-tradable endowment such that $S = \tau Y_0^N$. The intervention will eliminate the "bad" equilibrium if it is credible, which happens when the following condition holds:*

$$\overline{\tau} < \tau^H \equiv e_0^H \frac{L^*}{Y^N} \ .$$

Moreover, if the commitment to intervene is credible, the ECB would not have to intervene to prevent the collapse scenario.

Proof. The liquidity needs from global banks $e_0 L^*$ have to be cover by euro transfers from the ECB, thus

$$e_0 L^* = S \tag{37}$$

Moreover, these transfers are funded by taxes on EU households non-tradable endowment, thus

$$\tau Y_0^N = S \tag{38}$$

Combining (37) and (38), we get that $e_0 L^* = \tau Y_0^N$. Since τ is increasing in e_0, and given the upper bound on the tax rate, $\tau < \overline{\tau}$, the intervention will eliminate the "bad" equilibrium if it is credible, which happens when the following condition holds:

$$\overline{\tau} < e_0^H \frac{L^*}{Y_0^N} \ .$$

□

B.5. Proof of Proposition 4

Proposition 4. *Consider that both countries face the same tax limit $\overline{\tau}$, receive similar non-tradable endowments, $Y_t^N = Y_t^{*N}$, and that the exchange rate during a financial crisis is $e_0^H > 1$. To be effective, the intervention from the ECB requires setting $\tau = e_0^H \frac{L^*}{Y_0^N}$, which is higher than the required tax rate that the Fed has to impose $\tau^* = \frac{L^*}{Y_0^{*N}}$, so $\tau > \tau^*$. Moreover, only the Fed will be able to eliminate the "bad" equilibrium, if the following condition holds:*

$$\tau > \overline{\tau} > \tau^* \ .$$

Proof. To be effective, the intervention from the ECB requires setting $\tau = e_0^H \frac{L^*}{Y_0^N}$, while the Fed requires setting $\tau^* = \frac{L^*}{Y_0^N}$. Since $e_0^H > 1$, then $\tau = e_0^H \tau^* > \tau^*$. □

B.6. Derivation of $e_1^H > e_1^L$

As in period 0, given the lack of access to financial vehicles, the trade balance in EU in period 1 must also be 0 so that

$$p_1(Y_1^T - C_1^T) = p_1 Y_1^T - \frac{\omega}{1-\omega} Y_1^N = 0 \ .$$

By combining this equation with the price of tradables in term of the exchange rate

$$p_1 = \frac{\omega}{1-\omega} \frac{Y_1^N}{Y_1^T + Y_1^{*T}} (e_1 + 1) \ ,$$

it is possible to see that

$$e_1^H = \frac{1-\eta}{\eta} = e_0^H$$

The last part of the proof is straightforward and comes from the conditions already derived. Since $e_1^L \frac{R^*}{R} \equiv e_1^L \frac{Y^N + A^*}{Y^N} = e_0^L > e_1^L$ and $e_0^H > e_0^L$ and $e_1^H = e_0^H$, we conclude that

$$e_1^H > e_1^L \ .$$

B.7. Proof of Proposition ??

Proposition 5. *In both periods, the relative price of tradables in the EU increases during the collapse scenario, while decreasing in the US. In other words, $p_t^H > p_t^L$ and $p_t^{*H} < p_t^{*L}$ in both periods, where p_t^H and p_t^L are the corresponding prices during the collapse and normal scenario, respectively.*

Proof. To address the changes in the relative price of tradables in both countries and link them to the exchange rate, I will use equations (32) and (33). Consider first the price in the EU in period 0 under both scenarios:

$$\begin{aligned} p_0^L &= \tfrac{\omega}{1-\omega} \tfrac{Y_0^N}{Y_0^T + Y_0^{T*}} (1 + e_0^L) \\ p_0^H &= \tfrac{\omega}{1-\omega} \tfrac{Y_0^N}{Y_0^T + Y_0^{T*}} (1 + e_0^H) \ . \end{aligned}$$

Since $e_0^H > e_0^L$, it is straightforward to see that $p_0^H > p_0^L$, so prices in the EU in period 0 are higher in the collapse scenario. On the other hand, for the the US,

$$
\begin{aligned}
p_0^{*L} &= \tfrac{\omega}{1-\omega}\tfrac{Y_0^N}{Y_0^T+Y_0^{T*}}\frac{1+e_0^L}{e_0^L} \\
p_0^{*H} &= \tfrac{\omega}{1-\omega}\tfrac{Y_0^N}{Y_0^T+Y_0^{T*}}\frac{1+e_0^H}{e_0^H}\ .
\end{aligned}
$$

Since $e_0^H > e_0^L$, it must be that $\frac{1+e_0^L}{e_0^L} > \frac{1+e_0^H}{e_0^H}$ and thus $p_0^{*L} > p_0^{*H}$. As for prices in period 1, the changes in US non-tradable output must be considered. To focus on the exchange rate in period 0, I will use the following conditions that apply in equilibrium:

$$
i)\ e_0^H > e_0^L \qquad ii)\ e_0^L = e_1^L\frac{R}{R^*} \qquad iii)\ e_0^H = e_1^H \qquad iv)\ e_1^H > e_1^L
$$

Using condition $ii)$ and the fact that $\frac{R^*}{R} = \frac{Y_1^N+A}{Y_1^N}$, prices in the EU in period 1 are given by

$$
\begin{aligned}
p_1^L &= \tfrac{\omega}{1-\omega}\tfrac{1}{Y_1^T+Y_1^{T*}}(Y_1^N + e_1^L(Y_1^{*N} + A^*)) \\
&= \tfrac{\omega}{1-\omega}\tfrac{Y_1^N}{Y_1^T+Y_1^{T*}}(1+e_0^L)
\end{aligned}
$$

when banks operate. Similarly, using condition $iii)$, prices are given by

$$
p_1^H = \tfrac{\omega}{1-\omega}\tfrac{Y_1^N}{Y_1^T+Y_1^{T*}}(1+e_0^H)
$$

when banks shut down. Consequently, $p_1^H > p_1^L$. Finally, for the US case we have that

$$
\begin{aligned}
p_1^{*L} &= \tfrac{\omega}{1-\omega}\tfrac{Y_1^{*N}+A^*}{Y_1^T+Y_1^{T*}}\frac{1+e_0^L}{e_0^L} \\
p_1^{*H} &= \tfrac{\omega}{1-\omega}\tfrac{Y_1^{*N}}{Y_1^T+Y_1^{T*}}\frac{1+e_0^H}{e_0^H}
\end{aligned}
$$

which clearly shows that $p_1^{*L} > p_1^{*H}$. □

B.8. Proof of Proposition 5

Proposition 6. *Comparing the utility obtained by households under the "normal" and the "bad" equilibria, EU households always experience a welfare loss* ($\Psi > 0$) *due to higher prices of the tradable good. On the contrary, US households benefit from lower relative prices, but face lower consumption from non-tradable goods. The overall welfare outcome for these households is ambiguous* ($\Psi^* \lesseqgtr 0$) *and depend, in particular, on the magnitude of* A^*.

Proof. EU households' welfare is given by the consumption of tradable and non-tradable goods in both periods:

$$\mathcal{U} = (1-\omega)\ln(C_0^N) + \omega\ln(C_0^T) + \beta(1-\omega)\ln(C_1^N) + \beta\omega\ln(C_1^T)$$

Using the fact that non-tradable consumption is the same under the collapse and the normal scenario, and the households' first order condition $C_t^T = Y_0^N \frac{\omega}{1-\omega}\frac{1}{p_t}$, the welfare loss is given by

$$\Psi \equiv \mathcal{U}_L - \mathcal{U}_H = \omega \underbrace{\left[\ln\left(\frac{p_0^H}{p_0^L}\right) + \beta\ln\left(\frac{p_1^H}{p_1^L}\right)\right]}_{\text{Loss from higher prices}}$$

From Proposition **??**, $p_t^H > p_t^L$ and thus $\ln\left(\frac{p_0^H}{p_0^L}\right) + \beta\ln\left(\frac{p_1^H}{p_1^L}\right) > 0$. Following a similar approach, the welfare loss from converging to the "bad" equilibrium is given by

$$\Psi^* \equiv \mathcal{U}^*{}_L - \mathcal{U}^*{}_H = \beta^*(1-\omega^*)\underbrace{\ln\left(\frac{Y_1^{*N} + A^*}{Y_1^{*N}}\right)}_{\text{Loss from}\downarrow\text{NT}} + \omega^* \underbrace{\left[\ln\left(\frac{p_0^{*H}}{p_0^{*L}}\right) + \beta^*\ln\left(\frac{Y_1^{*N}+A^*}{Y_1^{*N}}\frac{p_1^{*H}}{p_1^{*L}}\right)\right]}_{\text{Gain from lower prices}}$$

Again from Proposition **??**, $p_0^{*H} < p_0^{*L}$ and $(Y_1^{*N} + A^*)p_1^{*H} < Y_1^{*N}p_1^{*L}$ thus

$$\ln\left(\frac{p_0^{*H}}{p_0^{*L}}\right) + \beta^*\ln\left(\frac{Y_1^{*N}+A^*}{Y_1^{*N}}\frac{p_1^{*H}}{p_1^{*L}}\right) < 0$$

On the other hand, it is straightforward to see that $\ln\left(\frac{Y_1^{*N} + A^*}{Y_1^{*N}}\right) > 0$. Therefore, US households will face a welfare loss or gain, depending on the parameters of the model, and especially on A^*, as shown in the numerical example. $\square$

Panel (a) shows the positive relationship between the exchange rate and the required tax rate for the intervention. For a given e_1^H and the corresponding τ^H, two different upper bounds on the tax rate are considered, where $\overline{\tau}' < \overline{\tau}''$. In this context, the maximum exchange rates that the ECB can effectively handle under $\overline{\tau}'$ and $\overline{\tau}''$ are given by $e^{\overline{\tau}'}$ and $e^{\overline{\tau}''}$, respectively. We can take those levels to the graph in Panel (b) showing the equilibria of the model. An intervention of this kind will basically extend the threshold $\overline{e}$ that the banking system can tolerate before collapsing. In other words, they can tolerate a larger exchange rate depreciation, depending on the resources that the central bank can transfer. It is possible to see in this figure that a tighter limit to tax rate ($\overline{\tau}'$) might lead to an unsuccessful intervention, since the ECB fails to transfer enough resources to global banks in order to cover their dollar liablities when the dollar is largely appreciated. On the other hand, a more flexible limit given by $\overline{\tau}''$ allows the ECB to avoid the "bad" equilibrium, as in the dashed blue line.

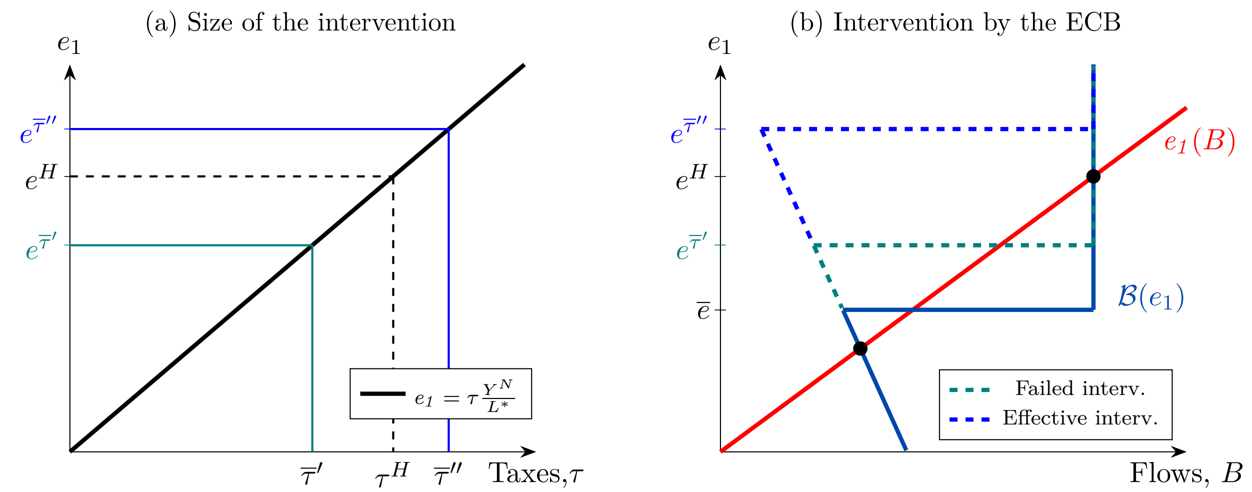


Figure B.1: Size and effectiveness of ECB intervention

C. Access to dollar bonds

In this Appendix I extend the standard model in the following ways. First, I allow households in the EU and in the US to trade *dollar*-denominated bonds with each other and without the need for intermediation. From the perspective of the US, in principle these bonds are equivalent to the bonds offered by global banks. For EU households, however, this implies that they have access to bonds in their domestic and in foreign currency.

I also introduce a non-pecuniary cost that EU households face from holding/trading assets in foreign currency. This tries to capture, in a very reduced-form, additional costs in transactions when holding foreign currencies, in line with Schmitt-Grohé and Uribe (2001) and Gopinath and Stein (2018). Similarly to Kekre and Lenel (2021), my model features money-in-utility with foreign currency, by assuming that the non-pecuniary cost affects the utility of EU households directly. I will show that in equilibrium, this cost could be interpreted as the negative impact of a banking crisis, from the perspective of the domestic country.

Finally, I relax one of the simplifying assumptions used in for the baseline model. In particular, I let the share of tradable endowment in EU η to change over time.

The reason I introduce these extensions is to better rationalize the patterns of capital inflows to the US during the GFC and the Covid-19 crisis. Even though this is not needed to demonstrate how the basic mechanism of the model opens the door to multiple equilibria, the dynamics of capital flows are relevant to fully understand the trade-offs that the Fed face when acting as the international lender of last resort. Intuitively, when banks are operating and the exchange rate is low, EU households prefer to trade euro-denominated bonds rather than paying the non-pecuniary cost and saving in dollars.

When banks collapse, their only savings vehicle are the dollar bonds. Given the negative wealth shock to which these households are exposed, and the consequent drop in aggregate demand, they will tend to increase savings in the form of a higher demand for dollar bonds.

C.1. EU households' problem

Given the extensions discussed previously, EU households face now a similar but more complex problem:

$$\max_{C_t} \quad U = \ln(C_0) + \beta \mathbb{E} \ln(C_1) - \zeta(\widetilde{D}) \tag{39}$$

subject to the budget constraint in both periods,

$$p_0 Y_0^T + Y_0^N = p_0 C_0^T + C_0^N + D + e_0 \widetilde{D} \tag{40}$$

$$\Pi + RD + e_1 R^* \widetilde{D} + p_1 Y_1^T + Y_1^N = p_1 C_1^T + C_1^N \ . \tag{41}$$

This problem shows that now they have access to euro deposits with banks D paying R, and to dollar bonds with US households, $\widetilde{D}$ paying R^*. Moreover, holding balances in foreign currency entails a small non-pecuniary cost:

$$\zeta(\widetilde{D}) = \begin{cases} \chi & \text{if } \widetilde{D} \neq 0 \\ 0 & \text{otherwise} \end{cases} , \qquad \chi > 0$$

In addition to the changes to the EU households' problem, I will allow the share of tradable endowment in EU to change over time. As in the previous section, let $\eta_t \equiv \frac{Y_t^T}{Y_t^T + Y_t^{*T}}$. Now, instead of setting $\eta_0 = \eta_1$ as a simplifying assumption, I will focus on the case where $\eta_0 > \eta_1$. This parametrization will generate positive net capital flows to the US during a crisis, which can be seen empirically and is the focus of this section.

C.2. Multiple equilibria

Normal times

The equilibrium under "normal" times will be similar to the one in the standard model, with the small difference in the parameter η_1. The reason for the similarity is that when the financial frictions do not bind, households prefer to trade bonds in their own currency and avoid the non-pecuniary cost of holding balances in foreign currency. This will be the case for any $\chi > 0$. In particular, if I set $\chi \to \infty$, the model converges back to the standard version, since EU households would not demand any dollar bonds, even if banks collapse. I will assume for this section that χ is small enough so that EU households find it optimal to trade dollar bonds if banks collapse.

In this state of the world, the equilibrium exchange rate is then

$$e_0^{L'} = \frac{1-\eta_0+\beta(1-\eta_1)}{\eta_0+\beta\eta_1+\frac{1-\omega}{\omega}\frac{1}{Y_0^N}(\frac{A^*}{R^*}-L^*)} \tag{42}$$

while by the UIP condition $e_1^{L'} = e_0^{L'}\frac{R}{R^*}$. Under a similar parametrization as for the standard model, this is also a stable equilibrium such that $e_0^{L'} < \bar{e}$. The capital flows to the US (in euros) in this case are again given by $D = e_0^{L'}(D^* - L^*) < 0$.

Collapse

I will focus now on the case when banks go bust. Most of the equations presented so far still apply to this case, except for a few that I present here. The EU households' euler equation, for example, becomes

$$p_1 C_1^T = \beta R^* \frac{e_1}{e_0} p_0 C_0^T \ . \tag{43}$$

Combining (43) with the usual euler condition of the US households gives an expression for the exchange rate in period 1 in terms of the exchange rate in period 0:

$$e_1 = e_0 \frac{Y_0^{*N}}{Y_1^{*N}} \tag{44}$$

This equation substitutes the UIP condition (14) that emerges when banks operate. It is important to mention that, since $A^* \to 0$ in this scenario, $R^* = \frac{Y_1^{*N}}{\beta^* Y_0^{*N}}$ which is lower than the dollar interest rate when banks operate. Moreover, contrary to the case in the standard framework, the exchange rate in period 0 is affected by the intertemporal decisions of the households even in the collapse scenario. As explained before, a negative wealth shock in the future leads EU households to save more (or borrow less) and drop consumption in period 0, which is accommodated by an increase in the price of tradables p_0 and thus a euro depreciation ($\downarrow e_0$). These dynamics are captured by the corresponding budget constraints,

$$e_0 \widetilde{D} = p_0(Y_0^T - C_0^T) \tag{45}$$

$$e_1 R^* \widetilde{D} = p_1(C_1^T - Y_1^T) \ . \tag{46}$$

Using (44), (45), (46) and the households' optimality conditions, it is possible to find the exchange rate under the collapse scenario $e_0^{H'}$ as follows

$$e_0^{H'} = \frac{1-\eta_0+\beta(1-\eta_1)}{\eta_0+\beta\eta_1} \tag{47}$$

which is equivalent to $e_0^{L'}$ considering that $A^*, L^* \to 0$ when banks collapse. On the other hand, $e_0^{H'} = e_1^{H'}$. In order for this to be an equilibrium, it must be that $e_0^{H'} > \bar{e}$.

Turning now to the capital flows, in the standard model it was shown that the exchange rate e_0^H was the one that cleared the market of tradables such that both countries were running balanced current accounts. It is possible to rewrite equation (45) in terms of the exchange rate to see this clearly,

$$\tilde{D} = \frac{\omega}{1-\omega} Y_0^N \left(\frac{\eta_0(1+e_0) - 1}{e_0} \right)$$

where $\tilde{D} = 0$ if and only if $e_0 = e_0^H$. Considering this, to generate positive capital flows to the US during a collapse it must be that $e_0^{H'} > e_0^H$, which can be achieved with the following condition

$$\eta_0 > \eta_1 \ .$$

The fact that EU tradable endowment is relatively lower in period 1 will force EU households to transfer more resources from period 0 and increase their demand for dollar bonds. Ultimately, US households benefit from this as they have access to "cheap" funding from abroad. These dynamics will eventually be reflected in prices, meaning that if one country has more affordable access to funding to buy a certain good, the price of that good should be lower in that country.

This aggregate condition can be divided into one condition for each country. More specifically, by focusing on period 0, equilibrium requires that the net foreign asset positions are

$$NFA_0 = p_0(Y_0^T - C_0^T) = D$$
$$NFA_0^* = p_0^*(Y_0^{*T} - C_0^{*T}) = D^* - L^*$$

where it is shown that the net exports have to be equal to the stock of deposits/bonds, in each country.

References

Acharya, V. and Schnabl, P. (2009), 'How banks played the leverage" game"', *Financial Markets, Institutions+ Instruments* **18**(2), 144. 5

Acharya, V. V. and Schnabl, P. (2010), 'Do global banks spread global imbalances? asset-backed commercial paper during the financial crisis of 2007–09', *IMF Economic Review* **58**(1), 37–73. 1, 3

Aguiar, M., Chatterjee, S., Cole, H. L. and Stangebye, Z. (2017), 'Self-fulfilling debt crises, revisited: The art of the desperate deal', *Available at SSRN 2927260* . 3

Aizenman, J., Ito, H. and Pasricha, G. K. (2021), Central bank swap arrangements in the covid-19 crisis, Technical report, National Bureau of Economic Research. 4

Aizenman, J. and Pasricha, G. K. (2010), 'Selective swap arrangements and the global financial crisis: Analysis and interpretation', *International Review of Economics & Finance* **19**(3), 353–365. 4

Aldasoro, I., Ehlers, T. and Eren, E. (2019), 'Global banks, dollar funding, and regulation', *Dollar Funding, and Regulation (April 9, 2019)* . 3

Aldasoro, I., Eren, E. and Huang, W. (2021), 'Dollar funding of non-us banks through covid-19'. 6, 37

Allen, F. and Gale, D. (2009), *Understanding financial crises*, OUP Oxford. 11

Baba, N. and Packer, F. (2009*a*), 'From turmoil to crisis: dislocations in the fx swap market before and after the failure of lehman brothers', *Journal of International Money and Finance* **28**(8), 1350–1374. 4

Baba, N. and Packer, F. (2009*b*), 'Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08', *Journal of Banking & Finance* **33**(11), 1953–1962. 4

Bagehot, W. (1873), *Lombard Street: A description of the money market*, HS King&Company. 4

Bahaj, S. and Reis, R. (2020), 'Central bank swap lines during the covid-19 pandemic', *Covid economics* **2**, 1–12. 4

Bahaj, S. and Reis, R. (2022*a*), 'Central bank swap lines: Evidence on the effects of the lender of last resort', *The Review of Economic Studies* **89**(4), 1654–1693. 4

Bahaj, S. and Reis, R. (2022*b*), 'The economics of liquidity lines between central banks', *Annual Review of Financial Economics* **14**, 57–74. 1

Bocola, L. and Lorenzoni, G. (2020), 'Financial crises, dollarization, and lending of last resort in open economies', *American Economic Review* **110**(8), 2524–57. 2, 3, 21, 22, 28

Borio, C. (2020), 'The covid-19 economic crisis: Dangerously unique', *Business Economics* **55**(4), 181–190. 5

Bräuning, F. and Ivashina, V. (2020), 'Monetary policy and global banking', *The Journal of Finance*

75(6), 3055–3095. 3

Broz, J. L. (2015), 'The politics of rescuing the world's financial system: The federal reserve as a global lender of last resort', *Korean Journal of International Studies* **13**(2), 323–351. 1

Brunnermeier, M. K. and Sannikov, Y. (2014), 'A macroeconomic model with a financial sector', *American Economic Review* **104**(2), 379–421. 11

Bruno, V. and Shin, H. S. (2015), 'Capital flows and the risk-taking channel of monetary policy', *Journal of Monetary Economics* **71**, 119–132. 4

Calvo, G. A. (1988), 'Servicing the public debt: The role of expectations', *The American Economic Review* pp. 647–661. 3

Cesa-Bianchi, A. and Eguren-Martin, F. (2021), 'Dash for dollars'. 23

Cesa-Bianchi, A., Eguren-Martin, F. and Ferrero, A. (2022), 'Dollar shortages and central bank swap lines', *Unpublished manuscript* . 4

Céspedes, L. F., Chang, R. and Velasco, A. (2017), 'Financial intermediation, real exchange rates, and unconventional policies in an open economy', *Journal of International Economics* **108**, S76–S86. 2, 3, 21

Cetorelli, N. and Goldberg, L. S. (2012), 'Banking globalization and monetary transmission', *The Journal of Finance* **67**(5), 1811–1843. 3

Chen, Z. (2021), 'Global safe assets and the us exorbitant privilege', *Available at SSRN 3963553* . 5

Choi, M., Goldberg, L. S., Lerman, R. I. and Ravazzolo, F. (2021), The fed's central bank swap lines and fima repo facility, Technical report, Staff Report. 8

Clayton, C. and Schaab, A. (2022), 'Multinational banks and financial stability', *The Quarterly Journal of Economics* **137**(3), 1681–1736. 11

Cole, H. L. and Kehoe, T. J. (2000), 'Self-fulfilling debt crises', *The Review of Economic Studies* **67**(1), 91–116. 3

Correa, R., Sapriza, H. and Zlate, A. (2016), 'Liquidity shocks, dollar funding costs, and the bank lending channel during the european sovereign crisis', *FRB Boston Risk and Policy Analysis Unit Paper No. RPA* pp. 16–4. 3

Corsetti, G. and Marin, E. (2020), 'The dollar and international capital flows in the covid-19 crisis', *VOX CEPR Policy Portal* . 5

Diamond, D. W. and Dybvig, P. H. (1983), 'Bank runs, deposit insurance, and liquidity', *Journal of political economy* **91**(3), 401–419. 4, 11

Eguren-Martin, F. (2020), 'Dollar shortages and central bank swap lines'. 4, 18

Farhi, E. and Maggiori, M. (2018), 'A model of the international monetary system', *The Quarterly Journal of Economics* **133**(1), 295–355. 3

Ferrara, G., Mueller, P., Viswanath-Natraj, G. and Wang, J. (2022), 'Central bank swap lines: micro-level evidence'. 4

FSB (2020), 'Holistic review of the march market turmoil', *Financial Stability Board. https://www. fsb. org/wp-content/uploads/P171120-2. pdf* . 5

Gabaix, X. and Maggiori, M. (2015), 'International liquidity and exchange rate dynamics', *The Quarterly Journal of Economics* **130**(3), 1369–1420. 3, 11, 26, 34

Gertler, M. and Kiyotaki, N. (2015), 'Banking, liquidity, and bank runs in an infinite horizon economy', *American Economic Review* **105**(7), 2011–43. 21

Goldberg, L. S. and Ravazzolo, F. (2022), The fed's international dollar liquidity facilities: New evidence on effects, Technical report, National Bureau of Economic Research. 4

Gopinath, G. and Stein, J. C. (2018), Trade invoicing, bank funding, and central bank reserve holdings, *in* 'AEA Papers and Proceedings', Vol. 108, pp. 542–46. 45

Gourinchas, P.-O., Rey, H., Govillot, N. et al. (2010), Exorbitant privilege and exorbitant duty, Technical report, Institute for Monetary and Economic Studies, Bank of Japan Tokyo. 4

Itskhoki, O. and Mukhin, D. (2021), 'Exchange rate disconnect in general equilibrium', *Journal of Political Economy* **129**(8), 2183–2232. 4

Ivashina, V., Scharfstein, D. S. and Stein, J. C. (2015), 'Dollar funding and the lending behavior of global banks', *The Quarterly Journal of Economics* **130**(3), 1241–1281. 3, 12, 19

Kalemli-Ozcan, S., Papaioannou, E. and Perri, F. (2013), 'Global banks and crisis transmission', *Journal of international Economics* **89**(2), 495–510. 3

Kekre, R. and Lenel, M. (2021), The flight to safety and international risk sharing, Technical report, National Bureau of Economic Research. 4, 18, 23, 45

Krugman, P. (1999), Balance sheets, the transfer problem, and financial crises, *in* 'International finance and financial crises', Springer, pp. 31–55. 3

Maggiori, M. (2017), 'Financial intermediation, international risk sharing, and reserve currencies', *American Economic Review* **107**(10), 3038–71. 4, 5, 18

Maggiori, M., Neiman, B. and Schreger, J. (2020), 'International currencies and capital allocation', *Journal of Political Economy* **128**(6), 2019–2066. 9

McCauley, R. N. and Schenk, C. R. (2020), 'Central bank swaps then and now: swaps and dollar liquidity in the 1960s'. 4

McGuire, P. and von Peter, G. (2012), 'The dollar shortage in global banking and the international policy response', *International Finance* **15**(2), 155–178. 1, 3, 6, 8

Milesi-Ferretti, G. M. (2009), Notes on the financial crisis and global financial architecture, *in* 'G-20 Workshop on Global Economy, Mumbai, India', pp. 24–26. 6

Moessner, R. and Allen, W. A. (2013), 'Central bank swap line effectiveness during the euro area sovereign debt crisis', *Journal of International Money and Finance* **35**, 167–178. 4

Morelli, J. M., Ottonello, P. and Perez, D. J. (2022), 'Global banks and systemic debt crises', *Econometrica* **90**(2), 749–798. 3

Obstfeld, M. (1996), 'Models of currency crises with self-fulfilling features', *European economic review* **40**(3-5), 1037–1047. 3

Obstfeld, M., Shambaugh, J. C. and Taylor, A. M. (2009), 'Financial instability, reserves, and central bank swap lines in the panic of 2008', *american Economic review* **99**(2), 480–86. 4

Rochet, J.-C. and Vives, X. (2004), 'Coordination failures and the lender of last resort: was bagehot right after all?', *Journal of the European Economic Association* **2**(6), 1116–1147. 4

Schmitt-Grohé, S. and Uribe, M. (2001), 'Stabilization policy and the costs of dollarization', *Journal of money, credit and banking* pp. 482–509. 45

Schmitt-Grohé, S. and Uribe, M. (2016), Multiple equilibria in open economy models with collateral constraints: Overborrowing revisited, Technical report, National Bureau of Economic Research. 3

Shin, H. S. (2012), 'Global banking glut and loan risk premium', *IMF Economic Review* **60**(2), 155–192. 1, 3, 5, 6

Tooze, A. (2018), *Crashed: How a decade of financial crises changed the world*, Penguin. 9

Williamson, J. (1983), 'On seeking to improve imf conditionality', *The American Economic Review* **73**(2), 354–358. 4