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Exchange Rate Determination Under Limits to CIP Arbitrage[*]

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Abstract

Recent theories of exchange rate determination have emphasized limited UIP arbitrage by international financial institutions. New regulations since 2008 have also led to imperfect CIP arbitrage. We show that under limited CIP arbitrage the exchange rate and CIP deviation are jointly determined by equilibrium in the FX spot and swap markets. The model is used to investigate the impact of a wide range of financial shocks. The exchange rate is affected by a new set of financial shocks that operate through the swap market, which have no effect under perfect CIP arbitrage. More familiar financial shocks that impact the spot market have an amplified effect on the exchange rate as a result of their feedback to the swap market. Implications of the model are consistent with a broad range of evidence.

Keywords: U.S. dollar, exchange rate, CIP deviations

JEL Classifications: F31, G15

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1 Introduction

Uncovered interest rate parity (UIP) has traditionally been the centerpiece of models of exchange rate determination. However, recent theories such as Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2021) have emphasized financial frictions that lead to limits to arbitrage and deviations from UIP.[1] In such models financial intermediaries absorb imbalances in currency demand associated with international financial flows and trade flows. They have limited risk bearing capacity and therefore demand expected excess returns for their willingness to intermediate these flows, which in turn affects exchange rates. These theories have emphasized financial forces as the main drivers of exchange rates. Without this intermediary arbitrage friction, these financial shocks would have no effect on the exchange rate.

While these models assume that financial intermediaries face a limited capacity to arbitrage risky excess returns, they are not constrained in arbitraging risk-free excess returns. In reality, trading desks of financial institutions involved in covered interest rate parity (CIP) arbitrage also face substantial constraints, especially during financial crises like the 2008 global financial crisis, the European debt crisis and the Covid crisis. A substantial literature has since developed documenting these CIP deviations and the role of post-2008 regulations.[2]

Our objective is to build a model of exchange rate determination in which the limited arbitrage capacity of financial institutions affects both UIP and CIP deviations. Our focus will be on the dollar since most evidence on CIP deviations applies to the dollar relative to other currencies and because of the central role of the dollar in the international financial system. Prior to 2007 these CIP deviations tended to be very small, but since then they have been substantial and time varying.

Limited CIP arbitrage implies a segmentation between the onshore dollar market and the offshore synthetic dollar market. Synthetic dollar borrowing and lending involves swapping

[1] In the same spirit, other models of exchange rate determination with various financial frictions, such as market segmentation, informational frictions and portfolio adjustment costs, include Bacchetta and van Wincoop (2010, 2021), Gourinchas et al. (2024), Greenwood et al. (2023), Hau and Rey (2005), Jeanne and Rose (2002) and Koijen and Yogo (2024). Engel and Wu (2024) provide empirical evidence on models of exchange rate determination, including variables that the more recent literature has emphasized.

[2] See for example Du et al. (2018), Diamond and Van Tassel (2023), Rime et al. (2022), Boyarchenko et al. (2020) and Cenedese et al. (2021). Du and Schreger (2022) provide a survey of the literature on CIP deviations. Several papers, including Du et al. (2018) and Cenedese et al. (2021), provide evidence that tighter bank leverage regulations since the GFC have led to a higher cost of financial intermediation that is responsible for the CIP deviations since that time.

borrowing and lending in foreign currencies into dollars through the FX swap market. CIP deviations develop when excess demand for dollar funding through the FX swap market is absorbed by financial institutions that have limited arbitrage capacity. They will demand a premium that is the difference between the synthetic dollar rate (e.g., the euro or yen rate swapped into dollars) and the onshore dollar rate.[3] In contrast to UIP deviations, this premium is not generated by exchange rate risk.

In terms of FX trading volume the swap market is larger than the spot market. It has nonetheless not played a role in traditional models of exchange rate determination since under perfect CIP arbitrage the swap rate or forward discount is simply equal to the interest rate differential and plays no independent role in affecting the exchange rate. But we show that under imperfect CIP arbitrage the swap market plays a key role in exchange rate determination.

The theory we develop leads to two equilibrium schedules, one for the spot market and one for the swap market. The exchange rate and CIP deviation are jointly determined by equilibrium in these two markets. The two equilibrium schedules can be represented graphically and solved algebraically. Under imperfect CIP arbitrage, shocks to either market affect the other market. This has two implications. First, a new set of financial shocks affect the exchange rate that operate through flows into the swap market. Examples are changes in demand for hedged liquid dollar assets, changes in the arbitrage capacity of CIP arbitrageurs and changes in central bank swap lines. These shocks play no role under perfect CIP arbitrage. Second, standard shocks that operate through the spot market (e.g., associated with unhedged international capital flows) have an amplified effect on the exchange rate when CIP arbitrage is limited. This is a result of their feedback to the swap market.

To understand how flows into the swap market affect the exchange rate, consider the effect of increased synthetic dollar borrowing. This raises the cost of synthetic dollar borrowing (raises the CIP deviation). Borrowers are then more likely to acquire the needed dollar balances by buying dollars in the spot market, leading to a dollar appreciation. McCauley and McGuire (2009) describe this mechanism during the 2008 global financial crisis. European banks found it hard to raise dollar funds in the interbank market and instead

[3]Papers discussing the impacts of net flows to the swap market on the CIP deviation include Borio et al. (2016), Borio et al. (2018), Avdjiev et al. (2020), Du and Huber (2023) and Hau and Bräuer (2022). Hedging by international investors of dollar assets plays a particularly important role.

turned to the swap market to swap euros, pounds and Swiss franc into dollars. The resulting spike in the cost of synthetic dollar funding made it hard for companies with dollar debts to roll over these debts, leading them to buy dollars in the spot market and causing the dollar to appreciate.

The paper relates to a variety of literatures. First, it connects closely to models of exchange rate determination with market segmentation such as Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2021), from hereon GM and IM. These are models with a spot FX market in which UIP arbitrageurs with limited risk bearing capacity intermediate cross-border financial flows. We add to that basic framework a swap market and CIP arbitrageurs that have limited capacity to absorb net flows through the swap market. GM and IM also provide a coherent explanation for the long standing exchange rate disconnect puzzle by pointing to the important role of financial shocks as drivers of exchange rates. We add to that a new set of financial shocks that drive the exchange rate through the swap market. Our model also has in common with this literature that exchange rate changes feed back to the real economy (output) through relative price changes.

The paper also relates to a substantial literature on central bank swap lines, which provide a good test of the theory. Foreign central banks that receive dollars from the Fed through a swap line will lend these dollars to the domestic financial sector. This reduces the need to acquire dollars through synthetic dollar borrowing. The resulting change in the swap rate or synthetic dollar borrowing rate in turn feeds back to the spot market. Several papers find that increased dollar swap lines by the Fed reduce CIP deviations.[4] Even more closely related, Kekre and Lenel (2024b) show that swap line announcements over the 2007-2010 and 2020-2021 periods not only lowered CIP deviations, but also lead to a dollar depreciation. This goes to the core of our theory.

The paper is also directly related to a small literature that has considered the link between exchange rates and CIP deviations. Liao and Zhang (2020) present a model with a forward and spot market, limited CIP arbitrage and hedging of dollar assets that leads to a demand for forward contracts. Motivated by evidence of time-varying hedge ratios, the model is used to investigate the impact of changing exchange rate volatility on the CIP devi-

[4] See for example Bahaj and Reis (2022), Cerutti et al. (2021), Rime et al. (2022), Ferrara et al. (2022) and Goldberg and Ravazzolo (2022)

ation and exchange rate.[5] Fang and Liu (2021) consider a framework in which US financial intermediaries arbitrage both CIP and UIP deviations.[6] An increase in uncertainty reduces their risk-bearing capacity, reducing both CIP and UIP arbitrage. This affects the exchange rate in a way similar to GM and also raises the CIP deviation. But there is no causal link from the CIP deviation to the exchange rate or the other way around. Avdjiev et al. (2019) discuss a mechanism through which an exogenous dollar appreciation reduces CIP arbitrage and therefore raises the CIP deviation.

The paper also relates to the literature on the dominant role of the dollar in international finance, a convenience yield on liquid dollar assets and dollar shortages. In our model liquid dollar assets are held as a result of the dominant role of the dollar in trade invoicing, similar to Gopinath and Stein (2021). Changes in demand for liquid dollar assets also relate the model to a substantial literature on relative US convenience yields.[7] The difference here is that agents can hedge positions in liquid dollar assets, affecting the swap market and CIP deviation. Finally, flows into the swap market can push up the cost of synthetic dollar borrowing. This relates to a literature documenting dollar shortages during times of global financial stress.[8]

The model is a simplification of that in an earlier version of this paper, Bacchetta, Davis, and van Wincoop (2023), from hereon BDvW, which had a narrower focus. That model includes some additional features that we abstract from here as they are not key to the results and complicate notation and analysis. We will occasionally refer back to that paper.

The remainder of the paper is organized as follows. Section 2 describes the model. Section 3 analyzes the implications of a variety of shocks. The model can be represented graphically through spot market and swap market schedules that relate the exchange rate and the CIP deviation. Section 4 concludes.

[5]An older paper, Tsiang (1959), is similar in also assuming limited CIP arbitrage and the model is summarized by equilibrium in spot and forward markets.

[6]In a related framework, Bacchetta, Benhima, and Berthold (2023) analyze FX interventions with both UIP and CIP deviations.

[7]See Valchev (2020), Kekre and Lenel (2024a), Engel and Wu (2023), Jiang et al. (2023), Jiang et al. (2021), Bianchi et al. (2021) and Devereux et al. (2023).

[8]McCauley and McGuire (2009) discuss dollar shortages during the GFC. Ivashina et al. (2015) document how stress in dollar funding markets during the European sovereign debt crisis led to dollar shortages that increased CIP deviations. Cesa-Bianchi et al. (2023) describe dollar shortages at the start of the Covid crisis.

2 Model Description

There are two countries (Home and Foreign). We think of the Home country as the US and the Foreign country as the rest of the world. For convenience we will refer to the latter as Europe and the currency as the euro. Although there are three periods (0, 1 and 2), it is more like a two period model (periods 1 and 2) as period 0 is the past. We take asset prices and financial holdings in period 0 as given. Our main focus will be on financial decisions and prices in period 1.

The assets are dollar and euro bonds, liquid dollar and euro assets and a synthetic dollar asset created by swapping the euro bond into dollars through the swap market. We often refer to the liquid dollar and euro assets as money, although they can also be other liquid assets such as Treasuries. The agents are the two central banks (Fed and ECB), US and European households, CIP arbitrageurs, UIP arbitrageurs and noise traders.

Central banks provide sufficient liquidity to the domestic bond market to target a certain desired policy interest rate, which we will take as given. The Fed also provides swap lines to the ECB, which the ECB uses to lend dollars domestically.[9]

US households only hold dollar bonds and money. European households hold euro bonds and euro and dollar liquid assets. Dollar money balances are needed as a result of assumed dollarization of trade. European households also borrow dollars. They can do so both by borrowing dollars synthetically and borrowing dollars directly. Synthetic dollar borrowing involves borrowing euros and swapping them into dollars. CIP arbitrageurs borrow dollars in the US and lend dollars synthetically to Europe. This involves lending euros and swapping them into dollars. They adopt a risk-free arbitrage position. UIP arbitrageurs and noise traders operate in the dollar and euro bond markets, but do not take positions in the swap market.

We assume that the only direct dollar borrowing by European households is from the ECB, who obtains the dollars through a swap line from the Fed. We will discuss an extension where European households can also borrow a limited amount of dollars directly in the US market. This has a similar effect as dollars obtained through the central bank swap line. In

[9]The first dollar liquidity swap lines during the GFC were set up between the Fed and the ECB and the Swiss National Bank in December 2007. Swap lines between the Fed and the five major central banks (including the Bank of England, the Bank of Japan and the Bank of Canada) were made permanent in 2013. On occasion swap lines have been extended to 9 smaller central banks as well.

BDvW we also allow European households to issue offshore dollar bonds that can be bought by US and European investors. We abstract from this here as it does not affect the key results and complicates notation.

CIP arbitrageurs face an intermediation friction. In the limit, when this friction goes away and there is perfect CIP arbitrage, the model is very similar to models of exchange rate determination with segmented markets such as GM and IM. In those models households then only take positions in the domestic bond market, while UIP arbitrageurs intermediate these positions across domestic and foreign currency bond markets. The UIP arbitrageurs are alternatively referred to as financial intermediaries in GM and risk-averse arbitrageurs in IM. Our contribution will be to analyze the additional role of the swap market for exchange rate determination when CIP arbitrage is imperfect.

The remainder of this section is organized as follows. We start by introducing notation. After that we discuss the swap market equilibrium, equilibrium in goods and money (liquid asset) markets and optimal portfolios of all agents. We finish with a discussion of equilibrium in the spot market and the pre-shock equilibrium of the model.

2.1 Notation

The countries are denoted H and F, respectively the US and Europe. The spot and forward exchange rates are denoted S_t and F_t, which are dollars per euro. The log exchange rate is $s_t = log(S_t)$. The buyer of swaps at time t exchanges dollars for euros at time t at the exchange rate S_t and exchanges euros back for dollars at time $t+1$ at the exchange rate F_t. We will define swap transactions more precisely below.

Financial wealth, excluding money balances, is denoted $W_{h,t}$ for households from country $h = H, F$. Their consumption is denoted $C_{h,t}$. US households only hold dollar money balances, denoted $M^{\$}_{H,t}$. European households hold both dollar and euro money balances, respectively $M^{\$}_{F,t}$ and $M^{€}_{F,t}$. European households have a euro bond position of $B^{€}_{F,t}$. They borrow $D^{\$}_{F,t}$ dollars synthetically. Borrowing of euros that are swapped into dollars are not included in $B^{€}_{F,t}$. In addition to the synthetic dollar borrowing, European households may also borrow $D^{\$}_{swap,t}$ dollars from the ECB. This originates from a central bank swap line from the Fed.

The remaining agents are CIP arbitrageurs, UIP arbitrageurs and noise traders. For convenience, they are assumed to all be US agents.[10] CIP arbitrageurs lend $B^{\$}_{CIP,t}$ dollars synthetically to European households, while borrowing the same amount of dollars in the US. UIP arbitrageurs take a position $B^{\$}_{UIP,t}$ in dollar bonds. They take an opposite position in the euro bond, so that $S_t B^{€}_{UIP,t} = -B^{\$}_{UIP,t}$. The dollar and euro positions of noise traders are $B^{\$}_{noise,t}$ and $B^{€}_{noise,t}$, with $S_t B^{€}_{noise,t} = -B^{\$}_{noise,t}$. Aggregate consumption of all three of these agents is denoted $C^{o}_{H,t}$ as they are all from the US, where the superscript o refers to these three agents "other" than households.

For $t = 0, 1$, interest rates on dollar and euro bonds are $i^{\$}_t$ and $i^{€}_t$. The synthetic dollar interest rate is denoted $i^{\$,syn}_t$, where

$$1 + i^{\$,syn}_t = \frac{F_t}{S_t}\left(1 + i^{€}_t\right) \tag{1}$$

The right hand side is obtained by taking 1 dollar, exchanging it for $1/S_t$ euros, investing in the euro bond and then exchanging back for dollars at the forward rate F_t.

2.2 Swap Market Equilibrium

Let there be a central bank swap line from the Fed to the ECB that is equal to an exogenous $D^{\$}_{swap,t}$ dollars. The ECB will lend the same amount of dollars to European households. To make sure that European households wish to borrow all $D^{\$}_{swap,t}$ dollars from the ECB, we assume that the ECB charges an interest rate $i^{\$,ECB}_t = i^{\$,syn}_t - \epsilon$ for some positive (possibly infinitesimal) ϵ. On top of this, European households borrow an additional $D^{\$}_{F,t}$ dollars synthetically.[11]

Synthetic dollar borrowing by European households leads to swap market transactions. A swap market position of 1 involves selling 1 dollar at time t in exchange for $1/S_t$ euros and then exchanging $(1 + i^{€}_t)/S_t$ euros at time $t + 1$ for $(1 + i^{€}_t)(F_t/S_t) = 1 + i^{\$,syn}_t$ dollars. In order to borrow $D^{\$}_{F,t}$ dollars synthetically, European households borrow $D^{\$}_{F,t}/S_t$ euros in combination with a swap market position of $-D^{\$}_{F,t}$. This amounts to receiving $D^{\$}_{F,t}$ dollars

[10] This assumption simplifies the algebra a bit, but is not a key assumption and can easily be relaxed, as in BDvW.

[11] An alternative, which we consider in BDvW and leads to similar results, is that the Fed offers a new swap line that is unlimited at an interest rate $i^{\$}_t + \tau$ that is lower than the current synthetic dollar rate. The ECB then passes this interest rate on to European households.

at time t and paying $(1+i_t^{\$,syn})D_{F,t}^{\$}$ dollars at time $t+1$.

The other agents that enter the swap market are CIP arbitrageurs. They adopt an arbitrage position of $B_{CIP,t}^{\$}$. This involves borrowing $B_{CIP,t}^{\$}$ in the US dollar funding market and lending $B_{CIP,t}^{\$}$ dollars synthetically. The $B_{CIP,t}^{\$}$ synthetic dollar position involves buying $B_{CIP,t}^{\$}/S_t$ euro bonds in combination with a swap market position of $B_{CIP,t}^{\$}$.

It then follows that swap market equilibrium is[12]

$$B_{CIP,t}^{\$} = D_{F,t}^{\$} \tag{2}$$

2.3 Goods Market and Money Demand

We first discuss the period 1 goods market, where prices are set in advance, and then the period 2 goods market, where prices are flexible. Consumption demand in period 1 also leads to proportional money demand expressions. There is no money demand in period 2.

2.3.1 Period 1 Goods Market

Home and Foreign agents produce differentiated goods. Prices are preset at 1 in the currency of invoicing. We assume full trade dollarization in that both US and European goods that are exported are invoiced in dollars. Goods sold domestically are invoiced in the domestic currency. Euro invoicing therefore only applies to European goods sold in Europe. All other invoicing is in dollars.

The period 1 consumption index for households in the Home and Foreign country is[13]

$$C_{H,1} = \left((1-\omega)^{\frac{1}{\theta}}\left(C_{HH,1}\right)^{\frac{\theta-1}{\theta}} + \omega^{\frac{1}{\theta}}\left(C_{HF,1}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}}$$
$$C_{F,1} = \left((1-\omega)^{\frac{1}{\theta}}\left(C_{FF,1}\right)^{\frac{\theta-1}{\theta}} + \omega^{\frac{1}{\theta}}\left(C_{FH,1}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}}$$

The double country subscript refers to respectively the buyer and the seller. For example,

[12] In BDvW we also allowed US households to access the swap market through synthetic euro borrowing to hedge euro currency exposure. This lead to an additional term in the swap market equilibrium that we have abstracted from here.

[13] This is analogous to Betts and Devereux (2000). One piece that we are not explicit about here is that goods are differentiated by agents producing them, giving them price setting power. But all agents producing the same good will end up setting the same price, which we normalize to 1 in the currency of invoicing.

$C_{HF,1}$ refers to consumption by Home households of goods produced in Foreign. Given these consumption indices, Home and Foreign consumer price indices in respectively dollars and euros are

$$P_1 = 1 \tag{3}$$

$$P_1^* = \left((1-\omega) + \omega S_1^{\theta-1}\right)^{\frac{1}{1-\theta}} \tag{4}$$

Optimal allocation across Home and Foreign goods by Home households is $C_{HH,1} = (1-\omega)C_{H,1}$ and $C_{HF,1} = \omega C_{H,1}$. Similarly, optimal allocation by Foreign households is

$$C_{FF,1} = (1-\omega)\left(\frac{1}{P_1^*}\right)^{-\theta} C_{F,1}; \quad C_{FH,1} = \omega\left(\frac{1}{S_1 P_1^*}\right)^{-\theta} C_{F,1} \tag{5}$$

The other agents (the arbitrageurs and noise traders) are from the US and allocate their aggregate consumption in the same way across Home and Foreign goods as US households. Production of the goods corresponds to demand from all agents. The resulting income of Home households in dollars and Foreign households in euros is denoted respectively $Y_{H,1}$ and $Y_{F,1}$:

$$Y_{H,1} = C_{HH,1} + C_{FH,1} + C^o_{HH,1} \tag{6}$$

$$Y_{F,1} = C_{FF,1} + \frac{1}{S_1}C_{HF,1} + \frac{1}{S_1}C^o_{HF,1} \tag{7}$$

2.3.2 Money Demand

We assume that only households hold money balances. Their money demand in period $t = 1$ is equal to a fraction ψ of consumption of goods invoiced in the corresponding currency:

$$M^{\$}_{H,1} = \psi C_{H,1} \tag{8}$$

$$M^{\$}_{F,1} = \psi\omega\left(S_1 P_1^*\right)^{\theta} C_{F,1} \tag{9}$$

$$M^{€}_{F,1} = \psi(1-\omega)\left(P_1^*\right)^{\theta} C_{F,1} \tag{10}$$

Trade dollar dominance therefore also implies financial dollar dominance as liquid assets need to be held in the currency of invoicing. This is analogous to Gopinath and Stein (2021).[14]

2.3.3 Period 2 Goods Market

In period 2 prices are flexible. There is a Home good and a Foreign good, with aggregate endowments of

$$Q_{H,2} = e^{\kappa_H \epsilon_q}$$
$$Q_{F,2} = e^{-\kappa_F \epsilon_q}$$

where $\kappa_H + \kappa_F = 1$ and ϵ_q is a period 2 endowment shock with mean of zero. There is a CES period 2 consumption index with equal weight to both goods and an elasticity of substitution of θ. Central banks target a price of 1 of the domestic good in the domestic currency.

We leave further details regarding the period 2 goods market equilibrium to Appendix A. In equilibrium $s_2 = \epsilon_q/\theta$, where s_2 is the log exchange rate in period 2. Therefore $E(s_2) = 0$. The period 2 income of households in both countries in the domestic currency is then

$$Y_{H,2} = e^{\kappa_H \theta s_2} \tag{11}$$
$$Y_{F,2} = e^{-\kappa_F \theta s_2} \tag{12}$$

Both countries then have exposure to the foreign currency through non-asset income, with a weaker foreign currency lowering their income.

2.4 Household Portfolios

Period 1 portfolios of European households are determined by maximizing a simple mean-variance objective related to period 2 consumption:

$$EC_{F,2} - 0.5\gamma var(C_{F,2}) \tag{13}$$

[14] Coppola et al. (2024) develop an alternative, liquidity-based, theory of dollar dominance in a model with endogenous search frictions, which does not rely on dollar dominance in trade invoicing. Another, more direct, approach is that taken by Kekre and Lenel (2024a), who model the perceived non-pecuniary benefits of liquid dollar assets through the utility function.

Since our focus is on financial markets, we simplify period 1 consumption decisions. After assuming that period 1 consumption is perfectly smoothed with expected period 2 consumption in a pre-shock equilibrium, we hold period 1 consumption constant after introducing various shocks in Section 3.

The financial wealth of European households, other than through money, is $W_{F,1} = B^{€}_{F,1} - (1/S_1)\left(D^{\$}_{F,1} + D^{\$}_{swap,1}\right)$. This is equal to their euro bond holdings minus their dollar debt from borrowing $D^{\$}_{F,1}$ dollars synthetically and $D^{\$}_{swap,1}$ dollars from the ECB. Their period 2 budget constraint is then

$$\begin{aligned} P_2^* C_{F,2} \;&=\; Y_{F,2} + \Pi_{FCB,2} + \frac{1}{S_2} M^{\$}_{F,1} + M^{€}_{F,1} + (1 + i^{€}_1) W_{F,1} \\ &\quad - \left(\frac{1 + i^{\$,syn}_1}{S_2} - \frac{1 + i^{€}_1}{S_1} \right) D^{\$}_{F,1} - \left(\frac{1 + i^{\$,ECB}_1}{S_2} - \frac{1 + i^{€}_1}{S_1} \right) D^{\$}_{swap,1} \end{aligned} \tag{14}$$

Here $\Pi_{FCB,2}$ denotes profits from the European central bank on its euro bonds holdings that are transferred to European households. As discussed in Section 2.2, since $i^{\$,ECB}_1 < i^{\$,syn}_1$, European households will first borrow the maximum of $D^{\$}_{swap,1}$ dollars from the ECB before borrowing an additional $D^{\$}_{F,1}$ dollars synthetically.

We linearize the second period budget constraint (14) around $s_2 = 0$, zero interest rates and $C_{F,2} = \bar{C}_{F,2}$, which is the pre-shock second period consumption level at $s_2 = 0$ discussed below. We then have[15]

$$\begin{aligned} C_{F,2} \;&=\; 1 - \rho s_2 + \Pi_{FCB,2} + (1 - s_2) M^{\$}_{F,1} + M^{€}_{F,1} + (1 + i^{€}_1) W_{F,1} \\ &\quad -(i^{\$,syn}_1 - i^{€}_1 - s_2 + s_1) D^{\$}_{F,1} - (i^{\$,ECB}_1 - i^{€}_1 - s_2 + s_1) D^{\$}_{swap,1} \end{aligned} \tag{15}$$

where $\rho = \kappa_F \theta - 0.5 \bar{C}_{F,2}$.

Maximizing the mean-variance second period consumption objective (13) then gives

$$D^{\$}_{F,1} = \rho + M^{\$}_{F,1} - D^{\$}_{swap,1} - \frac{i^{\$,syn}_1 - i^{€}_1 + s_1}{\gamma \sigma^2} \tag{16}$$

where $\sigma^2 = var(s_2)$. The last term captures expected excess return of synthetic dollars over

[15]This uses that the log Foreign period 2 price level in Appendix A is linearized as $-0.5 s_2$ and second period income $Y_{F,2}$ is linearized as $1 - \kappa_F \theta s_2$.

euro bonds, using that $E(s_2) = 0$.

The first two terms are hedge terms. The term ρ captures dollar currency exposure through period 2 non-asset income and the period 2 consumer price index. Higher dollar exposure leads to more synthetic dollar borrowing. Similarly, European households hedge their exposure to liquid dollar money balances by borrowing dollars synthetically. The third term reflects that European households have less of a need to borrow dollars synthetically the more dollars they are able borrow from the ECB. The last term captures the cost of dollar borrowing, the expected excess return of synthetic dollars over euros. A higher synthetic dollar interest makes it more expensive to hedge dollar exposure and therefore reduces the hedge ratio. We return to this below.

It is easy to extend the model by also allowing European households to borrow dollars directly in the US market. With a positive CIP deviation this would be attractive as $i_1^{\$} < i_1^{\$,syn}$. The extent to which non-US agents are able to access the US market is well known to be limited to large corporations and financial institutions.[16] If we put an exogenous bound on how much can be borrowed this way, this will generally be binding, analogous to the limit on how much European households can borrow dollars from the ECB. In that case $D_{swap,1}^{\$}$ in (16) would have a broader interpretation that also includes borrowing dollars in the US market.

2.5 CIP and UIP Arbitrageurs and Noise Traders

CIP arbitrageurs borrow $B_{CIP,1}^{\$}$ in the US dollar funding market and lend the same quantity in the synthetic dollar market. This delivers a period 2 profit equal to the difference between the synthetic and cash dollar rates times $B_{CIP,1}^{\$}$:

$$\Pi_{CIP,2} = \left(i_1^{\$,syn} - i_1^{\$} \right) B_{CIP,1}^{\$} \tag{17}$$

UIP arbitrageurs similarly start out with zero wealth. They choose positions in the dollar and euro bonds, going long in one and short in the other, such that $B_{UIP,1}^{\$} + S_1 B_{UIP,1}^{€} = 0$. This yields profits of

$$\Pi_{UIP,2} = B_{UIP,1}^{€} \left(i_1^{€} - i_1^{\$} + s_2 - s_1 \right) \tag{18}$$

[16] If they had unlimited access to borrowing in the US, naturally it is impossible to have a positive CIP deviation in equilibrium.

where the term in brackets is the log linearized excess return of euro bonds over dollar bonds.

For both CIP and UIP arbitrageurs we assume that they maximize expected profits minus a quadratic cost. An alternative, leading to the same result, is to assume that intermediaries are subject to a credit constraint as in GM or that UIP arbitrageurs have a mean-variance objective as in IM. We assume that CIP arbitrageurs maximize $\Pi_{CIP,2}$ minus the quadratic cost $0.5\Gamma_{CIP}\left(B_{CIP,1}\right)^2$. Similarly, UIP arbitrageurs maximize $E(\Pi_{UIP,2})$ minus the quadratic cost $0.5\Gamma_{UIP}\left(B^{€}_{UIP,1}\right)^2$. This leads to the following positions of CIP and UIP arbitrageurs:

$$B^{\$}_{CIP,1} = \frac{i_1^{\$,syn} - i_1^{\$}}{\Gamma_{CIP}} \tag{19}$$

$$B^{€}_{UIP,1} = \frac{i_1^{€} - i_1^{\$} - s_1}{\Gamma_{UIP}} \tag{20}$$

The higher Γ_{CIP} and Γ_{UIP}, the lower the arbitrage capacity of these intermediaries, which is their capacity to absorb financial flows. For UIP arbitrageurs this is referred to as risk bearing capacity in GM, but CIP arbitrageurs face no exchange rate risk. Their arbitrage capacity is linked to regulations that limit CIP arbitrage. Arbitrage capacity is also linked to the overall financial health of financial institutions. We also define the arbitrage capacity of European households as $\Gamma_F = \gamma\sigma^2$.

Finally, noise traders choose exogenous portfolios of dollar and euro bonds, with $B^{\$}_{noise,1} + S_1 B^{€}_{noise,1} = 0$. Let $B^{€}_{noise,1} = -n_1$, so that (after linearization around $n_1 = 0$) $B^{\$}_{noise,1} = n_1$. The aggregate consumption of these three types of agents is equal to the sum of the their profits.

2.6 Spot Market Equilibrium

Let $Q^{\$,spot}_{F,1}$ be spot market purchases of dollars in exchange for euros by Foreign households. $Q^{\$,spot}_{UIP,1}$ and $Q^{\$,spot}_{noise,1}$ are analogously spot market purchases of dollars by UIP arbitrageurs and noise traders. Spot market equilibrium is then

$$Q^{\$,spot}_{F,1} + Q^{\$,spot}_{UIP,1} + Q^{\$,spot}_{noise,1} = 0 \tag{21}$$

Purchases of dollars on the spot market by European households are

$$Q^{\$,spot}_{F,1} = dM^{\$}_{F,1} - Y^{\$}_{F,1} + C_{FH,1} - D^{\$}_{F,1} + (1 + i^{\$,syn}_0)D^{\$}_{F,0} - D^{\$}_{swap,1} \tag{22}$$

Here $dX_1 = X_1 - X_0$ and $Y^{\$}_{F,1} = C_{HF,1} + C^{o}_{HF,1}$ are dollar revenues from European exports. Consider the terms on the right hand side. A rise in desired dollar money balances raises demand for dollars. Dollar revenues from exports reduce demand for dollars. Dollar invoiced imports $C_{FH,1}$ raise demand for dollars. Synthetic dollar borrowing in period 1 lowers demand for dollars, while period 1 payments of interest and principal on synthetic dollar borrowing in period 0 raises demand for dollars. Finally, the dollar loan $D^{\$}_{swap,1}$ from the ECB reduces demand for dollars. We assume that $D^{\$}_{swap,0} = 0$.

US CIP arbitrageurs do not enter the spot market. The US UIP arbitrageurs receive $(1 + i^{€}_0)B^{€}_{UIP,0}$ euros from their time 0 euro position and buy $B^{€}_{UIP,1}$ new euro bonds. In the spot market they will then sell $(1 + i^{€}_0)B^{€}_{UIP,0} - B^{€}_{UIP,1}$ euros and therefore buy

$$Q^{\$,spot}_{UIP,1} = -S_1 dB^{€}_{UIP,1} + S_1 i^{€}_0 B^{€}_{UIP,0} \tag{23}$$

dollars. We assume that noise traders do not have a time zero position. Analogous to the UIP arbitrageurs, we then have

$$Q^{\$,spot}_{noise,1} = -S_1 B^{€}_{noise,1} \tag{24}$$

Substituting these dollar spot market purchases in (21), we obtain the following expression for the spot market equilibrium (see Online Appendix for details):

$$dM^{\$}_{F,1} + CA^{\$}_{H,1} - dD^{\$}_{F,1} - D^{\$}_{swap,1} - S_1 dB^{€}_{UIP,1} - S_1 B^{€}_{noise,1} = 0 \tag{25}$$

where $CA^{\$}_{H,1}$ is the US current account. Substituting the swap market equilibrium $D^{\$}_{F,1} = B^{\$}_{CIP,1}$, this can also be written as the familiar identity that the US current account is equal to net capital outflows (see Online Appendix).

2.7 Pre-Shock Equilibrium

Before introducing period 1 shocks, we solve the pre-shock equilibrium. Given any set of model parameters, including the values of period 0 variables that we take as given, we can solve for the period 1 equilibrium. However, we limit ourselves to parameters that generate a sort of pre-shock steady state, with the following features: (1) equilibrium period 1 variables are equal to period 0 variables, (2) consumption is smoothed in that period 1 consumption of households is equal to period 2 consumption when the period 2 shock ϵ_q is zero. We normalize $s_0 = 0$, so that s_1 is zero as well in the pre-shock equilibrium. Appendix B discusses how the pre-shock equilibrium is computed.

We assume $n_t = 0$ and $D^{\$}_{swap,t} = 0$ for $t = 0, 1$ in the pre-shock equilibrium. To simplify notation, we assume that arbitrage capacity of all agents is proportional to Γ. Specifically, we assume that in the pre-shock equilibrium $\Gamma_{UIP} = \Gamma_F = \Gamma$ and $\Gamma_{CIP} = \phi\Gamma$. The parameter ϕ goes to zero under perfect CIP arbitrage. The parameter Γ then broadly relates to the ability of all agents to absorb either risky positions (Foreign households and UIP arbitrageurs) or safe positions (CIP arbitrageurs).

Denote variables in the pre-shock equilibrium with a bar on top. The CIP deviation is $\overline{cip} = \bar{i}^{\$,syn} - \bar{i}^{\$}$. The UIP deviation is the expected excess return of dollars over euros. Since the expected change in the exchange rate is zero, it is equal to the dollar minus euro interest rate: $\bar{i}^d = \bar{i}^{\$} - \bar{i}^{€}$. Since this interest differential is controlled by central banks, we take it as exogenous.

Omitting period 0 and 1 time subscripts, the synthetic dollar borrowing by European households in the pre-shock equilibrium is

$$\bar{D}^{\$}_F = \rho + \bar{M}^{\$}_F - \frac{\overline{cip} + \bar{i}^d}{\Gamma} \tag{26}$$

The position of CIP arbitrageurs is $\bar{B}^{\$}_{CIP} = \overline{cip}/[\phi\Gamma]$. Imposing the swap market equilibrium, we then have

$$\overline{cip} = \frac{\phi}{1+\phi}\left[\Gamma\left(\rho + \bar{M}^{\$}_F\right) - \bar{i}^d\right] \tag{27}$$

First note that the CIP deviation goes to zero when $\phi \to 0$, which is the case of perfect CIP arbitrage. Assuming imperfect CIP arbitrage ($\phi > 0$), we see that there is a positive CIP deviation due to hedging of liquid dollar assets by European households as well as hedging of dollar exposure through non-asset income. Both lead European households to borrow dollars synthetically, which raises the CIP deviation. A higher value of ϕ represents a higher Γ_{CIP}, which implies lower arbitrage capacity of CIP arbitrageurs, leading to a higher CIP deviation.

Finally, the CIP deviation is lower when the dollar interest rate is higher than the euro interest rate. For a given CIP deviation a higher dollar interest rate also implies a higher synthetic dollar interest rate. This reduces synthetic dollar borrowing by European households, which lowers the equilibrium synthetic dollar interest rate and therefore CIP deviation.

Substituting (27) into (26), we have

$$\bar{D}_F^{\$} = \frac{1}{1+\phi}\left(\rho + \bar{M}_F^{\$} - \frac{\bar{i}^d}{\Gamma}\right) \tag{28}$$

European households have a dollar exposure of $\rho + \bar{M}_F^{\$}$. (28) tells us to what extent they choose to hedge this dollar exposure through synthetic dollar borrowing. When $\bar{i}^d = 0$, the hedge ratio is $1/(1+\phi)$. Imperfect CIP arbitrage ($\phi > 0$) leads to a positive CIP deviation, which makes hedging more expensive and therefore leads to a partial hedge ratio in equilibrium. Furthermore, a positive $\bar{i}^d$ further reduces the hedge ratio as for a given CIP deviation it further raises the cost of borrowing dollars.

3 Analysis of Response to Shocks

We now discuss how the exchange rate and CIP deviation are affected by a variety of shocks under imperfect CIP arbitrage. We start with a graphical presentation of the linearized spot and swap market equilibrium schedules. After that we examine the case of perfect CIP arbitrage, the standard case analyzed in the literature. The remainder of the section considers imperfect CIP arbitrage. We start with several shocks that only affect the swap market. These are financial shocks that under perfect CIP arbitrage would have no effect on the exchange rate. Next we consider shocks that only affect the spot market. We show that the exchange rate impact of these shocks is amplified with imperfect CIP arbitrage. We finally analyze monetary policy shocks and several hedge shocks that affect both the spot and swap market equilibria.

3.1 Linearized Spot and Swap Market Schedules

Appendix C derives linearized spot and swap market equilibrium schedules. We have

$$\nu_1 s_1 + cip_1 = shock_1^{spot} \tag{29}$$
$$\nu_2 s_1 + \frac{1+\phi}{\phi} cip_1 = shock_1^{swap} \tag{30}$$

where $shock_1^{spot}$ and $shock_1^{swap}$ are various shocks discussed below and the parameters ν_1 and ν_2 are

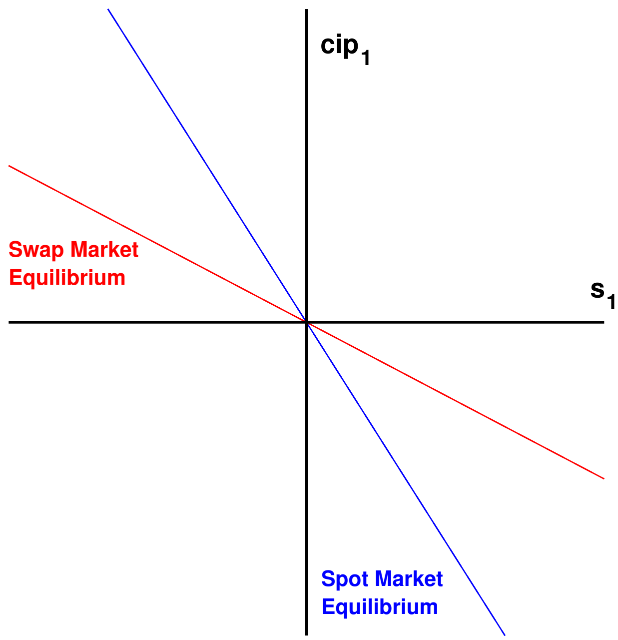
$$\nu_1 = \omega(1-\omega)\theta\bar{C}_{F,1}\Gamma + 2$$
$$\nu_2 = 1 - \psi(1-\omega)\omega\theta\bar{C}_{F,1}\Gamma$$

Here the CIP deviation $cip_1 = i_1^{\$,syn} - i_1^{\$}$ is in deviation from its pre-shock level. The two schedules are represented in Figure 1. First consider the spot market schedule. Since $\nu_1 > 0$, it is clearly negatively sloped. A higher synthetic dollar rate (raising cip_1) makes it more expensive for European households to borrow dollars synthetically to hedge their dollar exposure. They will instead buy the dollars they need on the spot market, implying a dollar appreciation (drop in s_1).

The swap market schedule is also drawn as negatively sloped in Figure 1. The parameter ν_2 can be positive or negative. In practice it is almost certainly positive, so that the swap market schedule is negatively sloped, though less negative than the spot market schedule. To see this, again consider a rise in the synthetic dollar rate (raising cip_1). This reduces synthetic dollar borrowing by European households and raises synthetic dollar lending by CIP arbitrageurs. To re-establish equilibrium, we need to raise synthetic dollar borrowing. This occurs when the dollar appreciates (s_1 falls), which implies an expected dollar depreciation. This makes borrowing synthetic dollars cheaper for European households.

The only counterpoint to this, which could make the swap market schedule positively sloped, operates through a trade channel and is likely to be weaker. A depreciation of the dollar (rise in s_1) lowers the relative price of US goods, which raises imports from the US, which raises demand for dollar money balances, which in turn raises borrowing of synthetic dollars as a hedge. Note that this channel would not even come into play in alternative theories, such as Coppola et al. (2024), where the demand for liquid dollar assets is unrelated to trade. While we focus on the case where the swap market schedule is negatively sloped in graphical illustrations, the direction in which the exchange rate changes does not depend on the sign of ν_2 for any of the 8 shocks that we analyze. The direction in which the CIP deviation changes depends on ν_2 only for two shocks that shift the spot market schedule.

Figure 1: Spot and Swap Market Equilibrium Schedules



We have

$$shock_1^{spot} = \Gamma\hat{\rho} - 2\hat{i}_1^d - \Gamma\hat{n}_1 + \left(\overline{cip} + \bar{i}^d\right)\frac{\hat{\Gamma}_F}{\Gamma_F} + \bar{i}^d\frac{\hat{\Gamma}_{UIP}}{\Gamma_{UIP}} \tag{31}$$

$$shock_1^{swap} = \Gamma\hat{\rho} - \hat{i}_1^d + \Gamma\omega\bar{C}_{F,1}\hat{\psi} + \left(\overline{cip} + \bar{i}^d\right)\frac{\hat{\Gamma}_F}{\Gamma_F} + \frac{\overline{cip}}{\phi}\frac{\hat{\Gamma}_{CIP}}{\Gamma_{CIP}} - \Gamma\hat{D}_{swap,1}^{\$} \tag{32}$$

where a hat denotes the deviation of a parameter from its pre-shock level. The interest rate differential $i_1^d = i_1^\$ - i_1^€$ is determined by monetary policy.

Two shocks only affect the spot market schedule, the noise trader shock $\hat{n}_1$ and the shock $\hat{\Gamma}_{UIP}$ to arbitrage capacity of UIP arbitrageurs. Three shocks only affect the swap market schedule: the liquidity preference shock $\hat{\psi}$, the shock $\hat{\Gamma}_{CIP}$ to the arbitrage capacity of CIP arbitrageurs and the shock $\hat{D}^{\$}_{swap,1}$ to central bank swap lines. The other three shocks affect both schedules. These are the the monetary policy shock $\hat{i}^d_1$ and the shocks $\hat{\rho}$ and $\hat{\Gamma}_F$ that affect currency hedging by the European households. Appendix C provides analytical expressions of the change in the exchange rate and CIP deviation in response to each of these shocks.

3.2 Perfect CIP Arbitrage

It is useful to first consider the case of perfect CIP arbitrage as this is the standard assumption in the literature on exchange rate determination. In this case $\phi \to 0$ and the CIP deviation is zero, both in the pre-shock equilibrium and after any of the shocks. We can then set $i_1^{\$,syn} = i_1^{\$}$. The spot market equilibrium is given by a standard interest parity condition with a deviation from UIP equal to a risk premium needed for UIP arbitrageurs and European households to absorb financial shocks and net trade flows. In deviation from pre-shock values of variables, we have

$$E_1\left(i_1^{€} + s_2 - s_1 - i_1^{\$}\right) = \frac{\Gamma}{2}\left(\hat{n}_1 + \widehat{TA}^{\$}_{H,1} - \hat{\rho}\right) - \frac{\bar{i}^d}{2}\hat{\tau} \tag{33}$$

Here $\hat{\tau} = [\hat{\Gamma}_{UIP}/\Gamma_{UIP}] + [\hat{\Gamma}_F/\Gamma_F]$ captures changes in arbitrage capacity of UIP arbitrageurs and European households. The US trade account $\widehat{TA}^{\$}_{H,1}$ is equal to $\omega(1-\omega)\theta\bar{C}_{F,1}s_1$.

Using that $E_1 s_2 = 0$, the period 1 exchange rate solves as

$$s_1 = \frac{1}{\nu_1}\left(\Gamma(\hat{\rho} - \hat{n}_1) - 2\hat{i}^d_1 + \bar{i}^d\,\hat{\tau}\right) \tag{34}$$

The consensus in the literature is that financial shocks are the main driver of exchange rates (e.g., GM, IM and Koijen and Yogo (2024)). Here these can be the noise trader shocks, which are standing in for a broader range of financial shocks, as well as the shocks to arbitrage capacity and hedge shocks. We also see that a relative US monetary policy contraction (rise in $\hat{i}^d_1$) leads to a dollar appreciation. We have not explicitly included a trade shock, but it is clear from (33) that a shock that raises the US trade account (e.g., a reallocation towards

US goods) also appreciates the dollar.

It is also useful to point out that changes in the exchange rate feed back to the real economy based on standard expenditure switching effects. Specifically, for US output we have

$$\hat{Y}_{H,1} = \omega(1-\omega)\theta\bar{C}_{F,1}s_1 \tag{35}$$

A depreciation of the dollar reduces the relative price of US goods from the perspective of European households, which raises demand of US goods and therefore US output.

We will now consider how the exchange rate behaves differently when there is imperfect CIP arbitrage. In that case the exchange rate is also affected by shocks to the swap market schedule, which play no role under perfect CIP arbitrage. In addition, imperfect CIP arbitrage amplifies the exchange rate impact of shocks to the spot market schedule.

3.3 Shocks to the Swap Market

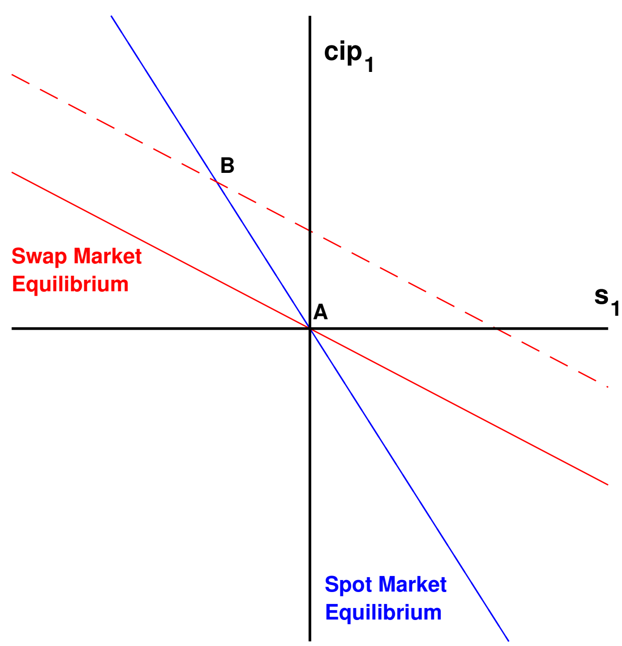
Shocks to the swap market schedule are a "new" set of financial shocks in the sense that in contrast to the financial shocks just discussed, they have no effect on the exchange rate under perfect CIP arbitrage. There are three shocks in the model that only affect the swap market schedule. The first shock is an increase in ψ, which we refer to as a liquidity preference shock as there is an increased demand for liquid assets. The second is a rise in Γ_{CIP}. It represents reduced arbitrage capacity for CIP arbitrageurs. Finally, an increase in $D^{\$}_{swap,1}$ represents increased central bank swap lines.

A rise in ψ represents an increased demand for liquidity generally, including both dollar and euro liquid assets. Since only liquid dollar assets are held across borders in the model, there is a cross-border dash for dollar liquidity that is analogous to convenience yield shocks. But an increased demand for dollar liquidity has a different effect from standard convenience yield shocks analyzed in the literature, which operate through a UIP shock to the interest rate parity equation (33), like the shock $\hat{n}_1$. The difference is that European households hedge the increased exposure to liquid dollar assets in the swap market. It can be seen from (16) that for a given exchange rate and CIP deviation, an increase in liquid dollar assets is completely hedged. European households obtain the dollars needed to buy the liquid dollar assets by borrowing dollars synthetically, so that they have no need to buy dollars on the spot market. The spot market schedule therefore remains unaffected.

While an increase in ψ affects the demand side of the synthetic dollar market (and therefore the swap market) by raising synthetic dollar borrowing, an increase in Γ_{CIP} affects the supply side by reducing synthetic dollar lending by CIP arbitrageurs. Both shocks lead to dollar shortages. In terms of the diagram, they both shift the swap market schedule upward. This is illustrated in Figure 2. It leads to an appreciation of the dollar and increased CIP deviation. The increase in the CIP deviation is natural as a result of the excess demand for synthetic dollar funding that raises the synthetic dollar rate.

The higher synthetic dollar rate leads to a dollar appreciation. It reduces synthetic dollar borrowing, which lowers dollar balances of European households. But European households still need dollars for various reasons, such as repaying their synthetic dollar debt from the previous period. They buy more dollars directly on the spot market, giving rise to a dollar appreciation.

Figure 2: Rise in ψ or Γ_{CIP}



An increase in central bank swap lines does the exact opposite. The ECB lends the dollars that it obtains from the swap line to European households. This reduces dollar shortages.

European households reduce their synthetic dollar borrowing, which shifts the swap market schedule downward. This depreciates the dollar and reduces the CIP deviation.

Under perfect CIP arbitrage, the swap market schedule does not shift and therefore nothing happens to the exchange rate. CIP arbitrageurs simply absorb the flows from the shocks to ψ and central bank swap lines at an unchanged zero CIP deviation.

These results are consistent with a variety of empirical evidence. The first relates to the literature on central bank swap lines that were established during and after the GFC. As discussed in the introduction, a large number of papers have established that these swap lines reduce CIP deviations. Moreover, Kekre and Lenel (2024b) show that swap line announcements over the 2007-2010 and 2020-2021 periods led to a dollar depreciation in addition to a lower CIP deviation. This is consistent with the theory.

The findings are also related to micro structure evidence about liquidity in spot and swap markets. Consider the shock to ψ as an illustration of a flow into the swap market. Appendix C shows that

$$s_1 = -\frac{\phi\Gamma\omega\bar{C}_{F,1}}{\nu_1 + \phi(\nu_1 - \nu_2)}\hat{\psi} \tag{36}$$

$$cip_1 = \frac{\phi\Gamma\nu_1\omega\bar{C}_{F,1}}{\nu_1 + \phi(\nu_1 - \nu_2)}\hat{\psi} \tag{37}$$

Kloks et al. (2023) develop a price impact measure that captures the impact on the CIP deviation of a flow into the swap market. They show that there is less liquidity (price impact is larger) around quarter-end reporting points when regulatory constraints become binding (see Du et al. (2018)). In our model this corresponds to a higher value of ϕ, which reduces the arbitrage capacity of CIP arbitrageurs. From (37) a higher value of ϕ raises the impact of a shock to ψ on the CIP deviation. The same is the case for the other shocks to the swap market.

For all three swap market shocks we consider here, a higher value of ϕ also raises the impact of the shock on the exchange rate. This is illustrated in (36) for the shock to ψ. This is consistent with Krohn and Sushko (2022). They measure spot market liquidity as bid-asked spreads, which is closely related to the price impact of flows on the exchange rate. They find that spot market liquidity is lower (price impact is higher) when CIP deviations are higher. In our model this is the case when ϕ is higher.

A bit more indirectly, other evidence that is consistent with the swap market shocks considered here relates to periods of financial stress. Lilley et al. (2022) report that post-2007 the dollar appreciates during periods of financial stress, as captured by various measures of risk and risk aversion. This is not the case pre-2007. We document the same in BDvW, where we also show that post-2007 the CIP deviation rises when measures of risk or risk-aversion increase.

This is exactly what happens in the model when there is a rise in ψ or Γ_{CIP}. They lead to a dollar appreciation and a rise in the CIP deviation when $\phi > 0$ (post-2007), while leaving both unchanged when $\phi = 0$ (perfect CIP arbitrage pre-2007). Both a drop in arbitrage capacity and a flight to liquidity are naturally related to periods of increased financial stress.[17]

3.4 Shocks to the Spot Market

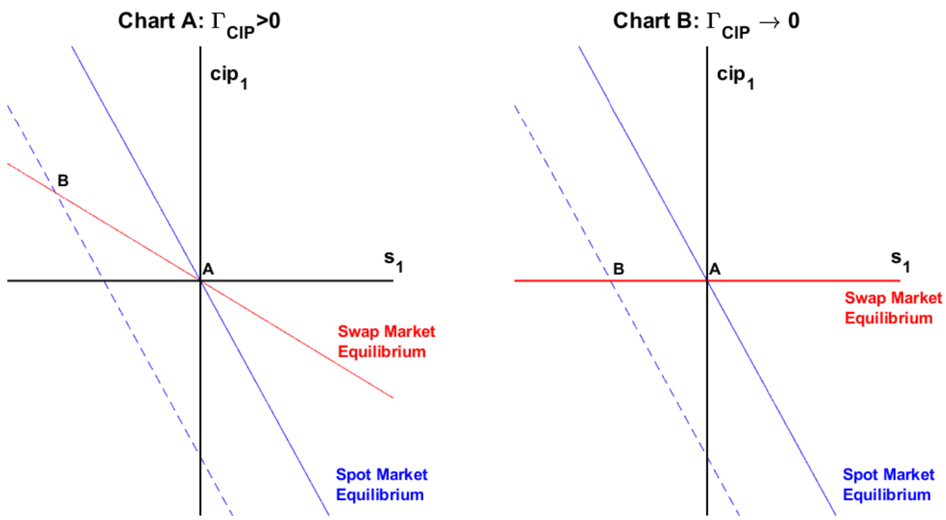
Two shocks only affect the spot market schedule: the noise trader shock $\hat{n}_1$ and the shock $\hat{\Gamma}_{UIP}$ to arbitrage capacity of UIP arbitrageurs. We can also think of these as UIP shocks as they lead to shifts to the interest parity equation (33). An increase in n_1 implies a portfolio shift towards dollar assets. The same is the case with a decrease in Γ_{UIP} when we start from a positive $\bar{i}^d$, so that in the pre-shock equilibrium there is a higher dollar interest rate and a positive expected excess return on dollars. Increased arbitrage capacity (reduced Γ_{UIP}) implies a larger flow towards dollars by UIP arbitrageurs in response to the positive expected excess return on dollars.

The impact of a rise in n_1 or drop in Γ_{UIP} is shown in Figure 3. Chart A shows the impact under imperfect CIP arbitrage ($\phi > 0$). For comparison, Chart B illustrates the impact under perfect CIP arbitrage ($\phi \to 0$). The latter corresponds to the solution in (34).

In both cases the dollar appreciates, but under imperfect CIP arbitrage it appreciates more and the CIP deviation rises. The dollar appreciation implies an expected dollar depreciation, making it more attractive for European households to hedge their dollar exposure

[17] Bianchi et al. (2021) refer to a flight to liquidity as "scrambling for dollars" during times of increased funding risk, where they have in mind both Treasury bills and reserves of banks at the Fed. In other contexts it refers to an increased demand for assets that are easily convertible into money. This is the case in Longstaff (2004) and Vayanos (2004), who both refer to it as a "flight to liquidity" in uncertain times. While these papers consider investors and banks, we also see an increased demand for cash by firms during increased uncertainty. See for example Li (2019).

Figure 3: Spot Market Shift to Dollars: rise n_1 or drop Γ_{UIP}



by borrowing dollars synthetically. This raises the CIP deviation. This in turn feeds back to the spot market through the same mechanism discussed before. A higher CIP deviation lowers synthetic dollar borrowing by European households, leading them to buy more dollars in the spot market, causing an additional dollar appreciation.[18]

The noise trader shock can be related to any type of financial shock that represents a portfolio shift from euro to dollar assets. This includes convenience yield shocks that are widely studied in the literature. This is different from a convenience yield shock associated with a rise in ψ. While both a rise in n_1 and a rise in ψ lead to a portfolio shift towards dollar assets, the difference is that this exposure is hedged under ψ shocks. As a result, it then affects the swap market rather than the spot market. Nonetheless in both cases we see that it leads to a dollar appreciation and increased CIP deviation. Moreover, in both cases the dollar appreciation is larger under imperfect CIP arbitrage. In the case of shocks to ψ,

[18]It should be noted that when $v_2 < 0$, so that the swap schedule is upward sloping, the direction in which the CIP deviation changes is reversed and the dollar appreciates less than under perfect CIP arbitrage. However, we have already argued that this empirically less plausible.

there is no effect on the exchange rate at all under perfect CIP arbitrage.

This larger dollar appreciation during times of imperfect CIP arbitrage is consistent with evidence reported in Engel and Wu (2023) and Jiang et al. (2021). Both find a larger dollar appreciation after 2007 than before 2007 in response to convenience yield shocks.[19] More generally, the amplified exchange rate effect when CIP arbitrage is limited is consistent with evidence in Krohn and Sushko (2022) discussed earlier.

We have discussed both shocks to intermediary capacity of UIP arbitrageurs ($\hat{\Gamma}_{UIP}$) and CIP arbitrageurs ($\hat{\Gamma}_{CIP}$). It is useful to briefly compare them. Focusing on shocks to intermediary capacity, the exchange rate is

$$s_1 = \frac{1}{\nu_1 + \phi(\nu_1 - \nu_2)} \left((1+\phi)\bar{i}^d \frac{\hat{\Gamma}_{UIP}}{\Gamma_{UIP}} - \overline{cip}\frac{\hat{\Gamma}_{CIP}}{\Gamma_{CIP}} \right) \tag{38}$$

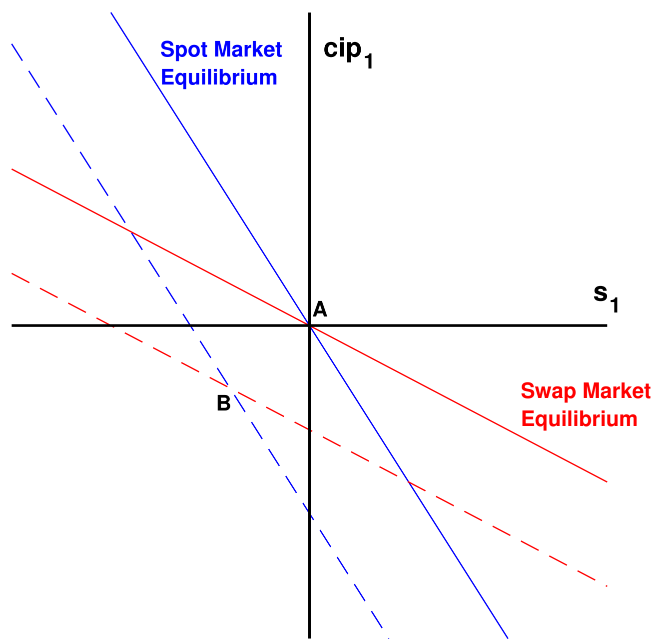
Consider a drop in intermediary capacity, either a rise in Γ_{UIP} or a rise in Γ_{CIP}. A rise in Γ_{UIP} leads to a dollar depreciation when UIP arbitrageurs are lending to the US ($\bar{i}^d > 0$), while it leads to a dollar appreciation when the UIP arbitrageurs are borrowing from the US ($\bar{i}^d < 0$). By contrast, a rise in Γ_{CIP} always leads to a dollar appreciation, assuming the currently observed positive CIP deviation. An increase in Γ_{CIP} reduces the supply of dollars to the synthetic dollar market, which raises the cost of synthetic dollar borrowing and leads to increased demand for dollars in the spot market. By contrast, an increase in Γ_{UIP} when $\bar{i}^d > 0$ reduces lending by UIP arbitrageurs to the US, which reduces demand for dollars in the spot market.

3.5 Monetary Policy Shocks

The remaining shocks we analyze affect both the spot and swap market schedules under imperfect CIP arbitrage. The first are monetary policy shocks. We consider a relative monetary policy contraction in the United States, which takes the form of a rise in the relative US interest rate i_1^d. This shifts down both the spot and swap market schedules, as illustrated in Figure 4. It leads to a dollar appreciation and a drop in the CIP deviation. Assuming $\nu_2 > 0$, the dollar appreciation is smaller than under perfect CIP arbitrage.

[19] See Table 4 in Engel and Wu (2023) and Table 3 in Jiang et al. (2021).

Figure 4: Monetary Policy Shock



Holding the CIP deviation $cip_1 = i_1^{\$,syn} - i_1^{\$}$ constant, a higher dollar interest rate on dollar bonds also implies a higher synthetic dollar interest rate. This raises synthetic dollar lending by CIP arbitrageurs and reduces synthetic dollar borrowing by European households. The synthetic dollar interest rate will then fall, leading to a lower CIP deviation. In the spot market the US monetary policy contraction naturally appreciates the dollar as it leads to a portfolio shift towards synthetic and non-synthetic dollar assets by European households and UIP arbitrageurs. But the reduced CIP deviation implies that the synthetic dollar interest rate rises less than the policy rate, which somewhat reduces the dollar appreciation.

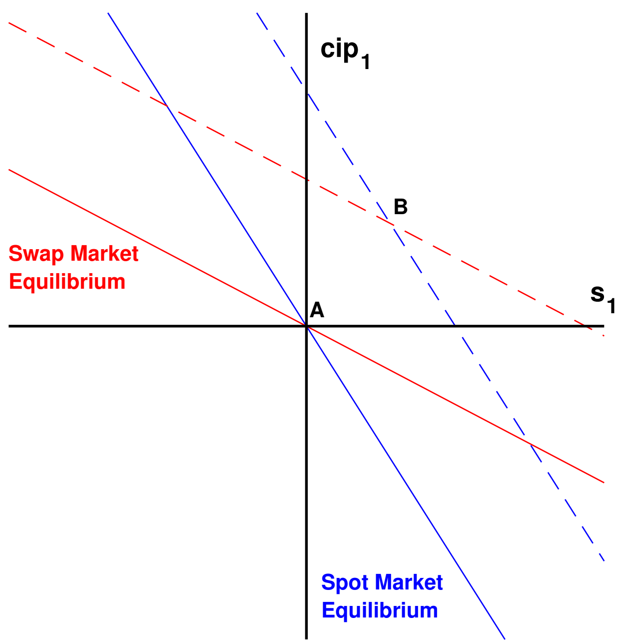
Cerutti et al. (2021) find evidence that post-2007 a rise in the dollar interest rate indeed lowers the CIP deviation. This is consistent with the effect of US monetary policy on the swap market.

3.6 Currency Hedge Shocks

A rise in ρ and Γ_F have similar effects. Both lead to an increased hedge of dollar exposure by European households. In the case of a rise in ρ this is the result of increased dollar exposure through non-asset income. An increase in Γ_F can be a result of higher risk aversion or higher exchange rate uncertainty. Assuming that European households partially hedge their dollar exposure in the pre-shock equilibrium, they wish to hedge their dollar exposure to a greater extent when Γ_F rises.

An increased hedge of dollar exposure affects both the spot and swap markets. It affects the swap market because it leads to increased synthetic dollar borrowing. It affects the spot market because it leads to reduced unhedged liquid dollar balances. These shocks shift up both the spot market and swap market schedules, as illustrated in Figure 5. As confirmed in Appendix C algebraically, the dollar depreciates and the CIP deviation rises.

Figure 5: Hedging shock



The rise in the CIP deviation is a result of increased synthetic dollar borrowing. At the same time, the increased synthetic dollar borrowing reduces the need to buy dollars on the spot market. This leads to a dollar depreciation.

These results are consistent with Liao and Zhang (2020). They present a model where investors increase currency hedging when exchange rate volatility rises and examine the impact on the exchange rate and the CIP deviation. In their model and empirical analysis the exchange rate and cross-currency basis are relative to individual foreign countries. When a country has a positive net dollar position, as is the case for Europe in our model, their analysis confirms our findings above.[20]

4 Conclusion

We have extended theories of exchange rate determination based on limited UIP arbitrage to also encompass limited CIP arbitrage. This leads the FX swap market to play a central role. The FX swap market is the largest segment of the foreign exchange market. It is even more dollar dominated than the spot market. The swap market is extensively used to hedge exposure to US dollar assets, as well as for synthetic dollar borrowing by companies and financial institutions that do not have access to the US money market. Non-US banks have massive off-balance sheet FX swap positions (e.g., Borio et al., 2022).

The theory we developed shows that under limited CIP arbitrage the dollar exchange rate and CIP deviation are jointly determined by equilibrium in FX spot and swap markets. We have shown that this has two important implications. First, shocks to the FX swap market affect the exchange rate, while they would have no effect under perfect CIP arbitrage. Second, more familiar shocks impacting the FX spot market have an amplified effect on the exchange rate. Both results occur because of the two-way feedback between the FX spot and swap markets. We have discussed a wide range of empirical support for the theory.

The role of the swap market is particularly important during times where the financial system is under increased stress. This often leads to dollar shortages outside the US, leading to a higher cost of synthetic dollar borrowing and increased demand for dollars in the spot market. The model has given several examples of shocks operating through the swap market

[20] They also consider the case where a country has a negative net dollar position (a net borrower of dollars). In that case the increased hedging has the opposite effect (lower CIP deviation and dollar appreciation). They provide evidence for the G-10 currencies over the period 1990-2017 that is consistent with these results.

related to financial stress, such as increased demand for liquidity and reduced arbitrage capacity of financial institutions. One extension would be to model non-US banks in greater detail. Non-US banks that are net long in dollars balance out their dollar exposure through synthetic dollar borrowing. Their balance sheets may be significantly affected during periods of dollar shortages.

Another extension of the model is to consider a multi-country framework with multiple currencies relative to the dollar. There is heterogeneity across countries in financial frictions, net dollar exposure, hedging of dollar assets and access to the US money market. This leads to both heterogeneity in pre-shock CIP deviations and the response of the exchange rate and CIP deviation to various shocks. Emerging markets may be affected more due to greater financial frictions and lower access to the US funding market.

Appendix

A Period 2 Goods Market Equilibrium

Country h households receive an endowment of $Q_{h,2}$ of the good of country h. The period 2 consumption index for households from country h is

$$C_{h,2} = \left((0.5)^{\frac{1}{\theta}} C_{hH,2}^{\frac{\theta-1}{\theta}} + (0.5)^{\frac{1}{\theta}} C_{hF,2}^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}} \tag{A.1}$$

Here $C_{hH,2}$ is consumption of the Home good by country h households and $C_{hF,2}$ is consumption of the Foreign good by country h households. The parameter θ is the elasticity of substitution among the two goods. Central banks target a price of $P_{H,2} = 1$ for the Home good in dollars and a price of $P_{F,2} = 1$ for the Foreign good in euros. The price index of consumption in dollars is then

$$P_2 = \left(0.5 + 0.5 S_2^{1-\theta}\right)^{\frac{1}{1-\theta}} \tag{A.2}$$

and the price index in euros is $P_2^* = P_2/S_2$. The standard intratemporal first-order conditions imply consumption of Home and Foreign goods of

$$C_{hH,2} = 0.5 \left(\frac{1}{P_2} \right)^{-\theta} C_{h,2} \tag{A.3}$$

$$C_{hF,2} = 0.5 \left(\frac{S_2}{P_2} \right)^{-\theta} C_{h,2} \tag{A.4}$$

for agents from both countries.

The "other" agents (CIP arbitrageurs, UIP arbitrageurs and noise traders) have the same consumption index. Using the expressions for the supply Q_H and Q_F of Home and Foreign goods, period 2 goods market clearing then implies

$$e^{\kappa_H \epsilon_q} = 0.5\left(\frac{1}{P_2}\right)^{-\theta}(C_{H,2} + C_{F,2} + C^o_{H,2}) \tag{A.5}$$

$$e^{-\kappa_F \epsilon_q} = 0.5\left(\frac{S_2}{P_2}\right)^{-\theta}(C_{H,2} + C_{F,2} + C^o_{H,2}) \tag{A.6}$$

Denote with a bar the levels of second period consumption when $s_2 = 0$, so that $S_2 = 1$. In that case $P_2 = 1$. Linearizing (A.5)-(A.6) around $\epsilon_q = s_2 = 0$, we get

$$1 + \kappa_H \epsilon_q = 0.5(C_{H,2} + C_{F,2} + C^o_{H,2}) + 0.25(\bar{C}_{H,2} + \bar{C}_{F,2} + \bar{C}^o_{H,2})\theta s_2$$
$$1 - \kappa_F \epsilon_q = 0.5(C_{H,2} + C_{F,2} + C^o_{H,2}) - 0.25(\bar{C}_{H,2} + \bar{C}_{F,2} + \bar{C}^o_{H,2})\theta s_2$$

First set $\epsilon_q = 0$. It follows immediately by first subtracting and then adding these equations that $s_2 = 0$ and

$$\bar{C}_{H,2} + \bar{C}_{F,2} + \bar{C}^o_{H,2} = 2 \tag{A.7}$$

Using this equation, taking the difference between the two market clearing conditions (using $\kappa_H + \kappa_F = 1$) gives $\epsilon_q = \theta s_2$ or $s_2 = \epsilon_q/\theta$.

B Pre-Shock Equilibrium

In the pre-shock equilibrium we assume that $D^{\$}_{swap,0} = D^{\$}_{swap,1} = 0$ and $n_1 = n_0 = 0$. Period 1 variables are equal to period 0 variables. For the exchange rate this implies $s_1 = s_0 = 0$. This also implies that $P_1 = P^*_1 = 1$. Consumption is smoothed in that period 1 consumption by households is equal to period 2 consumption when $s_2 = 0$. We denote pre-shock period 1 variables with a bar. They are equal to corresponding period 0 variables.

In the pre-shock equilibrium household wealth is the same in period 1 as in period 0. This implies that saving of Home and Foreign households is zero, so that

$$\bar{C}_{H,1} = \bar{Y}_{H,1} + \bar{\Pi}_{HCB,1} + i^{\$}_0 W_{H,0} \tag{B.1}$$

$$\bar{C}_{F,1} = \bar{Y}_{F,1} + \bar{\Pi}_{FCB,1} - i^{\$,syn}_0 D^{\$}_{F,0} + i^{€}_0 B^{€}_{F,0} \tag{B.2}$$

This sets period 1 consumption equal to income, which is the sum of income from production and interest income and transfers of central bank profits back to the households. Here $\bar{\Pi}_{HCB,1} = i_0^{\$} M_0^{\$}$ and $\bar{\Pi}_{FCB,1} = i_0^{€} M_0^{€}$. One of these equations is redundant as aggregate world saving is zero. We therefore remove the last equation.

In the pre-shock equilibrium we also have consumption smoothing: $\bar{C}_{h,1} = \bar{C}_{h,2}$. Substituting this into the period 2 budget constraints, we have

$$\bar{C}_{H,1} = 1 + \bar{\Pi}_{HCB,2} + \bar{M}_{H,1}^{\$} + (1 + \bar{i}_1^{\$})\bar{W}_{H,1} \tag{B.3}$$

$$\bar{C}_{F,1} = 1 + \bar{\Pi}_{FCB,2} + \bar{M}_{F,1}^{\$} + \bar{M}_{F,1}^{€} + (1 + \bar{i}_1^{€})\bar{W}_{F,1} - (\bar{i}_1^{\$,syn} - \bar{i}_1^{€})\bar{D}_{F,1}^{\$} \tag{B.4}$$

The last two equations needed to derive the pre-shock equilibrium are

$$\bar{C}_{H,1} + \bar{C}_{F,1} + \bar{C}_{H,1}^{o} = 2 \tag{B.5}$$

$$\bar{B}_{CIP,1}^{\$} = \bar{D}_{F,1}^{\$} \tag{B.6}$$

These correspond to the period 2 world goods market equilibrium (A.7), replacing $\bar{C}_{h,2} = \bar{C}_{h,1}$, and the period 1 swap market equilibrium. We then have a total of 5 equations: (B.1) and (B.3)-(B.6). This system can be solved by substituting expressions for money balances, portfolio holdings, central bank profits and period 1 production, setting $\bar{i}_1^{\$,syn} = i_0^{\$,syn}$, $s_1 = s_0 = 0$ and $\bar{W}_{h,1} = W_{h,0}$. We then have 5 equations in 5 variables: the 2 period 1 consumption levels, the 2 initial wealth levels $W_{h,0}$ and $\overline{cip}$. The interest differential $\bar{i}_1^d = i_0^d$ is exogenous.

As shown in the Online Appendix, after these substitutions, the 5 equations become

$$\omega\bar{C}_{H,1} = \omega\bar{C}_{F,1} + (1-\omega)\left[\frac{\overline{cip}^2}{\phi\Gamma} + \frac{\left(\bar{i}^d\right)^2}{\Gamma}\right] + \psi i_0^{\$}\left(\bar{C}_{H,1} + \omega\bar{C}_{F,1}\right) + i_0^{\$} W_{H,0} \tag{B.7}$$

$$(1-\psi)\bar{C}_{H,1} = 1 + \psi i_0^{\$}\left(\bar{C}_{H,1} + \omega\bar{C}_{F,1}\right) + (1 + i_0^{\$})W_{H,0} \tag{B.8}$$

$$(1-\psi)\bar{C}_{F,1} = 1 + \psi i_0^{€}(1-\omega)\bar{C}_{F,1} + (1 + i_0^{€})W_{F,0} - \frac{\overline{cip}(\overline{cip} + \bar{i}^d)}{\phi\Gamma} \tag{B.9}$$

$$\bar{C}_{H,1} + \bar{C}_{F,1} + \frac{\overline{cip}^2}{\phi\Gamma} + \frac{\left(\bar{i}^d\right)^2}{\Gamma} = 2 \tag{B.10}$$

$$\rho + \psi\omega\bar{C}_{F,1} - \frac{\overline{cip} + \bar{i}^d}{\Gamma} = \frac{\overline{cip}}{\phi\Gamma} \tag{B.11}$$

These can be used to solve for $\bar{C}_{H,1}$, $\bar{C}_{F,1}$, $W_{H,0}$, $W_{F,0}$ and the CIP deviation $\overline{cip}$ in the pre-shock equilibrium.

C Linearized Model

We first linearize the spot market equilibrium

$$dM^{\$}_{F,1} + CA^{\$}_{H,1} - dD^{\$}_{F,1} - dD^{\$}_{swap,1} - S_1 dB^{€}_{UIP,1} - S_1 dB^{€}_{noise,1} = 0 \tag{C.1}$$

In the Online Appendix we show that

$$CA^{\$}_{H,1} = TA^{\$}_{H,1} + i_0^{\$,syn} D^{\$}_{F,0} + S_1 i_0^{€} B^{€}_{UIP,0} \tag{C.2}$$

Changes relative to the pre-shock equilibrium will be denoted with a hat. A bar on top of a variable refers to its pre-shock level. We have

$$\hat{M}^{\$}_{F,1} = \omega \bar{C}_{F,1} \hat{\psi} + \psi(1-\omega)\omega\theta \bar{C}_{F,1} \hat{s}_1 \tag{C.3}$$

Next consider the current account. It is equal to the trade account plus two terms that capture net investment income. The first term is constant (only depends on time 0 variables). The second term depends on S_1. But we can replace S_1 with S_0 and then add $(S_1 - S_0) i_0^{€} B^{€}_{UIP,0}$. This is a third-order term, the product of the change in the exchange rate, euro interest rate and euro bond position by UIP arbitrageurs that itself depends on an expected excess return. So we ignore it (we only consider first-order terms). We then have $\widehat{CA}^{\$}_{H,1} = \widehat{TA}^{\$}_{H,1}$.

Regarding the trade account, we have $TA^{\$}_{H,1} = Y_{H,1} - C_{H,1} - C^{o}_{H,1}$. $C_{H,1}$ is held constant and $C^{o}_{H,1}$ is equal to the period 1 profits of Home UIP and CIP arbitrageurs based on period 0 interest rates and positions. Specifically

$$C^{o}_{H,1} = \left(i_0^{\$,syn} - i_0^{\$}\right) B^{\$}_{CIP,0} + (i_0^{€} - i_0^{\$} + s_1) B^{€}_{UIP,0} \tag{C.4}$$

Following IM, we abstract from the effect of s_1 on the consumption of UIP arbitrageurs as this effect is second-order. The last term is the product of an excess return and an expected excess return that determines the euro bond position of UIP arbitrageurs.

We therefore have $\widehat{TA}^{\$}_{H,1} = \hat{Y}_{H,1}$. Using

$$Y_{H,1} = C_{HH,1} + C_{FH,1} + C^{o}_{HH,1} = (1-\omega)\left(C_{H,1} + C^{o}_{H,1}\right) + \omega\left(S_1 P^*_1\right)^{\theta} C_{F,1} \tag{C.5}$$

and $\hat{p}^*_1 = -\omega\hat{s}_1$, it follows that

$$\widehat{TA}^{\$}_{H,1} = \hat{Y}_{H,1} = \omega(1-\omega)\theta\bar{C}_{F,1}\hat{s}_1 \tag{C.6}$$

Clearly therefore a dollar depreciation raises the US trade account.

We have

$$\hat{D}^{\$}_{F,1} = \hat{\rho} + \hat{M}^{\$}_{F,1} - \hat{D}^{\$}_{swap,1} - \frac{\hat{cip}_1 + \hat{i}^d_1 + \hat{s}_1}{\Gamma} + \frac{\overline{cip} + \bar{i}^d}{\Gamma}\frac{\hat{\Gamma}_F}{\Gamma_F} \tag{C.7}$$

where $\Gamma_F = \gamma\sigma^2$, which is equal to Γ in the pre-shock equilibrium. It follows that

$$\hat{M}^{\$}_{F,1} - \hat{D}^{\$}_{F,1} - \hat{D}^{\$}_{swap,1} = -\hat{\rho} + \frac{\hat{cip}_1 + \hat{i}^d_1 + \hat{s}_1}{\Gamma} - \frac{\overline{cip} + \bar{i}^d}{\Gamma}\frac{\hat{\Gamma}_F}{\Gamma_F} \tag{C.8}$$

Next consider UIP arbitrageurs. We can write

$$-S_1 dB^{€}_{UIP,1} = -S_0 dB^{€}_{UIP,1} - (S_1 - S_0)dB^{€}_{UIP,1}$$

We ignore the last term. It is second order as it is the product of the change in the exchange rate and the change in the euro position of UIP arbitrageurs. We have

$$-S_0 dB^{€}_{UIP,1} = -\hat{B}^{€}_{UIP,1} = \frac{\hat{i}^d_1 + \hat{s}_1}{\Gamma} - (\bar{i}^d/\Gamma)\frac{\hat{\Gamma}_{UIP}}{\Gamma_{UIP}} \tag{C.9}$$

Similarly, the term related to noise traders in (C.1) has a first-order component of

$$-\hat{B}^{€}_{noise,1} = \hat{n}_1 \tag{C.10}$$

Combining all terms, we can write the spot market equilibrium as

$$\nu_1\hat{s}_1 + \hat{cip}_1 = shock^{spot}_1 \tag{C.11}$$

where

$$shock_1^{spot} = \Gamma\hat{\rho} - 2\hat{i}_1^d - \Gamma\hat{n}_1 + \left(\overline{cip} + \bar{i}^d\right)\frac{\hat{\Gamma}_F}{\Gamma_F} + \bar{i}^d\frac{\hat{\Gamma}_{UIP}}{\Gamma_{UIP}} \tag{C.12}$$

and

$$\nu_1 = \omega(1-\omega)\theta\bar{C}_{F,1}\Gamma + 2 \tag{C.13}$$

Next consider the swap market equilibrium

$$B^{\$}_{CIP,1} = D^{\$}_{F,1} \tag{C.14}$$

We have

$$\hat{D}^{\$}_{F,1} = \hat{\rho} + \hat{M}^{\$}_{F,1} - \hat{D}^{\$}_{swap,1} - \frac{\hat{cip}_1 + \hat{i}_1^d + \hat{s}_1}{\Gamma} + \frac{\overline{cip} + \bar{i}^d}{\Gamma}\frac{\hat{\Gamma}_F}{\Gamma_F} \tag{C.15}$$

and

$$\hat{B}^{\$}_{CIP,1} = \frac{\hat{cip}_1}{\phi\Gamma} - \frac{\overline{cip}}{\phi\Gamma}\frac{\hat{\Gamma}_{CIP}}{\Gamma_{CIP}} \tag{C.16}$$

Therefore the swap market equilibrium becomes

$$\nu_2\hat{s}_1 + \frac{1+\phi}{\phi}\hat{cip}_1 = shock_1^{swap} \tag{C.17}$$

where

$$shock_1^{swap} = \Gamma\hat{\rho} - \hat{i}_1^d + \Gamma\omega\bar{C}_{F,1}\hat{\psi} + \left(\overline{cip} + \bar{i}^d\right)\frac{\hat{\Gamma}_F}{\Gamma_F} + \frac{\overline{cip}}{\phi}\frac{\hat{\Gamma}_{CIP}}{\Gamma_{CIP}} - \Gamma\hat{D}^{\$}_{swap,1} \tag{C.18}$$

and

$$\nu_2 = 1 - \psi(1-\omega)\omega\theta\bar{C}_{F,1}\Gamma \tag{C.19}$$

Algebraically, the effect of these shocks is as follows. For the shocks $\hat{\psi}$ and $\hat{D}^{\$}_{swap,1}$ we have

$$\hat{s}_1 = \frac{\phi\Gamma}{\nu_1 + \phi(\nu_1 - \nu_2)}\left(-\omega\bar{C}_{F,1}\hat{\psi} + \hat{D}^{\$}_{swap,1}\right) \tag{C.20}$$

$$\hat{cip}_1 = \frac{\nu_1\phi\Gamma}{\nu_1 + \phi(\nu_1 - \nu_2)}\left(\omega\bar{C}_{F,1}\hat{\psi} - \hat{D}^{\$}_{swap,1}\right) \tag{C.21}$$

For the shocks $\hat{\rho}$, $\hat{i}_1^d$ and $\hat{n}_1$we have

$$\hat{s}_1 = \frac{\Gamma\hat{\rho} - (2+\phi)\hat{i}_1^d - \Gamma(1+\phi)\hat{n}_1}{\nu_1 + \phi(\nu_1 - \nu_2)} \tag{C.22}$$

$$\hat{cip}_1 = \frac{\Gamma\phi(\nu_1 - \nu_2)\hat{\rho} + (2\nu_2 - \nu_1)\phi\hat{i}_1^d + \Gamma\nu_2\phi\hat{n}_1}{\nu_1 + \phi(\nu_1 - \nu_2)} \tag{C.23}$$

For the $\hat{\Gamma}_F$ shock we have

$$\hat{s}_1 = \frac{1}{\nu_1 + \phi(\nu_1 - \nu_2)}(\overline{cip} + \bar{i}^d)\frac{\hat{\Gamma}_F}{\Gamma_F} \tag{C.24}$$

$$\hat{cip}_1 = \frac{1}{\nu_1 + \phi(\nu_1 - \nu_2)}\phi(\nu_1 - \nu_2)(\overline{cip} + \bar{i}^d)\frac{\hat{\Gamma}_F}{\Gamma_F} \tag{C.25}$$

For the $\hat{\Gamma}_{UIP}$ and $\hat{\Gamma}_{CIP}$ shocks we have

$$\hat{s}_1 = \frac{1}{\nu_1 + \phi(\nu_1 - \nu_2)}\left((1+\phi)\bar{i}^d\frac{\hat{\Gamma}_{UIP}}{\Gamma_{UIP}} - \overline{cip}\frac{\hat{\Gamma}_{CIP}}{\Gamma_{CIP}}\right) \tag{C.26}$$

$$\hat{cip}_1 = \frac{1}{\nu_1 + \phi(\nu_1 - \nu_2)}\left(-\phi\nu_2\bar{i}^d\frac{\hat{\Gamma}_{UIP}}{\Gamma_{UIP}} + \nu_1\overline{cip}\frac{\hat{\Gamma}_{CIP}}{\Gamma_{CIP}}\right) \tag{C.27}$$

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