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Abstract

We explore the role of 'dollar shortage' shocks and central bank swap lines in a two-country New Keynesian model with financial frictions. Domestic banks issue both domestic and foreign currency debt and lend in domestic currency. Foreign currency-specific funding shocks, which are amplified via their effect on the exchange rate given balance sheet mismatches, lead to uncovered interest rate parity deviations, a contraction in lending and have a significant negative effect on macroeconomic variables. We show that central bank swap lines can attenuate these dynamics provided they are large enough.

Key words: Central bank swap lines, liquidity facilities, dollar shortages, uncovered interest rate parity condition, financial frictions.

JEL classification: E32, E44, E58, F33, F41, G15.

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1 Introduction

'Dollar shortage' shocks affecting non-US banking systems and policy responses in the form of central bank swap lines have been a recurrent feature in the three largest crises of the last decades. Perhaps surprisingly, research on these topics has focused almost exclusively on financial markets aspects, leaving the macroeconomic dimension largely unexplored. This gap is the more noticeable to the extent that swap line arrangements have by now become part of the permanent policy toolkit.

Originally set up during the Bretton Woods era as a tool to facilitate exchange rate intervention to defend currency pegs, a new version of central bank swap lines emerged as a response to a scarcity in US dollar funding for non-US banks and other financial institutions during the global financial crisis (Kennedy et al., 2011), with the Federal Reserve effectively resembling a global *dollar* lender of last resort. This happened after a period of structural change in the funding model of global banks, during which gross US dollar positions increased at a fast pace (McGuire and von Peter, 2012). The described sudden dollar scarcity was dubbed a 'dollar shortage' shock (McGuire and von Peter, 2009), borrowing the terminology from post-WWII discussions of the global economic landscape (Kindleberger, 1950). Since then, there has been evidence of recurrent US dollar shortages in the subsequent two major crises, namely the euro area crisis of 2010-2012 and the turmoil resulting from the Covid-19 pandemic of 2020. In the light of these developments, central bank swap lines have been proposed as a suitable tool for addressing sudden stop type episodes for banking systems (Reis, 2019), and are regarded as a central component of the global financial safety net (di Mauro and Zettelmeyer, 2017). In effect, they were at the forefront of the financial policy response to the Covid-19 pandemic (Bahaj and Reis, 2020).

This paper contributes to the understanding of the macro-financial consequences of 'dollar shortage' shocks, and the potential role for central bank swap lines in affecting these, by incorporating both features into a quantitative macroeconomic model. More specifically, we want to know whether and how 'dollar shortage' type shocks (that is, a sudden scarcity in US dollar funding for non-US financial institutions) can affect macroeconomic aggregates of non-US countries, and whether the existence of swap lines between the Federal Reserve and foreign central banks can help isolate these countries from potential adverse effects. Having a more developed understanding of the mechanisms at play and magnitudes involved in the interplay between 'dollar shortage' shocks and central bank swap lines seems crucial in the light of the events surrounding the last three major global crises.

In order to shed light on the questions posed above we develop a two-country New Keynesian model in which domestic banks fund their lending by borrowing both from residents in local currency and from non-residents in foreign currency, subject to differential financial frictions. The fact that all their lending is conducted in domestic currency leads to balance sheet mismatches. A shock to foreigners' willingness to lend in foreign currency to domestic banks (which can be interpreted as a 'dollar shortage' shock) leads to a contraction in lending, compounded with the effect on banks' net worth generated by the resulting exchange rate depreciation. This leads to a fall in investment, consumption and output, which is more marked under a monetary policy regime that favours nominal exchange rate stability. The presence of central bank swap lines allows the foreign central bank to lend foreign currency to the home central bank, which in turn channels those funds to the domestic banking system. We show that the use of this facility can attenuate the contraction in bank lending and therefore the negative impact of dollar shortage shocks on macroeconomic aggregates.

We calibrate the shock and policy response to match Korea's experience in the face of recent stress in global US dollar funding markets resulting from the Covid-19 pandemic, leveraging from the fact that Korea is an emerging market that has both suffered a sharp dollar shortage shock and has been granted access to a Federal Reserve dollar swap line.[1] We show that the impact of the shock on macro variables is significant from a quantitative perspective, and that the observed drawing from dollar swap lines is not enough to attenuate these dynamics on its own. However, an uptake in line with maxima set by the Federal Reserve would cushion a significant portion of the negative effect of the shock. The calibrated dollar shortage shock leads to a peak contraction in investment, consumption and output of 4%, 1% and 0.5%, respectively. In turn, the observed used of swap lines can attenuate this impact only marginally, but an uptake in line with the maximum set by the Federal Reserve would help cushion around 20% of the described hit to macro variables.

It is worth mentioning that this exercise does not constitute an explicit assessment of the policy conducted by the Bank of Korea, as the results described above are affected by the model's several simplifying assumptions (including on the price of swaps and the absence of signalling effects), and swap lines were certainly not the only tool tapped by authorities. In contrast, the objective is to sketch out the mechanisms through which central bank swap lines can attenuate the negative macro-financial consequences of dollar shortage shocks.

Our paper is related to two broad strands of the literature. On the one hand, it is directly related to papers studying central bank swap lines, most of which take an empirical approach. Beginning with Baba and Packer (2009), a series of papers have studied the effect of central

[1]Korea is classified as an emerging market by MSCI despite being classified as an advanced economy by the IMF. A clear-cut distinction is not central for the purposes of the model.

bank swap lines on asset prices, using event study methodologies. Baba and Packer (2009) and Moessner and Allen (2013) analyse the effect of Fed-ECB swap lines, Aizenman and Pasricha (2010) look at swap lines between the Fed and emerging market economies, and Andrieș et al. (2017) focus on Swiss National Bank (SNB) swap lines with eastern European economies. Bahaj and Reis (2018) rely on a better identified difference-in-difference specification to assess the effect of swap lines on covered interest rate parity (CIP) deviations, portfolio flows into US dollar assets, the price of US dollar corporate bonds and benefited banks' excess returns. In a follow-up article, they also assess the impact on funding costs of new swap line measures introduced as a response to tensions in US dollar markets arising from the Covid-19 pandemic (Bahaj and Reis, 2020). Despite differences across studies, the consensus seems to suggest that swap lines do indeed help ease strains in US dollar funding markets, as evidenced by a reduction in the level and volatility of CIP deviations.

On the theory side, the number of references is much more limited. Bahaj and Reis (2018) embed a model of the market for FX forwards into a small-scale, three-period general equilibrium model and find that central bank swap lines (i) reduce bank funding risk and (ii) increase the investment on US dollar assets of non-US investors. In contrast, our model embeds central bank swap-line agreements into a medium-scale infinite-horizon New Keynesian model and assesses their capacity to mitigate the consequence of 'dollar shortage' shocks for a wide range of both macroeconomic and financial variables.

Secondly, the methodology of our paper relates a series of recent papers which enrich canonical open-economy New Keynesian models with financial frictions and a bank currency portfolio problem (Akinci and Queraltó, 2019, Aoki et al., 2018). We draw our core modelling framework from these papers and depart along two dimensions. First, we allow the differential friction affecting foreign currency funding to vary over time, configuring a source of exogenous variation.[2] Second, we incorporate central bank swap lines into the picture, as a complementary tool to the interest rate-based monetary policy present in these models. Our modelling of swap lines in turn draws from the approach in Del Negro et al. (2017) for modelling Fed's (domestic) liquidity facilities during the global financial crisis.

The rest of the paper is organised as follows. Section 2 describes the basic workings of central bank swap lines and provides a snapshot of their use in the last two decades, with a special focus on the recent experience in Korea. Section 3 describes the basic features of our baseline model and its calibration, including the mechanisms surrounding central bank swap lines. In Section 4 we analyse the dynamics of the model in the face of a 'dollar shortage'

[2] In a sense, this provides a micro-foundation for the country premium shocks in Garcia-Cicco et al. (2010).

shock under various exchange rate arrangements and multiple scenarios for the use of swap lines. Section 5 concludes.

2 Central bank swap lines: key concepts and use

Given their less frequent use than conventional reference rate-based monetary policy, the main characteristics of central bank swap lines are typically less widely understood. In this Section we describe these basic features and provide some stylised facts on their use in the last few decades.

2.1 Swap line agreements

The basic features of central bank swap line agreements are common across most parties and currencies involved. For the sake of argument, let us consider a swap line between the Federal Reserve and a generic 'home' central bank, in which US dollars are swapped for 'domestic currency'. The focus on the Federal Reserve responds to the calibration of the model described in the next section, as well as to the dominant status of the US dollar as a global funding currency more generally.

At the core of the transaction there is an exchange in which the Fed gives the home central bank dollars, and in exchange it receives domestic currency at the spot exchange rate (which effectively acts as collateral). At the same time, both parties agree on reversing the operation after a certain period (typically between 1 and 90 days). Prices are fixed ex-ante, and the Fed typically charges an interest rate for the swap operation as a spread over overnight indexed swap (OIS) rates. Swap lines can be agreed on a fixed amount, or can be structured as a standing agreement, with or without limits, although each individual transaction typically requires explicit approval.

Once the home central bank receives the US dollars from the Fed, it typically lends them on to the domestic banking system, matching the maturity of this second loan with that of its swap with the Fed. This second leg of the operation happens independently of the swap between the Fed and the home central bank, but it still displays common characteristics across cases. The home central bank charges an interest rate to domestic banks, typically matching that incurred with the Fed, and requires collateral for the operation. This collateral tends to match that required for its other lending facilities.

Given that exchange rates and interest rates are all fixed at the time the swap is conducted, there is no exchange rate or interest rate risks involved in the contract. The Fed faces limited default risk as it effectively deals with a central bank which, even in the event of default by domestic commercial banks, might prefer to inflate the domestic economy by issuing the local currency needed to secure the dollars for repayment instead of defaulting, given the reputational risk attached.

In sum, the resulting situation mimics one in which the Fed lends dollars to the home economy banking system, but with the difference that the monitoring is conducted by the domestic central bank. Bahaj and Reis (2018) list a few reasons for the superiority of this latter arrangement, including home central bank's superior information on domestic commercial banks' solvency, the quality of the collateral posted, and the potential for ex-ante moral hazard. In practice, by supplying US dollars via swap line arrangements the Federal Reserve is effectively acting as an international lender of last resort, dealing directly with the banking system (differently than what an IMF credit line would do). In this regard, swap lines can be regarded as a 'bank sudden-stop' fighting tool (Reis, 2019).

In terms of the model outlined in Section 3, the key feature of central bank swap lines is that they represent an additional source of foreign currency for the domestic economy, which the domestic central bank channels on to the domestic banking system under collateral requirements that are similar to those of its other lending facilities and overall conditions typically more favourable than those banks would face in the market.

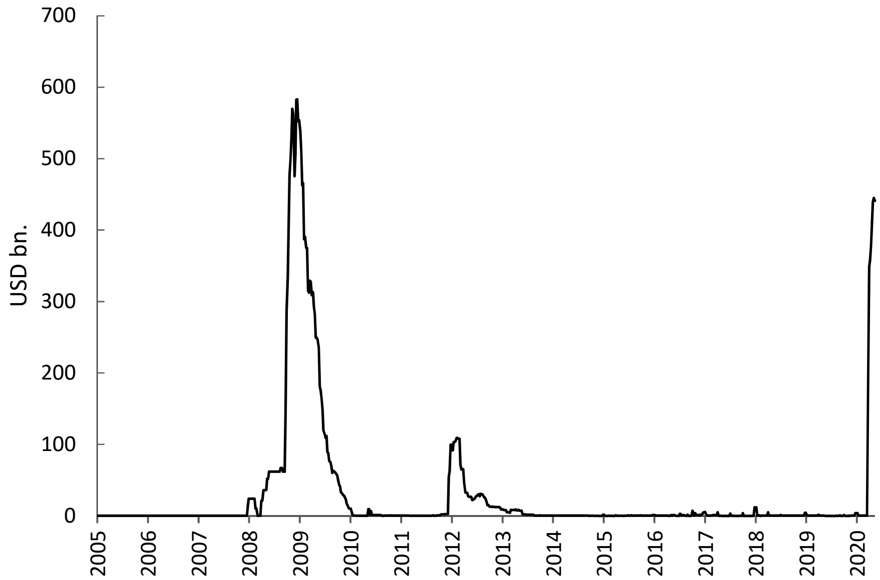
2.2 Observed use of swap lines

Central bank swap lines were first introduced by the US Federal Reserve vis-a-vis a set of advanced economies in the context of the Bretton Woods international monetary system, and mainly in order to facilitate counterparties' exchange rate interventions conducted to defend their respective currency pegs (Bordo et al., 2015).[3] The use of these swap lines was 'symmetric' in the sense that both the Federal Reserve and the foreign central banks actively tapped them at different times. These arrangements remained in place in the 1970s and 1980s after the abandonment of the currency pegs system, but their use became significantly less frequent on the back of less active foreign exchange intervention policies and an increase in the use of foreign exchange reserves for this purpose, before being formally phased out in the early 1990s.

After a brief and limited reemergence of Fed swap line arrangements with the ECB and Bank of England in the aftermath of the 9/11 terrorist attacks in the US, swap lines were

[3] McCauley and Schenk (2020) also emphasise their use to influence eurodollar market conditions (also mentioned in Bordo et al. (2015)), in a role more similar to their 'modern' counterpart.

Figure 1 Central Bank Liquidity Swaps held by the Federal Reserve



Source: FRED.

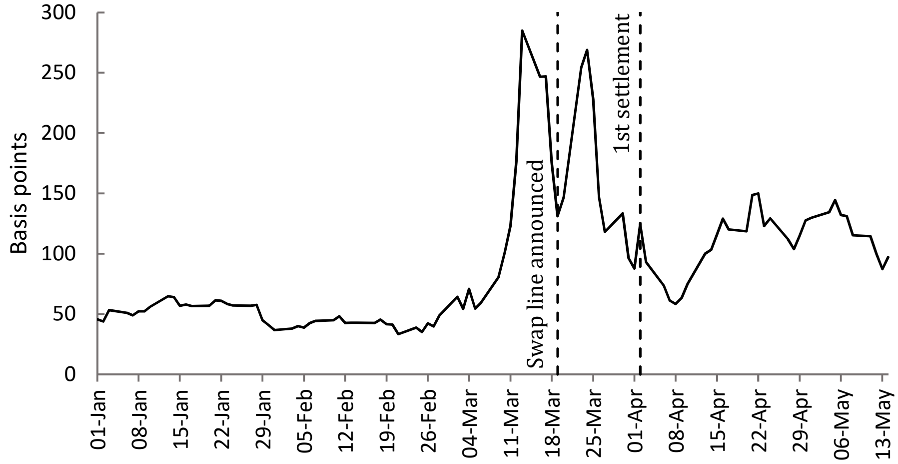
reintroduced more widely and aggressively in response to the global financial crisis in 2007. In contrast to their main use in the 1960s and 1970s, this most recent reincarnation of central bank swap lines was not aimed at facilitating sovereigns' foreign exchange interventions but at providing US dollar liquidity to non-US banking systems. In this sense, and also in contrast to previous experiences, the use of the swap lines was more 'asymmetric' as they were used for the provision of US dollars abroad.

There were two additional novelties in the reemergence of central bank swap line arrangements in response to the global financial crisis. First, the Fed not only set up swap lines with advanced economies as counterparties, but extended them to a set of emerging market economies.[4] Second, other central banks set up swap line arrangements of their own, without the provision of US dollars involved. For example, the Swiss National Bank set up currency swap lines with the central banks of Hungary and Poland to facilitate the availability of Swiss francs during the crisis. The proliferation of central bank swap line arrangements has continued beyond the global financial crisis and euro area crisis, and the network currently has an estimated 160 bilateral arrangements, including the more than 100 lines the People's Bank of China's has set up with more than 40 countries (Bahaj and Reis, 2018).[5]

[4]Namely, Brazil, Singapore, South Korea and Mexico, for which a swap line was already in place in the context of the trilateral US-Canada-Mexico relationship.

[5]See Denbee et al. (2016) for an estimated mapping of the global network of central bank swap lines as of 2016.

Figure 2 Korean won-US dollar 3-month CIP deviations



Source: Bloomberg and author's calculations.

More recently, central bank swap lines were at the forefront of the policy response to the tensions in off-shore US dollar funding markets resulting from the Covid-19 pandemic (Avdjiev et al., 2020, Bahaj and Reis, 2020), with an intervention of a scale comparable to that observed during the global financial crisis (Figure 1). The Federal Reserve improved the terms and frequency of its permanent standing facilities with a set of advanced economies, and extended the network of swap lines to nine additional recipient central banks, including some emerging markets.[6] The main motivation cited was to '*help lessen strains in global U.S. dollar funding markets, thereby mitigating the effects of these strains on the supply of credit to households and businesses, both domestically and abroad.*'[7]

Figure 2 zooms into one instance of this latest 'dollar shortage' shock, as it shows the evolution of Korean won-US dollar covered interest rate parity (CIP) deviations, a measure of stress in off-shore US dollar markets. It can be seen that stress built up beginning in early March, and then receded after the announcement of a swap line between the Federal Reserve and the Bank of Korea for a maximum of 60 billion US dollars on March 19th, and the settlement of the first such swap operation on April 2nd. Although this constitutes no conclusive evidence of a causal link between swap line operations and CIP deviations, the time-series dynamics coincide, at least directionally, with careful empirical assessments such

[6]The beneficiaries of the permanent facilities are the Bank of Canada, Bank of England, Bank of Japan, European Central Bank and Swiss National Bank. On March 19th 2020, new US dollar swap lines were established vis-a-vis the central banks of Australia, Brazil, Denmark, Korea, Mexico, Norway, New Zealand, Singapore and Sweden.

[7]See https://www.federalreserve.gov/newsevents/pressreleases/monetary20200319b.htm

as those in Bahaj and Reis (2018).

3 Model

Our baseline model is a two-country version of the canonical open economy New Keynesian model (Galí and Monacelli, 2005) as in Erceg et al. (2007), with financial frictions in the spirit of Akinci and Queraltó (2019) and Aoki et al. (2018). This class of models features financial intermediaries which borrow from domestic and foreign households (via non-contingent deposits) to fund the acquisition of domestic capital goods. The borrowing is conducted in domestic and foreign currency, respectively, and the lending is denominated in domestic currency, leading to balance sheet mismatches. An agency friction limits intermediaries' capacity to borrow (Gertler and Kiyotaki, 2010, Gertler and Karadi, 2011), and this friction is increasing in their foreign currency borrowing, leading to deviations from uncovered interest rate parity (UIP) in steady state (Akinci and Queraltó, 2019, Aoki et al., 2018). We allow for this differential friction when borrowing in foreign currency to evolve stochastically over time.

The model features two countries: a foreign economy and a domestic ('home') one. These countries are symmetric except for their size, their monetary policy rule and for the presence of financial intermediaries, which we only model in the domestic economy. Foreign households can invest abroad in 'home' intermediaries' deposits, and domestic households' can also hold deposits issued by their domestic banking system. The only other asymmetric feature of the model is the pricing of exports, which follows dominant currency pricing (in the foreign currency).

Countries are populated by households and firms, and the domestic economy is also populated by bankers. Financial markets are incomplete.

In this section we describe each of the model's blocks in turn.

3.1 Households

The representative household chooses consumption C_t, labour supply L_t and holdings of bank deposits D_t to maximise:

$$E_t\Big\{\sum_{j=0}^{\infty}\beta^j\big[\frac{\sigma}{1-\sigma}\big(C_{t+j}-\frac{\chi_0}{1+\chi}L_{t+j}^{1+\chi}\big)^{\frac{\sigma-1}{\sigma}}\big]\Big\}$$

The choice of a non-separable utility follows from the need to avoid an otherwise sharp increase in labor supply in the face of dollar shortage shocks, which results in an increase in employment (a feature that is not desirable from an empirical perspective).

Maximisation is subject to the budget constraint

$$C_t + D_t \leq \frac{W_t}{P_t} L_t + R_t D_{t-1} + \Xi_t \tag{1}$$

where

$$C_t = \left[(1-\omega)^{\frac{\rho}{1+\rho}} C_{Dt}^{\frac{1}{1+\rho}} + \omega^{\frac{\rho}{1+\rho}} M_{Ct}^{\frac{1}{1+\rho}} \right]^{1+\rho}$$

$$P_t = \left((1-\omega) P_{D_t}^{-\frac{1}{\rho}} + \omega P_{M_t}^{-\frac{1}{\rho}} \right)^{-\rho}$$

Variable C_t is a CES consumption basket of the domestic composite good C_{Dt} and the foreign (imported) composite good M_{Ct}. Parameter ω is (inversely) related to the degree of home bias in preferences, and therefore also works as a measure of the degree of openness of the economy (i.e. the share of output exported in steady state).

Variable P_t is the price of the home basket (a CES aggregate of the prices of the domestically produced and imported composite goods, P_{Dt} and P_{Mt} respectively), which results from a standard expenditure minimisation problem. D_t are deposits in domestic banks (which pay real gross interest rate R_t). Ξ_t are bank and firm profits, distributed to households.

We assume that exporters follow dominant currency pricing (DCP), and that the dominant currency is that of the foreign economy (i.e. the US dollar).[8] The price of home imports is given by $P_{Mt} = e_t P^*_{Dt}$, where e_t is the nominal exchange rate and $P^*_{D,t}$ is the (dollar) price of the foreign composite good.[9] Under DCP, home exporters set their export prices $P^*_{M,t}$ in US dollars (the foreign currency), and are subject to Calvo frictions in price setting. The real exchange rate is given by $\epsilon_t = e_t P^*_t / P_t$.

The representative household has bankers and workers as members. Bankers conform a mass f and workers a mass $1-f$. The survival of bankers into the following period is governed by an exogenous probability σ_b; upon retirement, they become workers and transfer

[8] In practical terms, and considering that the foreign economy is considered to be the US, dominant currency pricing effectively entails local currency pricing for domestic exporters and producer currency pricing for foreign (US) exporters.

[9] Given that the dominant currency is the foreign one, this is equivalent to PCP for foreign exporters.

their net worth to the household.[10] Each period there is a proportion of the mass of workers that become bankers (offsetting retirees so as to leave the proportion of bankers and workers unchanged) and receive an endowment (a fraction $\frac{\xi_b}{f}$ of the capital stock).

3.2 Banks

Banker i finances the purchase of domestic capital ($S_{i,t}$) using their net worth $N_{i,t}$ as well as funds borrowed by issuing non-contingent deposits to domestic ($D_{i,t}$) and foreign households ($D^*_{i,t}$ in units of the foreign good):

$$q_t S_{i,t} = D_{i,t} + \epsilon_t D^*_{i,t} + N_{i,t} \tag{2}$$

where ϵ_t is the price of the foreign good in terms of the domestic consumption basket (the real exchange rate), and q_t is the price of capital (also in terms of the domestic basket). Banks' lending is not subject to frictions, and hence one can think of bankers as holders of firms' equity, really representing 'bank-firms'.[11]

The budget constraint of a continuing banker is given by:

$$q_t S_{i,t} + R_t D_{i,t-1} + R^*_t \epsilon_t D^*_{i,t-1} \leq R_{K,t} q_{t-1} S_{i,t-1} + D_{i,t} + \epsilon_t D^*_{i,t} \tag{3}$$

where the return on capital $R_{K,t}$ is determined by capital rental rate Z_t and depreciation rate δ:

$$R_{K,t} = \frac{Z_t + (1-\delta)q_t}{q_{t-1}} \tag{4}$$

and R_t and R^*_t are the (real) interest rate paid on domestic and foreign currency deposits, respectively.

Combining (2) and (3) we can obtain the law of motion of a continuing bank's net worth:

$$N_{i,t+1} = (R_{K,t+1} - R_{t+1}) q_t S_{i,t} + (R_{t+1} - R^*_{t+1}\epsilon_{t+1}/\epsilon_t)\epsilon_t D^*_{i,t} + R_{t+1} N_{i,t} \tag{5}$$

In effect, net worth is an endogenous state variable, in contrast to traditional sudden stop models as in Mendoza (2010).

[10] Retirement is typically introduced in this class of models to avoid financial intermediaries saving their way out of the borrowing constraint.

[11] This is important when it comes to the balance sheet mismatch: even if banks hedge their foreign currency exposures, borrowing corporations might not.

Banker's borrowing is subject to an agency friction in the spirit of Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), motivated by limited enforcement: after borrowing funds, the banker can decide to default upon their obligations and instead divert the money. The payoff the banker obtains upon default is given by a fraction $\Theta(x_{i,t}, \gamma_{i,t})$ of their resources. This fraction takes the following form:

$$\Theta(x_{i,t}, \gamma_t) = \theta(1 + \frac{\gamma_t}{2} x_{i,t}^2) \tag{6}$$

where $x_{it} = \frac{\epsilon_t D_{i,t}^*}{q_t S_{i,t}}$ is the fraction of the balance sheet which is funded by issuing foreign currency deposits, and γ_t evolves as follows:

$$\gamma_t = (\gamma_{t-1})^{\rho_\gamma} (\gamma^{ss})^{(1-\rho_\gamma)} u_t^\gamma \tag{7}$$

That is, we allow the parameter governing the effect of foreign currency debt on the financing friction to vary over time. This is in contrast to Akinci and Queraltó (2019), in which γ is fixed and hence does not constitute a source of shocks.

Parameters are chosen such that $0 < \Theta(x_{i,t}, \gamma_t) < 1$, and hence the banker loses resources upon default. We will also focus on cases in which $\gamma_t > 0$; that is, the banker obtains a greater payoff upon default the larger the share of their balance sheet funded with foreign currency deposits. This captures the idea that foreigners have a worse monitoring technology than domestic agents.[12] While the narrow interpretation of γ is in terms of it parametrising foreigners monitoring technology, one can also think of it as capturing sudden changes in foreigners willingness to lend in foreign currency to the domestic banking system, independently of its fundamentals (which we will call 'dollar shortage' shocks). Any $\gamma_t \neq 0$ leads to UIP deviations in steady state, as agents incorporate this non-price effect of borrowing in foreign currency into their optimisation problem (driving a wedge in exchange rate-adjusted interest rate differentials to guarantee indifference at the optimum).

Banker i maximises their franchise value, which can be written in recursive form:

$$V_{i,t} = \max_{S_{i,t}, D_{i,t}^*} \quad (1 - \sigma_b) E_t(\Lambda_{t,t+1} N_{i,t+1}) + \sigma_b E_t(\Lambda_{t,t+1} V_{i,t+1}) \tag{8}$$

where $\Lambda_{t,t+1}$ is the (real) stochastic discount factor of the domestic household between t and $t + 1$. The maximisation is done subject to (5) and

[12] Also, $\gamma_t > 0$ leads to UIP deviations of the empirically relevant sign in steady state; that is, high interest rate currencies deliver excess returns with respect to low interest rate currencies. See Fama (1984) and Engel (1996).

$$V_{i,t} \geq \Theta(x_{i,t}, \gamma_t) q_t S_{i,t} \tag{9}$$

which constitutes an incentive compatibility constraint.

The optimum behaviour of banks is characterised by two first order conditions.[13] The first one pins down the relation between domestic credit spreads and UIP deviations, as a function of the share of foreign currency debt x_t:

$$\mu_t^* = \Big(\frac{\Theta(x_t, \gamma_t)}{\Theta_x(x_t, \gamma_t)} - x_t\Big)^{-1} \mu_t \tag{10}$$

where $\Theta_x(x_t, \gamma_t) = \frac{\partial \Theta(x_t, \gamma_t)}{\partial x_t}$ and domestic currency credit spreads μ_t and UIP deviations μ_t^* (which are the difference between foreign currency and domestic currency spreads) are given by:

$$\mu_t = E_t\big[\Omega_{t+1}(R_{K,t+1} - R_{t+1})\big] \tag{11}$$

$$\mu_t^* = E_t\big[\Omega_{t+1}(R_{t+1} - \frac{\epsilon_{t+1}}{\epsilon_t} R_{t+1}^*)\big] \tag{12}$$

In turn, Ω_{t+1} (marginal value of funds for banks) and ν_t (bank-specific savings in funding costs from an additional unit of net worth) are given by:

$$\Omega_{t+1} = \Lambda_{t,t+1}(1 - \sigma + \sigma \psi_{t+1})$$

$$\nu_t = \big[\Omega_{t+1} R_{t+1}\big]$$

Optimality condition (10) shows how banks choose x_t to equalise the marginal cost and benefit of foreign currency funds.

The second optimality condition determines the optimal leverage ratio ($\phi_t = \frac{q_t S_t}{N_t}$) and is given by:

$$\phi_t = \frac{\nu_t}{\Theta(x_t, \gamma_t) - (\mu_t + \mu_t^* x_t)} \tag{13}$$

Optimality condition (13) tells us that the optimal leverage ratio is decreasing in the share of assets banks are able to divert ($\Theta(x_t, \gamma_t)$) and increasing in the discounted excess return on bank's assets ($\mu_t + \mu_t^* x_t$, see Appendix A.1 for a derivation).

[13] See Appendix A.1 for a derivation.

In sum, banks optimise over the scale of their operations (ϕ_t) and their currency funding mix (x_t).

3.3 Firms

Final domestic output Y_t is produced under perfect competition using a variety of differentiated intermediate goods $Y_{i,t}$ by retailer $i \in [0,1]$ as inputs and a constant returns to scale technology:

$$Y_t = \Big(\int_0^1 Y_{i,t}^{\frac{1}{1+\theta_p}} di \Big)^{(1+\theta_p)} \tag{14}$$

The price level of domestic final output is given by $P_{Dt} = \Big(\int_0^1 P_{Dit}^{-\frac{1}{\theta_p}} \Big)^{-\theta_p}$, where $P_{Di,t}$ is the price set by retailer i.

The producer of each differentiated intermediate good, which operates in a monopolistically competitive environment, faces the following demand curve for their product:

$$Y_{i,t} = \Big(\frac{P_{Di,t}}{P_{Dt}} \Big)^{-\frac{1+\theta_p}{\theta_p}} Y_t \tag{15}$$

Each differentiated intermediate good is produced according to:

$$Y_{i,t} = K_{i,t}^{\alpha} L_{i,t}^{1-\alpha} \tag{16}$$

Labour earns wage W_t and capital earns a rental rate given by Z_t. Intermediate goods producers are subject to Calvo pricing frictions, such that in every period firm i can reset its price with probability $1-\xi_p$. Otherwise, prices follow an indexation rule such that $P_{Di,t} = P_{Di,t-1}\pi_{t-1}^{\iota_p}$, with $\pi_t = P_{D,t}/P_{D,t-1}$. Intermediate goods producers therefore choose $P_{Di,t}$ so as to maximise:

$$E_t \Big\{ \sum_{j=0}^{\infty} \Lambda_{t,t+j} \xi_p^j \Big[(P_{Di,t} - \zeta_{i,t+j}) Y_{i,t+j} \Big] \Big\} \tag{17}$$

subject to (15) and (16), where $\zeta_{i,t+j} = W_{t+j} L_{i,t+j} + Z_{t+j} K_{i,t+j}$.

Capital producers choose I_{t+j} to maximise

$$E_t \Big\{ \sum_{j=0}^{\infty} \Lambda_{t,t+j} \Big[q_{t+j} I_{t+j} - p_{D,t} \phi_{I,t} \Big] \Big\} \tag{18}$$

where $\phi_{I,t}$ is an adjustment cost of investment, which takes the form:

$$\phi_{I,t} = \frac{\psi_I}{2}(I_t/I_{t-1} - 1)^2 I_t \tag{19}$$

Investment goods I_t are a composite of domestically produced and imported goods, in an analogous fashion to consumption goods:

$$I_t = \left[(1-\omega)^{\frac{\rho}{1+\rho}} I_{Dt}^{\frac{1}{1+\rho}} + \omega^{\frac{\rho}{1+\rho}} M_{It}^{\frac{1}{1+\rho}}\right]^{1+\rho}$$

3.4 Market clearing

The market for home economy's domestic good clears as follows:

$$Y_t = C_{Dt} + I_{Dt} + \frac{\xi^*}{\xi}(M_{Ct}^* + M_{It}^*) + \phi_{It} \tag{20}$$

where $\frac{\xi^*}{\xi}$ is the relative size of the foreign economy. Market clearing for claims on capital (entirely owned by domestic banks) implies:

$$S_t = K_{t+1} \tag{21}$$

where $K_t = \int_0^1 K_{i,t} di$ is the aggregate stock of capital, which evolves according to:

$$K_{t+1} = (1-\delta)K_t + I_t \tag{22}$$

The balance of payments equation for the home economy is given by:

$$\epsilon_t D_t^* = \epsilon_t R_t^* D_{t-1}^* - NX_t \tag{23}$$

where NX_t represents the trade balance (i.e. net exports) and is given by:

$$NX_t = p_{dt} Y_t - C_t - I_t - p_{dt}\phi_{It} \tag{24}$$

where $p_{dt} = P_{Dt}/P_t$ is the relative price of the domestically produced good in terms of the home consumption basket.

3.5 Policy

3.5.1 Monetary policy

Monetary policy follows a Taylor rule which displays inertia and targets domestic inflation π_t and changes in the nominal exchange rate e_t:

$$R^n_{t+1} = \left(R^n_t\right)^{\gamma_r} \left(\beta^{-1} \pi_t^{\frac{1-\gamma_e}{\gamma_e}} \left(e_t/e_{t-1}\right)^{\frac{\gamma_e}{1-\gamma_e}}\right)^{(1-\gamma_r)} u^r_t \tag{25}$$

where u^r_t constitutes an exogenous shock. The functional form draws from Akinci and Queraltó (2019) and Galí and Monacelli (2016), but considers *changes* in the nominal exchange rate rather than deviations from steady state.

The inclusion of the exchange rate as a monetary policy target follows from the fact that in our model the 'home economy' resembles an emerging market (i.e. given balance sheet mismatches), for which there is evidence of exchanges rates being part of the monetary policy setting process (Ghosh et al., 2016). This is also consistent with the calibration in Section 3.7.1, which aims to match the experience of Korea during the Covid-19 pandemic, as Mohanty and Klau (2004) also find evidence of exchange rates entering the monetary policy rule for Korea specifically. In the calibration section we experiment with different degrees of exchange rate targeting, ranging from freely floating to a peg, by changing the values of parameter γ_e.

3.5.2 Central bank swap lines

The domestic central bank can borrow foreign currency from the foreign central bank (i.e. the Federal Reserve) using a central bank swap facility. As described in Section 2.1, swap lines entail no interest or exchange rate risk for the Federal Reserve, only credit risk (as the collateral received is fiat currency subject to depreciation). Given that in the model there is no default in equilibrium (and swaps in fact improve macro dynamics in the face of dollar shortage shocks), the provision of swaps is effectively risk free.[14]

The domestic central bank draws foreign currency from the swap line as a function of observed deviations in the UIP condition, which, in the context of this model, can reflect underlying tensions in private US dollar funding markets ('dollar shortage' shocks).

$$F_t = \phi^F (\mu^*_t - \mu^*_{ss}) \tag{26}$$

where $\phi^F > 0$ and F_t represents the (foreign currency) funds drawn from the swap line.

We follow Del Negro et al. (2017) in specifying a linear policy rule that reacts to changes in the main financial friction in the model, but depart from their paper in assuming that

[14]Even if it is hard to motivate the supply of US dollars via swap lines alluding to US self-interest, strictly speaking in the model dollar shortage shocks lead to a small contraction in US output and a negative deviation in US inflation, which a risk-neutral Federal Reserve would be willing to avoid by the provision of risk-free swaps.

the central bank reacts to an observable series (UIP deviations μ_t) which reflects changes in the underlying friction rather than to the friction itself. While their paper studies Fed's purchases of commercial paper in response to a tighter liquidity friction in a closed economy model, ours models Fed's foreign currency lending to foreign central banks in response to a 'dollar shortage' shock. The Fed charges $R_t^* + fp_t$ for these funds, where fp_t is the spread the domestic central bank pays on top of the US dollar (real) interest rate.

In line with the description of the functioning of swap lines in Section 2.1, the domestic central bank in turn lends the foreign currency funds to the domestic commercial banks. Let $D_t^{*,s}$ be the amount lent, for which an interest rate R_t^s is charged. Importantly, the central bank does not require the same collateral as foreign households when lending these foreign currency funds to domestic banks, but instead asks for the same collateral domestic households require of banks for lending local currency funds. In other words, $D_t^{*,s}$ does not feed into $\Theta(x_t, \gamma_t)$ via x_t, which continues to reflect the share of banks balance sheet funded via *private* foreign currency funds.[15]

The consolidated balance sheet of the domestic central bank and fiscal authority looks as follows:

$$\epsilon_t D_t^{*,s} + \epsilon_t F_{t-1}(R_t^* + fp_t) = T_t + \epsilon_t F_t + R_t^s \epsilon_t D_{t-1}^{*,s} \tag{27}$$

where T_t are lump sum taxes the fiscal authority can raise in the event of losses in their foreign currency positions. For simplicity we will assume that $R_t^s = R_t^* + fp_t$ such that the central bank actually never incurs into losses. For simplicity, we also assume that $fp_t = 0$ (the Fed does not charge a spread for its swap line facility).

After demanding $D_t^{*,s}$ foreign currency funds from the domestic central bank the balance sheet of domestic banks changes from (2) to:

$$q_t S_{i,t} = D_{i,t} + \epsilon_t D_{i,t}^* + \epsilon_t D_{i,t}^{*,s} + N_{i,t} \tag{28}$$

and the evolution of its net worth from (5) to:

$$N_{i,t} = R_{K,t} q_{t-1} S_{i,t-1} - R_t D_{i,t-1} - \epsilon_t R_t^* D_{i,t-1}^* - \epsilon_t R_t^{*,s} D_{i,t}^{*,s} \tag{29}$$

The optimisation problem of the domestic banks is analogous to the one laid out in Section 3.2, but now there is an additional choice variable $D_t^{*,s}$ and an additional constraint:

[15] There is an effective market segmentation in that domestic households cannot lend to domestic banks in foreign currency but the domestic central bank can. This can be justified if one thinks that the domestic central bank is acting as an agent for the Federal Reserve, with better monitoring technology.

$$D_t^{*,s} \leq F_t \tag{30}$$

which imposes that the domestic central bank can only lend its domestic banking system the dollars it obtained via the swap lines.

Appendix A.2 contains a derivation of the new optimum, but it is intuitive to see that given that (i) there are positive UIP deviations (and hence an excess return of foreign currency funded lending over local currency funded lending) and (ii) central bank foreign currency loans only require collateral that matches that of domestic currency deposits, then domestic banks will demand all funds offered by the domestic central bank:

$$D_t^{*,s} = F_t \tag{31}$$

The conditions that characterise the optimal choice of banks in Section (3.2) change as follows. Condition (10) becomes

$$\mu_t^* = \left(\frac{\Theta(x_t, \gamma_t)}{\Theta_x(x_t, \gamma_t)} - x_t - sw_t\right)^{-1} \mu_t \tag{32}$$

with $sw_t = \frac{\epsilon_t D_t^{*,s}}{q_t S_t}$ (the share of commercial banks' balance sheet funded with foreign currency loans from the central bank). Condition (13) becomes:

$$\phi_t = \frac{\nu_t}{\Theta(x_t, \gamma_t) - \mu_t - \mu_t^* sw_t - \mu_t^* x_t} \tag{33}$$

We can see from equation (33) that any non-negative borrowing from the central bank results in an increase in leverage for commercial banks.

The inflow of foreign currency funds from the swap line also 'loosens' the balance of payments constraint, which changes from equation (23) to:

$$\begin{gathered} \epsilon_t D_t^* + \epsilon_t F_t = \\ \epsilon_t R_t^* D_{t-1}^* + \epsilon_t (R_t^* + fp_t) F_{t-1} - NX_t \end{gathered} \tag{34}$$

3.6 Foreign economy

The foreign economy is analogous to the domestic one except for three features. First, households invest in 'home'-economy bank deposits, albeit in foreign currency (there are no foreign banks). Second, monetary policy is set according to a Taylor rule that, in contrast to the home economy, only responds to domestic inflation and not to changes in the exchange rate:

$$R_{t+1}^{n,*} = (R_t^{n,*})^{\gamma_r} (\beta^{*-1} \pi_t^{*\gamma_\pi})^{(1-\gamma_r)} u_t^{r*} \tag{35}$$

Finally, exporters follow producer currency pricing (PCP) since the dominant currency is their home currency.

3.7 Calibration

Our calibration of the core part of the model follows Akinci and Queraltó (2019) for the most part, which in turn draws significantly from Justiniano et al. (2010). The calibration of the dollar shortage shock and the policy response in terms of central bank swap lines are calibrated to match the experience of Korea during the financial stress resulting from the Covid-19 pandemic.

Domestic households are parametrised so as to be more impatient than foreign ones, leading to net borrowing in the desired direction in steady state. In particular, β equals 0.9925, which leads to a steady state real interest rate of roughly 3%, while β^* is set at 0.9950, leading to a 2% equivalent rate. The difference in discount rates, which in turn leads to uncovered interest rate parity deviations in steady state, is needed to pin down the solution to the funding portfolio problem of banks facing a collateral constraint that penalises local and foreign currency borrowing in different ways.

The only other asymmetry in the model is countries' relative size; the home economy is calibrated to be one third of the foreign one ($\xi/\xi^* = 1/3$).

Turning to the parameters which are common across countries, the capital share (α), depreciation rate (δ) and intertemporal elasticity of substitution (σ) are calibrated to the conventional values of 0.33, 0.025 and 1, respectively. Price mark-ups (θ_p) are set at 20%. The parameters governing the inverse Frisch elasticity of labour supply (χ) and those determining price rigidities (ξ_p, ι_p) are fairly conventional and come from Justiniano et al. (2010). The investment adjustment cost (ψ_I) is set at 0.5, lower than the value used in Akinci and Queraltó (2019) with the objective of matching a higher volatility of investment with respect to consumption.

The trade price elasticity ($(1+\rho)/\rho$) is set at 1.5, following Erceg et al. (2007). Home country openness (ω, the share of output exported in steady state) is set at 20%, and foreign country openness is determined by the restriction that $\omega^* = \omega\xi/\xi^*$ (Blanchard et al., 2017).

Banks survival rate (σ_b) is set at 0.93, which implies an average of 3.5 years of operations before retirement.[16] The parameters governing the financial frictions in the model are picked so as to approximately match observed quantities for Korea. This leads to steady state credit spreads of approximately 300 basis points, a leverage ratio of roughly 6.5 and a ratio of foreign currency debt of 0.2. This is achieved by setting $\theta = 0.27$, $\xi_b = 0.07$ and $\gamma^{ss} = 3$.

Finally, Taylor rule parameters are set as follows. The inertia coefficient (γ^r) is common across both countries and set at 0.82, following Justiniano et al. (2010) and also very closely in line with evidence for emerging markets in Ghosh et al. (2016). The foreign Taylor rule features an inflation coefficient (ϕ_π) set at the standard 1.5. In terms of the home Taylor rule, the relative weight attached to inflation and the exchange rate is governed by γ_e. We consider three values for this parameter: 0.05, 0.4 and 0.99. The first two follow from Akinci and Queraltó (2019) for ease of comparison, and represent a (quasi) freely floating regime and a regime featuring some degree of exchange rate targeting, which can be regarded as a 'managed float'. We also consider $\gamma_e = 0.99$ to analyse the dynamics of our model under a quasi-fixed exchange rate regime.

3.7.1 Calibration of dollar shortage shock and swap lines

We do a joint calibration of the size of the 'dollar shortage' shock (u^γ) and the parameter governing the domestic central bank demand for swaps (ϕ^F) so as to broadly match the experience of Korea during the market turmoil resulting from the Covid-19 pandemic. In particular, we aim to match the observed dynamics of (i) US dollars swapped between the Fed and the Bank of Korea and (ii) observed maximum CIP deviations between the US dollar and the Korean won during the period. We choose Korea as our calibration target as an emerging market that both suffered dollar shortages during the Covid-19 pandemic and had access to Federal Reserve swap lines.

Figure 2 suggests an increase of approximately 215 basis points between the pre-stress period and the peak of the stress.[17] This level of CIP deviations was reached before swap lines were announced, and hence the the 'dollar shortage' shock is calibrated so as to deliver the observed stress under no (swap) policy action, that is, $\phi^F = 0$. We then calibrate ϕ^F in

[16] This relatively short lifespan is chosen so as to avoid an excessive accumulation of net worth in the event of a dollar shortage shock which leads to a significant widening in credit spreads. It is worth noting that in the model banks only pay dividends upon exit, while in reality they usually do so at the quarterly frequency, which also leads to an excessive accumulation of net worth in the model.

[17] Specifically, this number is achieved by subtracting the January-February average of 49 basis points from a peak-stress figure of 265 basis points, obtained from averaging the two days of maximum CIP deviations (March 13th and 16th).

two alternative ways. First, we try to match the amount of dollars effectively drawn at the time of writing (c. 17 billion US dollars, or 1% of domestic lending in Korea). Second, we consider the maximium amount of US dollars that the Bank of Korea can draw from the line (60 billion US dollars, approximately 3.6% of domestic lending in Korea).[18] This delivers two different values for ϕ^F (49 and 270, respectively), which we consider in turn.

While the model delivers predictions in terms of UIP deviations, we target observed CIP deviations for calibrating the size of the underlying shock given greater measurement accuracy. Given the absence of an explicit market for FX forwards in our model, and considering the rational expectations framework used, the two series can be expected to be close to each other.

Table B.1 in Appendix B.1 lists the chosen parameter values.

4 Dollar shortage shock and the role of swap lines

In this section we show the dynamics of our model in the face of a 'dollar shortage' shock; that is, a sudden increase in the additional collateral foreign households require to lend foreign currency to home economy banks (γ_t). This shock is unrelated to home economy's 'fundamentals', and hence has some resemblance of 'sudden stop'-type shocks, albeit with endogenous amplification and negative feedback originating from banks' balance sheet mismatches.

We conduct this exercise in two steps. We first feed the model with a shock calibrated to match the observed dynamics of Korean won-US dollar CIP deviations during the Covid-19 pandemic, as explained in Section 3.7.1. However, we do not allow the home central bank to draw US dollars from its swap line. We explore the model dynamics under three different scenarios for the degree of exchange rate targeting in the Taylor rule, namely, a quasi-free float, a managed exchange rate and a quasi-peg.

Secondly, we focus on the intermediate exchange rate arrangement (which best characterises the monetary policy of emerging markets such as Korea) and introduce the possibility for the home central bank to draw from its US dollar swap line with the Fed. We explore three different scenarios: a baseline case, in which the amount of swaps drawn matches the observed quantities effectively used by the Bank of Korea during the Covid-19 pandemic, and two hypothetical cases, one of no swap access (matching the first exercise described above) and one in which the amount of swaps drawn increases to the maximum offered by the Federal Reserve to Korea during the Covid-19 pandemic (as described in Section 3.7.1).

[18]Data sources and transformations can be found in Appendix B.2.

4.1 Dollar shortage shocks under different exchange rate regimes

In the face of a sudden increase in the amount of collateral needed to borrow foreign currency (an increase in γ_t) banks become less willing to do so. However, since (i) dollar deposits are fully intermediated by domestic banks and (ii) the corresponding dollar flows are sticky to the extent that they need to fulfil the balance of payments equation, there is an adjustment in prices to encourage dollar borrowing and deliver an equilibrium in that market. This takes the form of an increase in UIP deviations, delivered by a sudden real depreciation and subsequent appreciation path of the local currency vis-a-vis the dollar (Figure 3). Given the tighter borrowing constraint arising from the shock, spreads need to increase to motivate banks' continuation; domestic currency spreads increase, and foreign currency-funded spreads increase by more, as required to deliver an increase in UIP deviations.

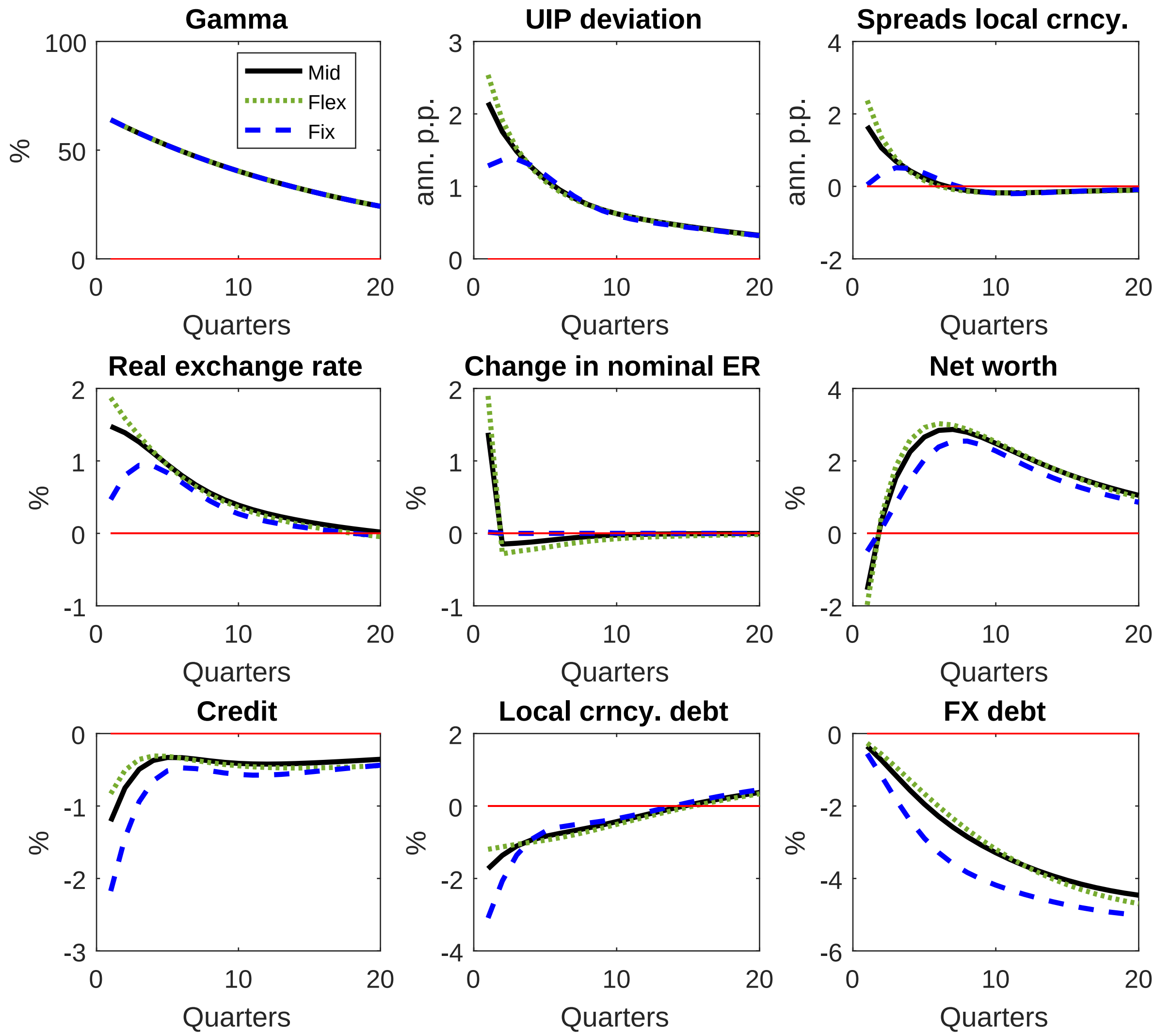
The exchange rate depreciation hits banks' net worth given the currency mismatch in their balance sheets. On the liabilities side, and given the combination of the underlying shock and the moves in relative prices described above, dollar deposits only decrease gradually, while the more nimble local currency deposits fall more sharply and then recover. Given the fall in net worth and market funding, bank lending contracts.

The heterogeneity in dynamics across exchange rate regimes is more quantitative than qualitative, as the impulse responses differ in magnitude but not in direction. The starkest difference can be found under the quasi-fixed nominal exchange rate system, when the adjustment in the real exchange rate is milder given the more aggressive reaction of interest rates observed in Figure 4. The increase in interest rates by itself opens up the UIP deviation and lowers the need of a sharp appreciation path to encourage US dollar borrowing by banks. The smaller hit to net worth is nevertheless compensated by a sharper fall in the price of capital (Tobin's Q in Figure 4), leading to a sharper contraction in bank lending.

On the real economy side, the fall in the price of capital and the contraction in bank lending coincide with a fall in investment, while the negative wealth effect (and the more expensive imports) results in consumption also falling, which combine into a contraction in output (Figure 4). Net exports increase on the back of a sharp contraction in imports and mildly higher exports (given DCP), which effectively leads to an improvement in the current account, and less dollar inflows, in line with the initial 'dollar shortage' characterisation of the shock. Once more, these directional impacts are common across exchange rate regimes, but reactions are larger in magnitude under a fixed exchange rate arrangement, leading to a more negative impact of the 'dollar shortage' shock.[19]

[19] Akinci and Queraltó (2019) explore the inferiority of fixed exchange rate arrangements in more detail in

Figure 3 Model dynamics after 'dollar shortage' shock, financial variables



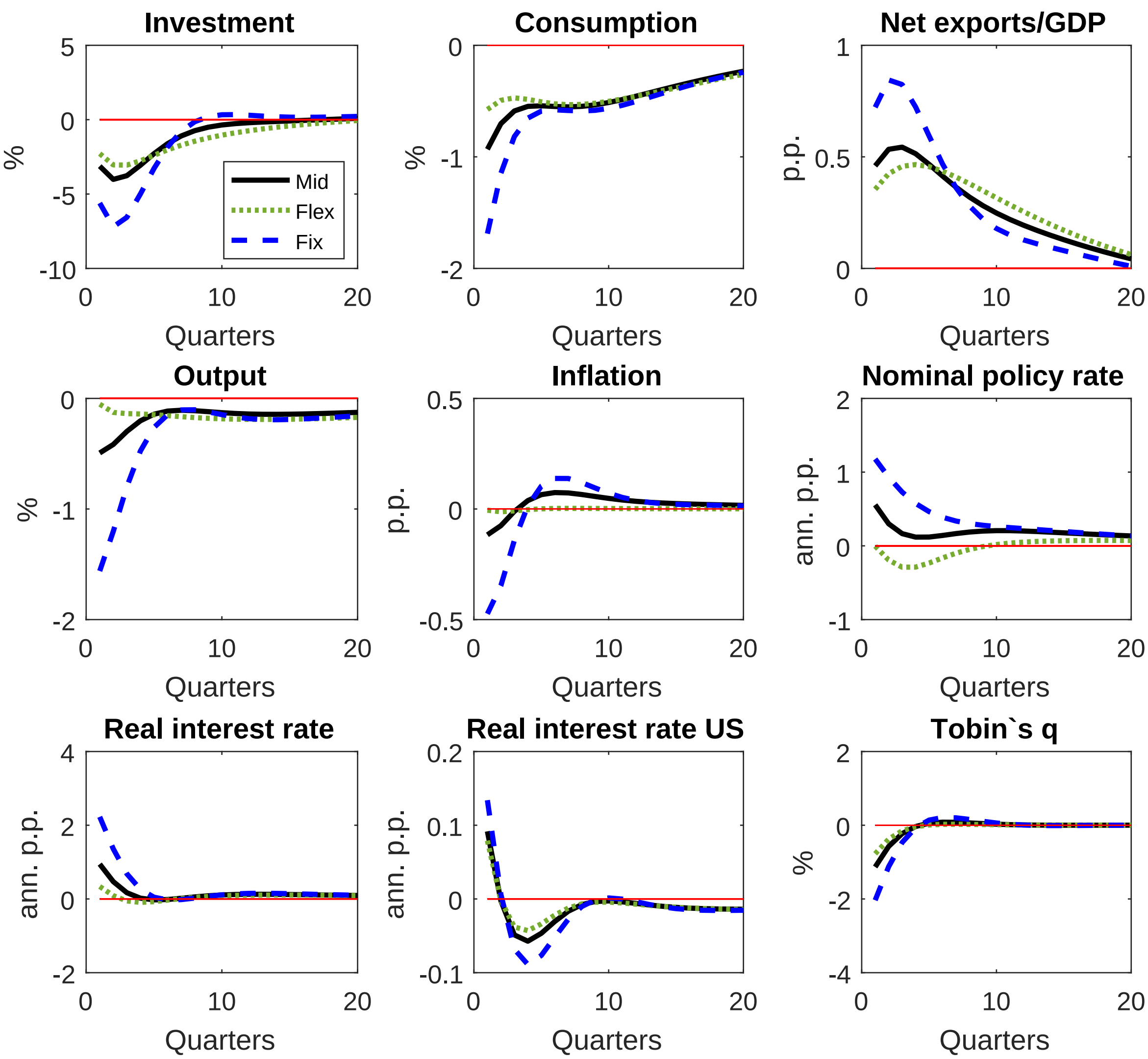
Note: Impulse response functions of model following a 'dollar shortage' shock (an increase in γ_t). Black solid lines correspond to scenario of an intermediate degree of exchange rate targeting ($\gamma_e = 0.4$), green dotted lines to scenario of flexible exchange rates ($\gamma_e = 0.05$) and blue dashed lines to scenario of a quasi-peg ($\gamma_e = 0.99$).

The starkest heterogeneity across exchange rate regimes can be seen in the reaction of the policy rate and inflation (Figure 4). Faced with a negative drag on domestic inflation and depreciation pressures resulting from the dollar shortage shock, monetary policy under a flexible exchange rate arrangement loosens to offset the fall in inflation, allowing the exchange rate to depreciate. In contrast, a policy rule which targets the exchange rate to some degree aims to smooth the (nominal) exchange rate depreciation by raising interest rates, at the

a similar model in the face of US monetary policy shocks.

expense of some domestic deflation. This is of course more extreme in the case of the quasi-fixed exchange rate regime.

Figure 4 Model dynamics after 'dollar shortage' shock, macro variables



Note: Impulse response functions of model following a 'dollar shortage' shock (an increase in γ_t). Black solid lines correspond to scenario of an intermediate degree of exchange rate targeting ($\gamma_e = 0.4$), green dotted lines to scenario of flexible exchange rates ($\gamma_e = 0.05$) and blue dashed lines to scenario of a quasi-peg ($\gamma_e = 0.99$).

It can be seen that the effect of a dollar shortage shock calibrated to match the experience of Korea during the Covid-19 pandemic is sizeable from a quantiative perspective: investment falls by nearly 4%, consumption by nearly 1% and output by 0.5% under the intermediate exchange rate regime.

4.2 The role of swap lines

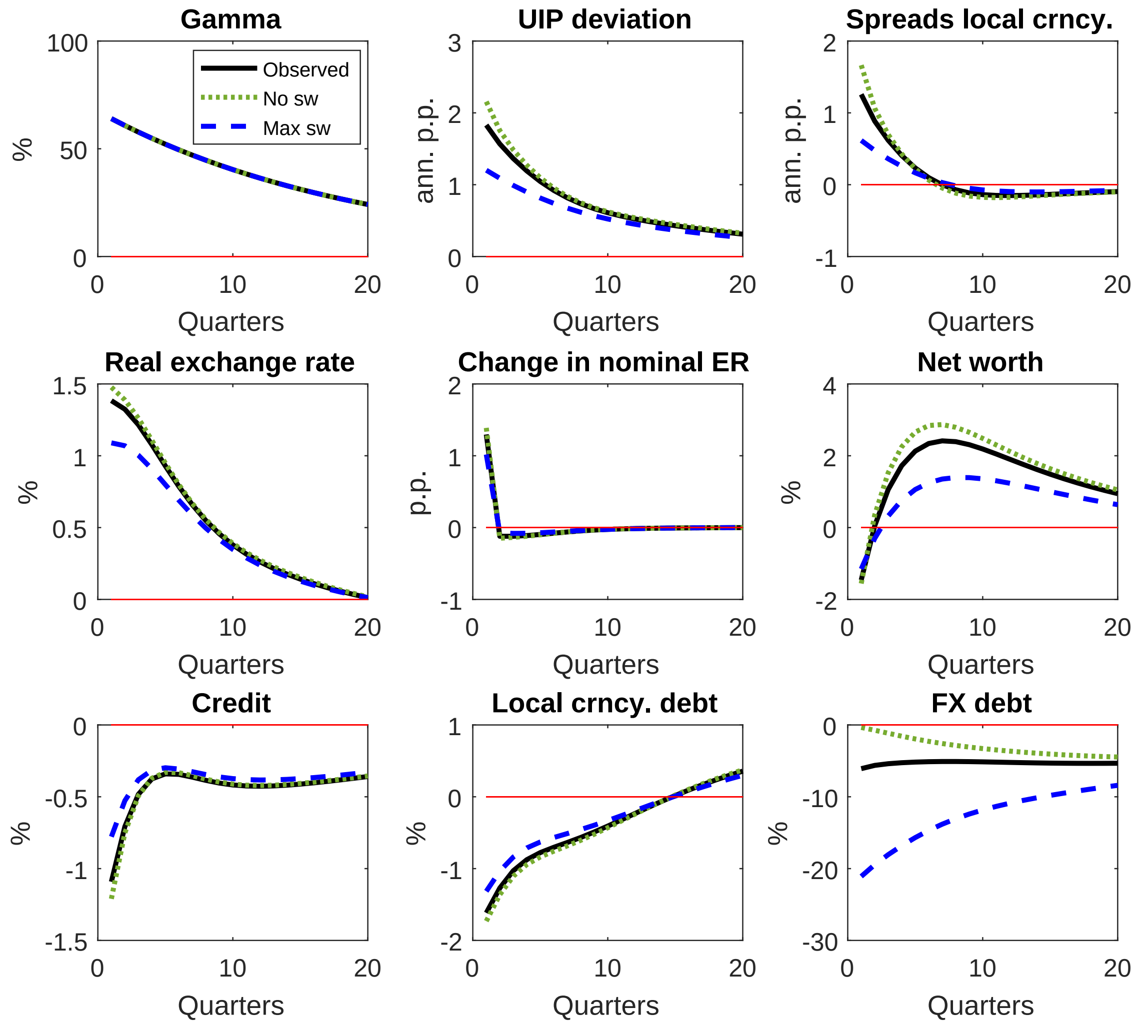
We now focus on the case of the intermediate exchange rate targeting monetary arrangement ($\gamma_e = 0.4$) and allow for the home central bank to borrow US dollars from the Fed via a swap line. We consider three cases: a baseline case in which the amount of dollars borrowed and channeled to domestic banks matches the amount drawn by the Bank of Korea during the Covid-19 pandemic at the time of writing, and two hypothetical scenarios, one in which this amount matches the maximum offered by the Fed in this instance and another one in which the amount of US dollars drawn from the swap lines is set to zero (matching the results in Section 4.1). See Section 3.7.1 for more information.

Beginning with the effect of swap lines on prices, we can see that the borrowing of Fed-supplied US dollars in the face of a 'dollar shortage' shock leads to less pressure being put on prices to encourage foreign currency borrowing from private lenders (Figure 5). The increase in UIP deviation is milder, as is the exchange rate depreciation and the increase in domestic currency spreads. This happens as the newly supplied dollars (i) allow banks to cut back private foreign currency funding more sharply and (ii) loosen the balance of payments constraint. In terms of magnitudes, we can see that an intervention matching the amount of US dollars actually drawn by the Bank of Korea at the time of writing does not cushion the effects of the shock significantly, but that an intervention scaled up to the maximum allowed by the Fed has larger effects. Interestingly, the difference in the reaction of UIP deviations between the no swaps scenario and the scenario considering maximum swap uptake (c.120 bps) is close to the fall in observed CIP Korean won-US dollar deviations after the announcement of the Fed-Bank of Korea swap lines (c.150 bps, see Figure 2), suggesting an important role for signalling effects.

In terms of quantities related to domestic banks, we can see that the dollars supplied by the domestic central bank lead to a contraction in foreign currency borrowing from foreign households, which in turn explains the price dynamics described above. The decrease in (private) dollar borrowing makes banks' borrowing constraint more slack in comparison to the baseline case, which means that local currency borrowing contracts by less. This, together with a milder drop in net worth arising from the smaller exchange rate depreciation, lead to a milder contraction in credit. Once more, the contraction in credit in the observed uptake scenario is not significantly different from the no-swaps counterfactual, while the improvement is more noticeable in the event of the maximum uptake scenario.

Finally, macro quantities also display more benign dynamics in the event of central bank intervention via FX swaps (Figure 6). The milder contraction in credit shown in Figure 5, and

Figure 5 Model dynamics after 'dollar shortage' shock with swaps, financial variables

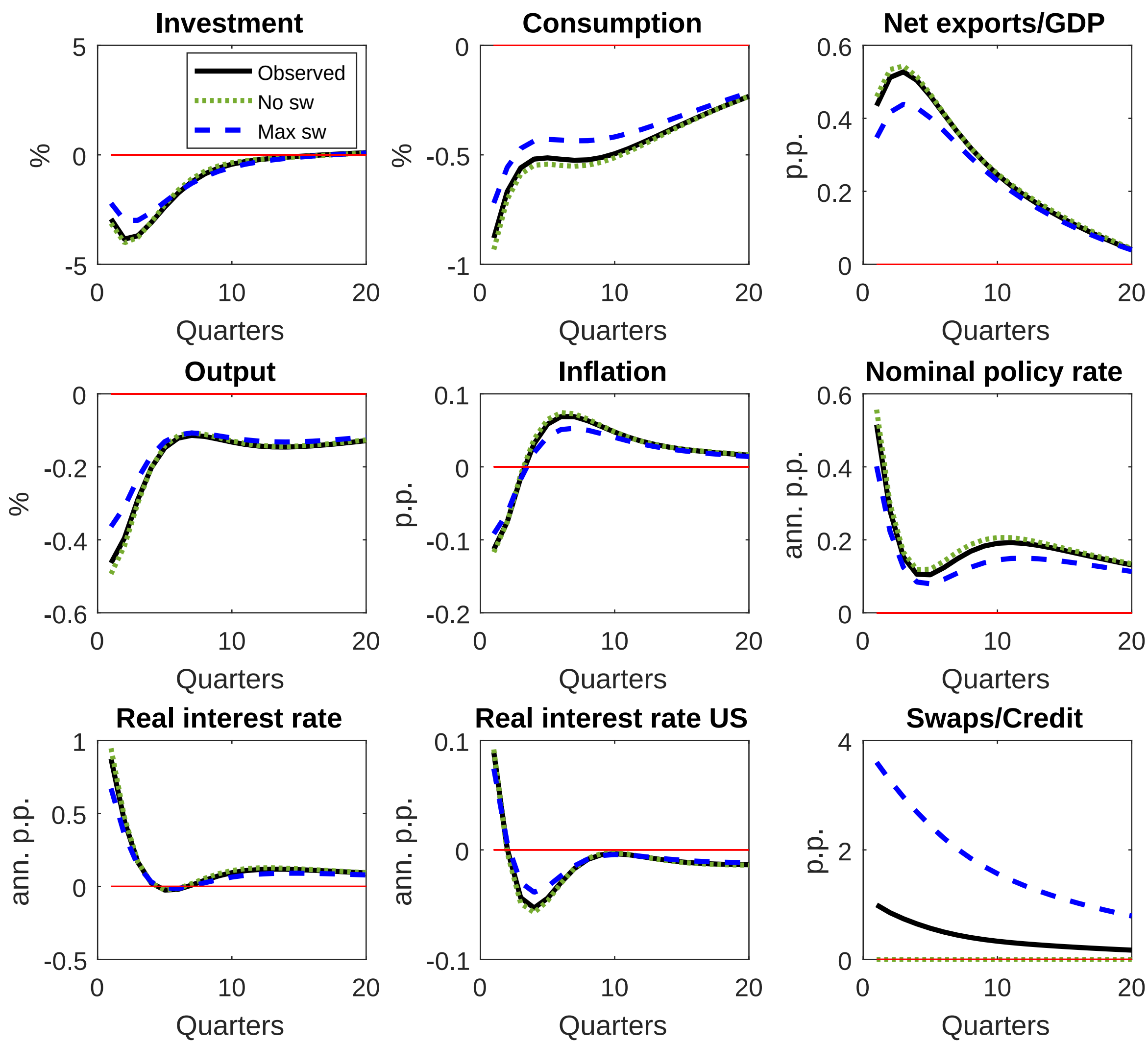


Note: Impulse response functions of model following a 'dollar shortage' shock (an increase in γ_t). Black solid lines correspond to the case of observed uptake of swap lines by the Bank of Korea during the Covid pandemic (1% of credit), green dotted lines correspond to a scenario of no swap lines and blue dashed lines to a scenario of an uptake matching the maximum amount offered by the Federal Reserve (3.6% of credit).

the less aggressive tightening in policy rates in the face of smaller exchange rate pressure lead to a smaller fall in investment, while consumption also reacts by less, leading to a smaller fall in output and domestic inflation. The smaller exchange rate depreciation (and milder import contraction) lead to less of an increase in net exports, and a smaller improvement in current account balances. Once more, the effect of intervention is only quantitatively important in the case of maximum swap uptake, while an uptake matching that observed during the Covid-19 pandemic has only marginal effects. In the case of a maximum swap uptake scenario, the falls in investment, consumption and output are 20% smaller approximately compared to a no-swaps scenario, highlighting the quantitative importance of this tool.

As mentioned before, it is worth clarifying that this exercise does not constitute an explicit assessment of the policy conducted by the Bank of Korea, as the results described in this section are affected by the model's several simplifying assumptions (including on the price of swaps and the absence of signalling effects). In contrast, the objective is to sketch out the mechanisms through which central bank swap lines can attenuate the negative macro-financial consequences of dollar shortage shocks.

Figure 6 Model dynamics after 'dollar shortage' shock with swaps, macro variables



Note: Impulse response functions of model following a 'dollar shortage' shock (an increase in γ_t). Black solid lines correspond to the case of observed uptake of swap lines by the Bank of Korea during the Covid pandemic (1% of credit), green dotted lines correspond to a scenario of no swap lines and blue dashed lines to a scenario of an uptake matching the maximum amount offered by the Federal Reserve (3.6% of credit).

5 Conclusion

In this paper we conduct a joint analysis of the economic and financial consequences of 'dollar shortage' shocks and the role of central bank swap lines in influencing those effects. Calibrating our model to the experience of Korea during the Covid-19 pandemic, we show that 'dollar shortage' shocks can have sizeable negative consequences for domestic bank lending, investment, consumption and ultimately depress domestic output. We also show that the possibility of relying on US dollar swap lines with the Federal Reserve has the capacity to significantly attenuate such negative impact, provided the provision of dollars is aggressive enough.

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A Appendix A: Bankers' problem

A.1 Baseline model

Banker i's problem is:

$$V_{i,t} = \max_{S_{i,t}, D^*_{i,t}} \quad E_t\big[(1-\sigma_b)\Lambda_{t,t+1}N_{i,t+1}) + \sigma_b\Lambda_{t,t+1}V_{i,t+1}\big] \tag{A.1}$$

subject to:

$$N_{i,t+1} = (R_{K,t+1} - R_{t+1})q_t S_{i,t} + (R_{t+1} - R^*_{t+1}\epsilon_{t+1}/\epsilon_t)\epsilon_t D^*_{i,t} + R_{t+1}N_{i,t} \tag{A.2}$$

$$V_{i,t} \geq \Theta(x_{i,t}, \gamma_t)q_t S_{i,t} \tag{A.3}$$

Both the objective and incentive constraints are constant returns to scale, and hence the value function can be re-written as:

$$\psi_t \equiv \frac{V_t}{N_t} = E_t\Big[\Lambda_{t,t+1}(1-\sigma_b+\sigma_b\psi_{t+1})\frac{N_{t+1}}{N_t}\Big] \tag{A.4}$$

where ψ_t can be interpreted as Tobin's Q ratio of the bank. Using (A.2) and the definition of the leverage multiple $\phi_t = \frac{q_{i,t}S_{i,t}}{N_{i,t}}$, (A.1) and (A.3) can be re-written as:

$$\begin{aligned} \psi_t = \max_{\phi_t, x_t} \quad & \big[\mu_t\phi_t + \mu^*_t\phi_t x_t + \nu_t\big] \\ \text{s.t.} \quad & \psi_t \geq \Theta(x_t,\gamma_t)\phi_t \end{aligned} \tag{A.5}$$

where

$$\mu_t = E_t\big[\Omega_{t+1}(R_{K,t+1} - R_{t+1})\big] \tag{A.6}$$

$$\mu^*_t = E_t\big[\Omega_{t+1}(R_{t+1} - \frac{\epsilon_{t+1}}{\epsilon_t}R^*_{t+1})\big] \tag{A.7}$$

$$\Omega_{t+1} = \Lambda_{t,t+1}(1-\sigma+\sigma\psi_{t+1}) \tag{A.8}$$

$$\nu_t = \big[\Omega_{t+1}R_{t+1}\big] \tag{A.9}$$

Let λ_t be the Lagrange multiplier associated with the incentive compatibility constraint. The first order conditions with respect to x_t and ϕ_t are (respectively) given by:

$$\mu_t^* \phi_t + \lambda_t(\mu_t^* \phi_t - \Theta'(x_t, \gamma_t)\phi_t) = 0 \tag{A.10}$$

$$\mu_t + x_t \mu_t^* + x_t[\mu_t + x_t \mu_t^* - \Theta(x_t, \gamma_t)] = 0 \tag{A.11}$$

Combining (A.10) and (A.11) we obtain optimality condition (10) in the main text. Optimality condition (13) follows from the incentive compatibility constraint being binding.

A.2 Model with swaps

With the introduction of swaps, banks' maximisation problem changes as described in equations (28)-(30) in the main text. In turn, the scaled problem given by (A.5) becomes:

$$\begin{aligned} \psi_t = \max_{\phi_t, x_t, sw_t} \quad & \left[\mu_t \phi_t + \mu_t^* \phi_t x_t + \mu_t^* \phi_t sw_t + \nu_t\right] \\ \text{s.t.} \quad & \psi_t \geq \Theta(x_t)\phi_t \\ & D_t^{*,s} \leq F_t \end{aligned} \tag{A.12}$$

First order condition (A.10) is unchanged, while condition (A.11) becomes:

$$\mu_t + x_t \mu_t^* + sw_t \mu_t^* + x_t[\mu_t + x_t \mu_t^* + sw_t \mu_t^* - \Theta(x_t, \gamma_t)] = 0 \tag{A.13}$$

which, combined with (A.10), yields optimality condition (32) in the main text. Optimality condition (33) is again derived from the incentive compatibility constraint being binding. Finally, optimality condition (31) results from the borrowing constraint being binding, which in turn arises from the superiority of central bank supplied funds with respect to private funds (in excess return space with respect to local currency funds given positive UIP deviations, and in collateral terms with respect to foreign currency funds).

B Appendix B: Calibration and data

B.1 Calibration

Table B.1

Concept	Parameter	Value
Home discount factor	β	0.9925
Foreign discount factor	β^*	0.9950
Relative home size	ξ/ξ^*	0.33
Capital share	α	0.33
Depreciation rate	δ	0.025
IES	σ	1
Price mark-up	θ_p	0.2
Inverse Frisch elasticity	χ	3.79
Prob. keeping prices fixed	ξ_p	0.84
Price indexation parameter	ι_p	0.24
Investment adjustment cost	ψ_I	0.5
Trade price elasticity	$(1+\rho)/\rho$	1.5
Home trade openness	ω	0.2
Foreign trade openness	ω^*	0.2/0.33
Bank survival rate	σ_b	0.93
Divertable fraction upon default	θ	0.27
Bank endowment	ξ_b	0.07
Home bias in bank funding	γ^{ss}	3
Policy rate persistence	γ^r	0.82
Foreign Taylor rule inflation coeff.	ϕ_π	1.5
Home Taylor rule FX coeff.	γ_e	0.05,0.4,0.99

B.2 Data

- Swaps use
  - Central Bank Liquidity Swap Data from the Federal Reserve Bank of New York, available at: https://apps.newyorkfed.org/markets/autorates/fxswap
  - Size of banking sector balance sheets (scaling factor for swap amounts) is measured as the size of "Domestic claims to non-financial corporations in all currencies" as of 2019Q1, obtained from the BIS International Banking Statistics.
- CIP deviations
  - Interest rate differentials are measured using US dollar 3-month Libor rates (US0003M CMPL Index) and Korean won-denominated 3-month CD rates (KWCDC CMPL Curncy), obtained from Bloomberg.
  - Korean won-US dollar spot rates (KRW CMPL Curncy) and 3-month forwards (KWN3M CMPL Curncy) also come from Bloomberg.
- Korean FX debt statistics come from IIF's Global Debt Monitor. The target ratio of 0.2 is an average of mean FX debt over total debt and mean USD debt over debt total for 2005-2019.
- Korean won corporate spreads come from Bloomberg. The target value of 320 basis points is an average of mean AAA Korean won 3-year corporate spreads (KCP1-3Y Index - GTKRW3Y Govt) and BBB- Korean won corporate spreads (KCP13YB- Index - GTKRW3Y Govt) over 2006-2020.