

Essays in Financial Economics

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Statement of Authorship

I, Fernando Eguren-Martin, declare that the first two chapters of my thesis are joint work with Andrew Meldrum and Wen Yan (first chapter), and Matias Ossandon Busch and Dennis Reinhardt (second chapter). The third chapter is entirely my own work.

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Abstract

This dissertation consists of three chapters discussing issues in the field of financial economics. The first two chapters are largely empirical; the third chapter is mainly theoretical.

In the first chapter (co-authored with Andrew Meldrum and Wen Yan) we develop a model for pricing hypothetical financial instruments that have their pay-offs tied to the evolution of a country's gross domestic product (GDP) growth ('GDP-linked bonds'). We first develop a no-arbitrage pricing model for these bonds in line with those applied to other financial securities. Absent data on actual prices given lack of trading, we device an alternative empirical strategy for estimation of our model. This strategy entails inferring the risk profile of GDP from a second term-structure model, this time of 'zero-coupon' equities, which can be taken to the data. After estimating the prices of GDP-linked bonds we decompose them into their components (including GDP growth expectations and GDP risk premia) and study their time series and term structure dynamics.

In the second chapter (co-authored with Matias Ossandon-Busch and Dennis Reinhardt) we study the effect of price dislocations in the market for foreign currency (FX) swaps, an important source of funding for banks, on cross-border bank lending. Armed with a detailed balance sheet level dataset for banks operating from the UK, we examine how ex-ante exposure to FX swap-based funding affects the reaction of banks cross-border positions in the face of the mentioned dislocations in pricing. We also explore the role of potential shielding factors, including banks' reliance on intra-group funding.

In the third chapter I develop a theoretical macroeconomic model featuring shocks to the availability of FX funding for banks ('dollar shortage shocks') and central bank swap lines as a monetary policy tool. First, I show that dollar shortage shocks can have significant negative consequences for macroeconomic aggregates by affecting bank lending.

Second, I show how the availability of central bank swap lines, through which the local central bank can access foreign currency, can attenuate the negative consequences of dollar shortage shocks on the macroeconomy.

1 | No-Arbitrage Pricing of GDP-Linked Bonds

This chapter is based on joint work with Andrew Meldrum and Wen Yan.

Abstract

We develop a novel term-structure model for pricing GDP-linked bonds, hypothetical securities with cash-flows indexed to the level of U.S. GDP. For this purpose, we rely on a term-structure model of equity yields estimated using the prices of dividend swaps, which we assume span GDP growth. Our approach provides a novel way of estimating the relative cost of conventional and GDP-linked bonds, as well as measuring more general market-based expectations of (and risks around) GDP growth. Our model predicts that U.S. GDP-linked bonds would typically have yields lower than those on conventional Treasury bonds with the same maturity in our sample from 2010 to 2017. Positive expected future GDP growth lowers the yield on GDP-linked bonds relative to conventional bonds, which typically more than offsets the estimated GDP risk premium demanded by investors for holding GDP risk.

Keywords: Affine term structure model (ATSM), dividend swaps, GDP-linked bonds, spanned macroeconomic factors.

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1.1 Introduction

Several central banks and other policy institutions have recently expressed an interest in GDP-linked sovereign debt as a potential means of promoting financial stability.[1] While no GDP-linked bonds currently exist, they present an obvious attraction: the repayment burden for a GDP-linked bond would be relatively low at times when the economy is growing relatively slowly (that is, periods typically associated with relatively low growth in tax revenues).[2] A greater share of the risk of weak growth outcomes would therefore be borne by the holders of GDP-linked bonds than by holders of conventional bonds.

As a consequence, issuers of GDP-linked bonds would likely need to pay an additional risk premium relative to conventional government bonds, in order to compensate investors for the fact that cash-flows from the bond would be relatively small in bad times. However, it is not straightforward to quantify this risk premium in the absence of an existing market for GDP-linked bonds. Indeed, uncertainty about the size of the risk premium may be one reason why no sovereign has yet issued a GDP-linked bond.[3] Previous attempts to quantify the GDP risk premium have significant limitations.[4] Some studies combine a model of the time-series properties of GDP with assumptions about investors' preferences, and solve for the required risk premium. For example, Barr et al. (2014) assume that investors have constant relative risk aversion. However, such standard utility functions cannot explain the magnitude and dynamics of risk premiums of existing assets, so it is not clear why we should attach great weight to their predictions for risk premiums on assets that do not currently exist. Other studies (including Borensztein and Mauro, 2004, Kamstra and Shiller, 2009 and Bowman and Naylor, 2016) have adopted an approach based on the Capital Asset Pricing Model (CAPM), and use the beta of observed GDP

[1] See, for example, the German G20 presidency's Compass document, available here.

[2] See Benford et al. (2016) for a summary of other potential benefits of GDP-linked bonds.

[3] Borensztein and Mauro (2004) discuss this and other possible explanations for the lack of previous GDP-linked bond issuance.

[4] Some studies have ignored this risk compensation altogether, and instead relied on a risk-neutral framework to estimate a price for GDP-linked debt (see, for example, Chamon and Mauro (2006)).

growth with respect to returns on the market portfolio as a proxy for the beta of GDP-linked bonds. Unfortunately, it is by no means obvious that returns on hypothetical GDP-linked bonds would have the same covariance with returns on the market portfolio as GDP growth. Moreover, no previous studies that attempt to quantify the GDP risk premium consider how it may vary with the maturity of the GDP-linked bond, which is a crucial practical question for prospective issuers.

In this paper, we develop a novel asset pricing approach to estimate U.S. nominal GDP (NGDP) risk premiums using the prices of existing assets. Specifically, we build a no-arbitrage affine term structure model (ATSM) of equity yields derived from the prices of S&P 500 dividend swaps, which we assume span GDP growth, hence allowing us to estimate predicted yields of bonds with payoffs linked to nominal GDP. Our approach avoids the limitations of previous studies: it allows a much more flexible specification of investors' preferences, which is known to match risk premiums on existing assets; it avoids any assumptions about the relative covariances of GDP growth and returns on GDP-linked bonds with the market portfolio; and it allows us to study how the nominal GDP risk premium varies with the maturity of the bond. The key assumption underpinning our analysis is that nominal GDP and dividend growth are "spanned" by the cross section of the term structure of equity yields. The spanning assumption requires that—in the absence of measurement error—we can invert nominal GDP growth and dividend growth from the term structure of equity yields. In consequence, we can back out the risk-neutral dynamics of nominal GDP growth and dividends from observed equity yields—which allows us to compute predicted yields on GDP-linked bonds. Hence, a second output from our model is a set of market-implied expectations of (and risks around) GDP growth at various horizons.

In our framework, the spread (or "breakeven") of the yield on a conventional bond minus the yield on a GDP-linked bond of the same maturity is affected by two main factors. First, if GDP growth is expected to be positive, this pushes up the terminal cash-flow on a GDP-linked bond, raises the current price, and lowers the current yield relative to

conventional bonds. Second, if GDP growth is expected to be relatively low in bad times (that is, when discount factors are relatively high), investors will demand an additional risk premium for bearing GDP risk. This GDP risk premium pushes down the current prices of GDP-linked bonds and raises the yields relative to conventional bonds; that is, the GDP risk premium component of the breakeven is likely to be negative (and hence increase the yields of GDP-linked bonds).

We find that our model can fit nominal GDP growth precisely, while also reproducing the broad movements in equity yields. Using the output from the model we can then compute the price of GDP-linked bonds. We find that the unconditional average term structure of GDP risk premiums is indeed negative but increase monotonically with maturity. At relatively short maturities between 6 months and 2 years the average premiums are in the region of -7 percent to -4 percent, but increase to -1 percent at the 10-year maturity. That is, the increase in the yield of GDP-linked bonds owing to GDP risk premia decreases with maturity. This seems intuitive if we consider the relatively low persistence of shocks to NGDP growth, which should hence be less important over the lifespan of bonds with longer maturities.

The remainder of the paper is structured as follows. In Section 1.2, we describe the basic structure of the hypothetical GDP-linked bonds we consider and provide some basic inuition for the difference in yields between GDP-linked and conventional government bonds. In Section 1.3, we present a joint no-arbitrage term structure model of GDP-linked bond and equity yields. In Section 1.4, we explain how we estimate this joint model in the absence of observed GDP-linked bond yields. In Section 1.5 we present our main results. In Section 1.6, we summarize our conclusions.

1.2 GDP-Linked Bonds

In this section we describe the basic structure of the hypothetical GDP-linked bonds that we consider and provide some intuition for the difference in yields between GDP-linked

and conventional government bonds. Specifically, we decompose the difference between the yield on a conventional bond and a GDP-linked bond with the same maturity into the expected average rate of GDP growth over the lifetime of the bonds and an additional "GDP risk premium" that compensates investors for GDP risk.

We start by analyzing the prices of conventional (or "nominal") bonds, which make up the majority of government debt in most countries. A k-period nominal (zero-coupon) bond pays one dollar at maturity at time $t+k$. Under the assumption of no arbitrage, the time-t price ($P_{t,n}^{(k)}$) of such a bond is given by

$$P_{t,n}^{(k)} = \mathbb{E}_t \left[\prod_{j=1}^{k} M_{t+j} \right] \tag{1.1}$$

where M_{t+j} is the nominal stochastic discount factor that discounts dollar cash-flows from time $t+j$ back to $t+j-1$. The yield on a nominal bond is defined as $y_{t,n}^{(k)} = -\frac{1}{k} \log P_{t,n}^{(k)}$. A second-order approximation of equation (1.1) shows that the yield is approximately given by

$$y_{t,n}^{(k)} \approx -\frac{1}{k} \left\{ \mathbb{E}_t \left[\sum_{j=1}^{k} m_{t+j} \right] + \frac{1}{2} \mathbb{V}_t \left[\sum_{j=1}^{k} m_{t+j} \right] \right\} \tag{1.2}$$

where $m_{t+j} = \log M_{t+j}$.[5]

We now turn to GDP-linked bonds. We assume that a hypothetical zero-coupon GDP-linked bond has a dollar cash-flow linked to the growth in nominal GDP between the time of issue and the maturity of the bond. More precisely, we assume that a k-period GDP-linked bond pays $\frac{Y_{t+k}}{Y_t}$ dollars at maturity at time $t+k$, where Y_t is the level of nominal GDP at time t.[6,7] Under the assumption of no arbitrage, the time-t price ($P_{t,g}^{(k)}$) is given by

[5] These second-order approximations hold exactly when the pricing kernel is log-normal, as in our models.

[6] We choose this payoff structure as it is the simplest, but the model can accomodate alternatives in which coupons and not the principal of the bond are tied to the evolution of NGDP.

[7] One can easily note the analogy with the widely-used inflation-linked bonds by replacing the level of NGDP with a price index.

$$P_{t,g}^{(k)} = \mathbb{E}_t \left[\prod_{j=1}^{k} M_{t+j} \frac{Y_{t+k}}{Y_t} \right] \tag{1.3}$$

The yield on a GDP-linked bond is defined as $y_{t,g}^{(k)} = -\frac{1}{k} \log P_{t,g}^{(k)}$. Taking a second-order approximation of equation (1.3) shows that the yield is approximately given by

$$y_{t,g}^{(k)} \approx -\frac{1}{k} \left\{ \mathbb{E}_t \left[\sum_{j=1}^{k} (m_{t+j} + g_{t+j}) \right] + \frac{1}{2} \mathbb{V}_t \left[\sum_{j=1}^{k} m_{t+j} \right] + \frac{1}{2} \mathbb{V}_t \left[\sum_{j=1}^{k} g_{t+j} \right] + \mathbb{C}_t \left[\sum_{j=1}^{k} m_{t+j}, \sum_{j=1}^{k} g_{t+j} \right] \right\}, \tag{1.4}$$

where $g_{t+j} = \log Y_{t+j} - \log Y_t$ is the growth rate of nominal GDP.

The difference between the yields on a conventional bond and a GDP-linked bond of the same maturity is therefore given by

$$y_{t,n}^{(k)} - y_{t,g}^{(k)} \approx \frac{1}{k} \left\{ \mathbb{E}_t \left[\sum_{j=1}^{k} g_{t+j} \right] + \mathbb{C}_t \left[\sum_{j=1}^{k} m_{t+j}, \sum_{j=1}^{k} g_{t+j} \right] + \frac{1}{2} \mathbb{V}_t \left[\sum_{j=1}^{k} g_{t+j} \right] \right\} \tag{1.5}$$

The first term on the right-hand side of equation (1.5) is the expected rate of nominal GDP growth. All else equal, the higher expected GDP growth, the higher the expected terminal cash-flow on a GDP-linked bond, the higher the current price of the GDP-linked bond, and the lower the current yield. Thus, if GDP growth is expected to be relatively high, the cost today of issuing a GDP-linked bond is relatively low compared with the cost of issuing a conventional bond.

The second term on the right-hand side of equation (1.5) is a risk premium. If GDP growth tends to be relatively low in "bad times" (that is, times when the stochastic discount factor is relatively high and investors put higher value on cash flows), then cash-flows on GDP-linked bonds will be lowest at times when they are most valued and the covariance term will be negative. This raises the yield on a GDP-linked bond relative to the yield on a conventional bond, reducing the spread $y_{t,n}^{(k)} - y_{t,g}^{(k)}$. The final term on the right-hand side of equation (1.5) is a convexity term that arises from working with log prices. In our

ATSM, this conditional variance is constant over time and is relatively small compared with the other terms. When we report results from our ATSM below we group the final two terms together as a single "GDP risk premium," reflecting the average expected return on GDP-linked bonds in excess of the nominal yield and expected GDP growth.

1.3 Model of GDP-Linked Bond and Equity Yields

In this section, we explain how we compute GDP risk premiums using the prices of existing assets whose payoffs are affected by GDP risk. In Section 1.3.1 we set out a hypothetical ATSM of GDP-linked bonds, while in Section 1.3.2 we extend this model to price equity yields, which is the model that we take to the data.

1.3.1 An ATSM of GDP-Linked Bond Yields

We can equivalently write equation (1.3) as

$$P_{t,g}^{(k)} = \mathbb{E}_t \left[M_{t+1} \exp\left(g_{t+1}\right) P_{t+1,g}^{(k-1)} \right]. \tag{1.6}$$

We assume that the GDP growth rate is an affine function of an $n_x \times 1$ vector of pricing factors ($\mathbf{x}_t$), that is,

$$g_t = g_0 + \mathbf{g}_1' \mathbf{x}_t, \tag{1.7}$$

where g_0 is a scalar and $\mathbf{g}_1$ is an $n_x \times 1$ vector. We further assume that the stochastic discount factor takes the form

$$M_{t+1} = \exp\left(-r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} \right), \tag{1.8}$$

where r_t is the short-term risk-free nominal interest rate, the $n_x \times 1$ vector λ_t contains the market prices of risk, and $\varepsilon_{t+1} \sim \mathcal{N}(\mathbf{0}, \mathbf{I})$ is an $n_x \times 1$ vector of random shocks. The short rate and market prices of risk are affine functions of the factors, that is,

$$r_t = \rho_0 + \rho_1' \mathbf{x}_t \text{ and} \tag{1.9}$$

$$\lambda_t = \lambda_0 + \mathbf{\Lambda}_1 \mathbf{x}_t, \tag{1.10}$$

where ρ_0 is a scalar; λ_0 and ρ_1 are $n_x \times 1$ vectors; and $\mathbf{\Lambda}_1$ an $n_x \times n_x$ matrix. The factors follow a first-order Gaussian vector autoregression (VAR), that is,

$$\mathbf{x}_{t+1} = \mu + \mathbf{\Phi} \mathbf{x}_t + \mathbf{\Sigma} \varepsilon_{t+1}. \tag{1.11}$$

Under the assumption of no-arbitrage, we can equivalently write the price of a k-period GDP-linked bond as

$$P_{t,g}^{(k)} = \mathbb{E}_t^{\mathbb{Q}} \left[\exp\left(-r_t + g_{t+1}\right) P_{t+1,g}^{(k-1)} \right], \tag{1.12}$$

where expectations are formed with respect to the equivalent risk-neutral probability measure, which we denote $\mathbb{Q}$. The above assumptions also imply that the factors follow a first-order VAR under $\mathbb{Q}$, that is,

$$\mathbf{x}_{t+1} = \mu^{\mathbb{Q}} + \mathbf{\Phi}^{\mathbb{Q}} \mathbf{x}_t + \mathbf{\Sigma} \varepsilon_{t+1}^{\mathbb{Q}}, \tag{1.13}$$

where $\mu^{\mathbb{Q}} = \mu - \mathbf{\Sigma}\lambda_0$, $\mathbf{\Phi}^{\mathbb{Q}} = \mathbf{\Phi} - \mathbf{\Sigma}\mathbf{\Lambda}_1$, and $\varepsilon_{t+1}^{\mathbb{Q}} \sim \mathcal{NID}(\mathbf{0}, \mathbf{I})$ (see Duffee, 2002). It follows that the yield on a GDP-linked bond is an affine function of the pricing factors, that is,

$$y_{t,g}^{(k)} = -\frac{1}{k} \left(a_{k,g} + \mathbf{b}_{k,g}' \mathbf{x}_t \right), \tag{1.14}$$

where $a_{n,g}$ and $\mathbf{b}_{n,g}$ follow the recursive equations

$$a_{k,g} = -\rho_0 + g_0 + a_{k-1,g} + (\mathbf{g}_1 + \mathbf{b}_{k-1,g})' \mu^{\mathbb{Q}} + \frac{1}{2} (\mathbf{g}_1 + \mathbf{b}_{k-1,g})' \boldsymbol{\Sigma}\boldsymbol{\Sigma}' (\mathbf{g}_1 + \mathbf{b}_{k-1,g}), \tag{1.15}$$

$$\mathbf{b}'_{k,g} = -\rho'_1 + (\mathbf{g}_1 + \mathbf{b}_{k-1,g})' \boldsymbol{\Phi}^{\mathbb{Q}}, \tag{1.16}$$

with boundary conditions $a_{0,g} = 0$ and $\mathbf{b}_{0,g} = \mathbf{0}_{n_x \times 1}$. Appendix A.1 provides further details.

1.3.2 A Joint Model of GDP-Linked Bond Yields and Equity Yields

If we observed yields on a cross-section of GDP-linked bond yields, then we could estimate the model set out in Section 1.3.1 using standard approaches for estimating ATSMs. But the fact that we do not observe GDP-linked bond yields means that we must employ an alternative approach. The option we consider is to use a joint term structure model of GDP-linked bond yields and equity yields.[8] A joint model of GDP-linked bonds and conventional Treasury bonds is an obvious alternative to our modelling choice, but preliminary results suggested that the implied prices of GDP-linked bonds from such a model were wildly implausible. This could be due to the well-known weak spanning of GDP growth by conventional bonds (see, for example, Joslin et al., 2014 and Bauer and Rudebusch, 2016).

In our joint model, the pricing of GDP-linked bonds is exactly the same as set out in Section 1.3.1. In the remainder of this section we therefore discuss the pricing of zero-coupon equities, which requires us to make only one additional assumption.

A k-period zero-coupon equity is one which pays a dividend D_{t+k} at maturity.[9] Under

[8] Although this specific joint model has not been considered previously, several studies have considered analogous joint models of conventional yields in multiple countries (for example, Anderson et al., 2010) or of nominal and real yields within a single country (for example, D'Amico et al., 2014 and Abrahams et al., 2016). Besides the different type of yields being modelled, the difference between our paper and these previous studies is that we use only data on one class of yields, together with observed macroeconomic data, to infer all of the parameters of the model.

[9] We describe the construction of these zero-coupon equity yields in Section 1.4.3. The seminal reference

the assumption of no-arbitrage, the time-t price of a zero-coupon equity ($P_{t,d}^{(k)}$) scaled by the current level of dividends is given by

$$\frac{P_{t,d}^{(k)}}{D_t} = \mathbb{E}_t \left[\prod_{i=1}^{k} M_{t+i} \frac{D_{t+k}}{D_t} \right] = \mathbb{E}_t \left[M_{t+1} \exp\left(\Delta d_{t+1}\right) \frac{P_{t+1,d}^{(k-1)}}{D_{t+1}} \right] \tag{1.17}$$

where $\Delta d_{t+1} = \log D_{t+1} - \log D_t$ is the one-period dividend growth rate. Equivalently, under the $\mathbb{Q}$ measure, we can write

$$\frac{P_{t,d}^{(k)}}{D_t} = \mathbb{E}_t^{\mathbb{Q}} \left[\exp\left(-r_t + \Delta d_{t+1}\right) \frac{P_{t+1,d}^{(k-1)}}{D_{t+1}} \right] \tag{1.18}$$

In addition to the assumptions set out in Section 1.3.1, the dividend growth rate is an affine function of the pricing factors, that is,

$$\Delta d_t = \delta_0 + \delta_1' \mathbf{x}_t, \tag{1.19}$$

where δ_0 is a scalar and δ_1 is an $n_x \times 1$ vector. With this one additional assumption, the equity yield—defined as $y_{t,d}^{(k)} = -\frac{1}{k}\left(\log P_{t,d}^{(k)} - \log D_t\right)$ following van Binsbergen et al. (2013)—is an affine function of the factors, that is,

$$y_{t,d}^{(k)} = -\frac{1}{k}\left(a_{k,d} + \mathbf{b}_{k,d}' \mathbf{x}_t\right), \tag{1.20}$$

where $a_{k,d}$ and $\mathbf{b}_{k,d}$ follow the recursive equations

$$a_{k,d} = -\rho_0 + \delta_0 + a_{k-1,d} + \left(\delta_1 + \mathbf{b}_{k-1,d}\right)' \mu^{\mathbb{Q}} + \frac{1}{2}\left(\delta_1 + \mathbf{b}_{k-1,d}\right)' \mathbf{\Sigma}\mathbf{\Sigma}' \left(\delta_1 + \mathbf{b}_{k-1,d}\right), \tag{1.21}$$

$$\mathbf{b}_{k,d}' = -\rho_1' + \left(\delta_1 + \mathbf{b}_{k-1,d}\right)' \mathbf{\Phi}^{\mathbb{Q}}, \tag{1.22}$$

is van Binsbergen et al. (2013).

with boundary conditions $a_{0,d} = 0$ and $\mathbf{b}_{0,d} = \mathbf{0}_{n_x \times 1}$. Appendix A.2 provides further details.

1.4 Estimation

We now turn to the question of how we can estimate this joint model in the absence of data on GDP-linked bond yields. As a preliminary step, in Section 1.4.1, we show how to eliminate the short-term nominal interest rate r_t from the model, leaving a model that we can estimate without any information from conventional bond yields. In Section 1.4.2, we show how to estimate the model parameters using only data on equity yields and GDP growth. In Section 1.4.3, we describe the data set we use to estimate the model.

1.4.1 Eliminating the Nominal Short Rate from the Model

As currently formulated, both GDP-linked bond yields (in equation (1.12)) and equity yields (in equation (1.18)) depend on the one-period nominal short rate (r_t). However, over most of our sample the nominal short rate has been at the zero lower bound, which means that a Gaussian model for the short rate is likely to suffer from problems of mis-specification (see, for example, Bauer and Rudebusch, 2016). In practice, therefore, we reformulate equations (1.12) and (1.18) to solve out the nominal short rate. As we show in Appendix A.3, we can equivalently price zero-coupon equities according to

$$\frac{P_{t,d}^{(k)}}{D_t} = \mathbb{E}_t^{\mathbb{Q}_d}\left[\exp\left(-r_{t,d}\right)\frac{P_{t+1,d}^{(k-1)}}{D_{t+1}}\right], \tag{1.23}$$

where $\mathbb{Q}_d$ denotes the equivalent probability measure for pricing zero-coupon equities when we discount payoffs using the short-term equity yield

$$r_{t,d} = \rho_{0,d} + \rho_{1,d}'\mathbf{x}_t, \tag{1.24}$$

with $\rho_{d,0} = \rho_0 - \delta_0 - \delta_1'\mu^{\mathbb{Q}} - \frac{1}{2}\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1$ and $\rho_{d,1} = \rho_1 - \boldsymbol{\Phi}^{\mathbb{Q}\prime}\delta_1$; and where the factors follow the law of motion under the $\mathbb{Q}_d$ measure

$$\mathbf{x}_{t+1} = \mu^{\mathbb{Q}_d} + \boldsymbol{\Phi}^{\mathbb{Q}_d}\mathbf{x}_t + \boldsymbol{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}_d}, \tag{1.25}$$

with $\mu^{\mathbb{Q}_d} = \mu^{\mathbb{Q}} + \boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1$ and $\boldsymbol{\Phi}^{\mathbb{Q}_d} = \boldsymbol{\Phi}^{\mathbb{Q}}$. As we show in Appendix A.3, equity yields are equivalently given by

$$y_{t,d}^{(k)} = -\frac{1}{k}\left(a_{k,d}^* + \mathbf{b}_{k,d}^{*\prime}\mathbf{x}_t\right), \tag{1.26}$$

where $a_{k,d}$ and $\mathbf{b}_{k,d}$ follow the recursive equations

$$a_{k,d}^* = -\rho_{0,d} + a_{k-1,d}^* + \mathbf{b}_{k-1,d}^{*\prime}\mu^{\mathbb{Q}_d} + \frac{1}{2}\mathbf{b}_{k-1,d}^{*\prime}\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\mathbf{b}_{k-1,d}^* \text{ and} \tag{1.27}$$

$$\mathbf{b}_{k,d}^{*\prime} = -\rho_{1,d}' + \mathbf{b}_{k-1,d}^{*\prime}\boldsymbol{\Phi}^{\mathbb{Q}_d}, \tag{1.28}$$

with boundary conditions $a_{0,d}^* = 0$ and $\mathbf{b}_{0,d}^* = \mathbf{0}_{n_x\times 1}$.

If we price GDP-linked bonds under the $\mathbb{Q}_d$ measure, we have

$$P_{t,g}^{(k)} = \mathbb{E}_t^{\mathbb{Q}_d}\left[\exp\left(-r_{t,d} + g_{t+1}\right)P_{t+1,g}^{(k-1)}\right].$$

The yield on a GDP-linked bond is therefore equivalently given by

$$y_{t,g}^{(k)} = -\frac{1}{k}\left(a_{k,g}^* + \mathbf{b}_{k,g}^{*\prime}\mathbf{x}_t\right), \tag{1.29}$$

where $a_{k,g}^*$ and $\mathbf{b}_{k,g}^*$ follow the recursive equations

$$a_{k,g}^* = -\rho_{0,d} + g_0 + a_{k-1,g}^* + \left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}^*\right)'\mu^{\mathbb{Q}_d} + \frac{1}{2}\left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}^*\right)'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}^*\right), \tag{1.30}$$

$$\mathbf{b}_{k,g}^{*\prime} = -\rho_{1,d}^{\prime} + \left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}^{*}\right)^{\prime} \mathbf{\Phi}^{\mathbb{Q}_d} \tag{1.31}$$

with boundary conditions $a_{0,g}^{*} = 0$ and $\mathbf{b}_{0,g}^{*} = \mathbf{0}_{n_x \times 1}$. Thus, we can parameterize a joint model of equity and GDP-linked bond yields in terms of the parameters

$$\mathbf{\Theta} = \left\{\mu, \mathbf{\Phi}, \mu^{\mathbb{Q}_d}, \mathbf{\Phi}^{\mathbb{Q}_d}, \mathbf{\Sigma}, \rho_{0,d}, \rho_{1,d}, g_0, \mathbf{g}_1\right\}.$$

As is well-known (see, for example, Dai and Singleton, 2000, Joslin et al., 2011, and Hamilton and Wu, 2012), we must impose additional identifying restrictions on the parameters of an ATSM to ensure identification. We impose the restrictions $\mu^{\mathbb{Q}} = \mathbf{0}$, that $\mathbf{\Phi}^{\mathbb{Q}_d}$ is lower triangular with ordered diagonal elements $\phi_{11}^{\mathbb{Q}_d} \geq \phi_{22}^{\mathbb{Q}_d} \geq ...\phi_{n_x n_x}^{\mathbb{Q}_d}$, and $\mathbf{\Sigma} = \mathbf{I}$. Additionally, we impose that the GDP risk premium component of the breakeven must be negative during our sample period. This seems reasonable because it requires that GDP growth was expected to be relatively low during "bad times" (that is, when the marginal utility is relatively high), as discussed in Section 1.2.[10]

1.4.2 Maximum-Likelihood Estimator

The standard approach for estimating a joint ATSM of yields on two classes of assets is to use data from both of those asset classes. For example, suppose that we observed a vector of equity yields $\mathbf{y}_{t,d} = \left[y_{t,d}^{(n_{d,1})}, y_{t,d}^{(n_{d,2})}, ..., y_{t,d}^{(n_{d,D})}\right]^{\prime}$ and a vector of GDP-linked bond yields $\mathbf{y}_{t,g} = \left[y_{t,g}^{(n_{g,1})}, y_{t,g}^{(n_{g,2})}, ..., y_{t,g}^{(n_{g,G})}\right]^{\prime}$. With the additional assumption that all yields are measured with error, we could compute a maximum likelihood estimator of the free parameters. For example, the measurement equation of the joint model could be

[10] Econometrically, we can think of the restriction in a Bayesian sense: it implies a prior distribution that puts zero weight on in-sample risk premium estimates that are inconsistent with this economic intuition. Of course we would have hoped that the risk premium would turn out to be negative without imposing the prior. In practice, we find that in the absence of the restriction the GDP risk premium is sometimes implausibly positive. We interpret this as an indication that the model finds it hard to pin down the unconditional mean GDP risk premium from the sample data alone, which is consistent with previous findings about the difficulty of estimating unconditional means in term structure models (see, for example, Kim and Orphanides, 2012). Imposing the additional prior helps to ensure that the unconditional mean is reasonable.

given by

$$\begin{bmatrix} \mathbf{y}_{t,d} \\ \mathbf{y}_{t,g} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_d \\ \mathbf{A}_g \end{bmatrix} + \begin{bmatrix} \mathbf{B}_d \\ \mathbf{B}_g \end{bmatrix} \mathbf{x}_t + \begin{bmatrix} \mathbf{w}_{t,d} \\ \mathbf{w}_{t,g} \end{bmatrix}, \tag{1.32}$$

where the definitions of $\mathbf{A}_d$, $\mathbf{A}_g$, $\mathbf{B}_d$, and $\mathbf{B}_g$ follow from equations (1.27), (1.28), (1.30), and (1.31); $\mathbf{w}_{t,d} \sim \mathcal{NID}\left(\mathbf{0}, \sigma^2_{w_d} \times \mathbf{I}\right)$ and $\mathbf{w}_{t,g} \sim \mathcal{NID}\left(\mathbf{0}, \sigma^2_{w_g} \times \mathbf{I}\right)$.

However, because we do not observe yields on GDP-linked bonds, we must adopt an alternative approach. We instead include proxies for current GDP growth and expectations of future GDP growth at various horizons in the measurement equation, alongside equity yields, that is,

$$\begin{bmatrix} \mathbf{y}_{t,d} \\ \mathbf{s}_t \end{bmatrix} = \begin{bmatrix} \mathbf{A}_d \\ \mathbf{s}_0 \end{bmatrix} + \begin{bmatrix} \mathbf{B}_d \\ \mathbf{S}_1 \end{bmatrix} \mathbf{x}_t + \begin{bmatrix} \mathbf{w}_{d,t} \\ \eta_t \end{bmatrix}. \tag{1.33}$$

Here $\mathbf{s}_t = \left[g_t, \overline{g}_{t+25,t+36}, \overline{g}_{t+37,t+48}, \overline{g}_{t+49,t+60}, \overline{g}_{t+61,t+120}\right]'$, where $\overline{g}_{t+h,t+i}$ is the expected average growth rate of nominal GDP between periods $t+h$ and $t+i$, that is, $\overline{g}_{t+h,t+i} = \mathbb{E}_t\left[\frac{1}{12}\sum_{m=0}^{11} g_{t+h+m}\right]$. Summarizing, we include average GDP growth expectations 3, 4, and 5 years ahead, as well as the average GDP growth expectation from 6 to 10 years ahead. We assume that that measurement error on $\mathbf{s}_t$ is given by $\eta_t \sim \mathcal{NID}\left(\mathbf{0}, \sigma^2_\eta \times \mathbf{I}\right)$.[11] Strictly speaking, we could identify the parameters g_0 and $\mathbf{g}_1$ if we only included g_t in the measurement equation alongside equity yields and omitted the surveys of future GDP growth. However, including the expectations of future GDP growth provides additional observations with which to infer g_0 and $\mathbf{g}_1$ in addition to the $\mathbb{P}$ dynamics of the pricing factors in a short sample (similar to the rationale for including surveys of nominal interest rates in ATSMs of conventional yields proposed by Kim and Orphanides, 2012).

Equations (1.11) and (1.33) make up a linear-Gaussian state-space system, so we can estimate the free parameters of the model by maximum likelihood, using the Kalman filter to evaluate the likelihood function. Then with the resulting estimates of the pricing factors and parameters we can compute predicted GDP-linked bond yields according to

[11] Given the very accurate fit of the GDP series (see Figure 1.3), it does not make a material difference to results whether we allow for measurement error on it or not. If we did not, we could rotate the factors and have one to mimick GDP dynamics.

(1.29).

It is worth stressing the key assumption that underlies our estimation approach: it implicitly assumes that GDP growth is fully "spanned" by equity yields. To understand the importance of the spanning assumption, suppose that we can partition the factors as $\mathbf{x}_t = \left[\mathbf{x}'_{t,s}, \mathbf{x}'_{t,u}\right]'$, where $\mathbf{x}_{t,s}$ is a vector of $n_x - n_u$ factors spanned by equity yields and $\mathbf{x}_{t,u}$ is a vector of n_u factors unspanned by equity yields. From equation (1.28), we can see that $\mathbf{x}_{t,u}$ will be unspanned by equity yields if the loadings of the short-term equity yields take the form $\rho_{d,1} = \left[\rho'_{d,1,s}, \mathbf{0}'_{n_u \times 1}\right]'$ and if we can partition $\mathbf{\Phi}^{\mathbb{Q}_d}$ conformably as

$$\mathbf{\Phi}^{\mathbb{Q}_d} = \begin{bmatrix} \mathbf{\Phi}^{\mathbb{Q}_d}_{ss} & \mathbf{0} \\ \mathbf{\Phi}^{\mathbb{Q}_d}_{us} & \mathbf{\Phi}^{\mathbb{Q}_d}_{uu} \end{bmatrix}.$$

Under these conditions, the parameters $\mathbf{\Phi}^{\mathbb{Q}_d}_{us}$ and $\mathbf{\Phi}^{\mathbb{Q}_d}_{uu}$ will be unidentified, that is, we cannot infer the dynamics of $\mathbf{x}_{t,u}$ from equity yields and we cannot use the model to infer GDP-linked bond yields. In effect, we are assuming that these zero restrictions do not hold in practice.[12]

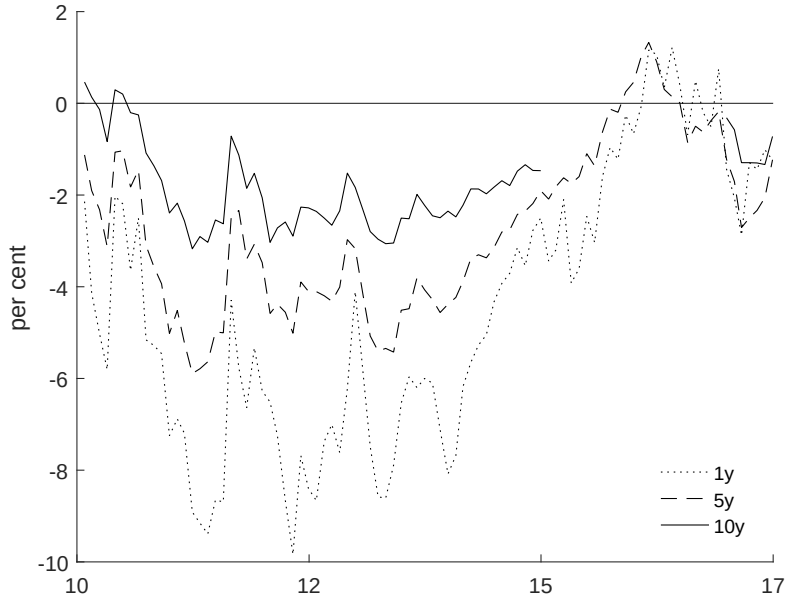
1.4.3 Data

We estimate our model of equity yields using end-month U.S. zero-coupon equity yields with maturities of 1, 2, 3, 5, 7, and 10 years over a sample period from January 2010 to June 2017.[13] We construct these zero-coupon equity yields from S&P 500 dividend

[12] As pointed out by Duffee (2011) in the context of ATSMs of conventional bond yields, they are "knife-edge" restrictions: in the absence of measurement error on equity yields, even a tiny non-zero loading of the short-term equity yield on GDP growth would mean that we can fully identify $\mathbf{\Phi}^{\mathbb{Q}_d}$. However, in practice, in the presence of measurement error the loading may be sufficiently small that GDP growth is "partly hidden" (borrowing another term from Duffee, 2011)—that is, the dynamics of GDP growth under the $\mathbb{Q}_g$ measure may be estimated imprecisely.

[13] Although data are also available for an earlier period, we found that including the sharp swings in prices around the global financial crisis resulted in these outliers dominating the whole sample and leading to implausible results. Therefore, we decided to start our sample in 2010. During our sample there are a small number of missing observations for the 10-year equity yields, which is easily dealt with using the Kalman filter.

Figure 1.1 EQUITY YIELDS 2010-2017



Note: Monthly data on US spot equity at various maturities. Equity yields are constructed following van Binsbergen et al. (2013) and using dividend swaps prices from Goldman Sachs Global Investment Research and dividend indices from Datastream, all based on the S&P 500. The sample period is from January 2010 to June 2017.

swap prices provided by Goldman Sachs and dividend indices published by Datastream, following the approach of van Binsbergen et al. (2013).[14] Figure 1.1 plots equity yields at selected maturities. As shown in Table 1.1, the average equity yield curve is upward sloping, with standard deviations that decrease with maturity. Equity yields are highly persistent, with first-order autocorrelation coefficients close to one.[15] And, as shown in Table 1.2, three principal components are sufficient to explain about 99.9 percent of the variation in the cross-section of equity yields, which is similar to the well-known result for conventional bond yields (see, for example, Litterman and Scheinkman, 1991). As is standard in the literature on no-arbitrage models of conventional bonds, we therefore adopt a three-factor specification for our models of equity yields.

[14]For a detailed discussion of the properties of the underlying assets see Manley and Mueller-Glissmann (2008).We use dividend futures, which prices are very close to those of swaps, from October 2016 to June 2017 for data availability reasons.

[15]Summary statistics are comparable to those in van Binsbergen et al. (2013), with small differences owing to the fact that we show these for spot yields rather than forwards.

Table 1.1 EQUITY YIELDS SUMMARY STATISTICS

Maturities	1y	2y	3y	5y	7y	10y
Mean (%)	-4.44	-4.47	-3.77	-2.73	-2.02	-1.81
Stdev (%)	3.01	2.63	2.31	1.81	1.55	0.93
AR(1)	0.92	0.93	0.93	0.94	0.94	0.87

Note: Monthly data on US spot equity yields are constructed following van Binsbergen et al. (2013) and using dividend swaps prices from Goldman Sachs Global Investment Research and dividend indices from Datastream, all based on the S&P 500. The sample period is from January 2010 to June 2017.

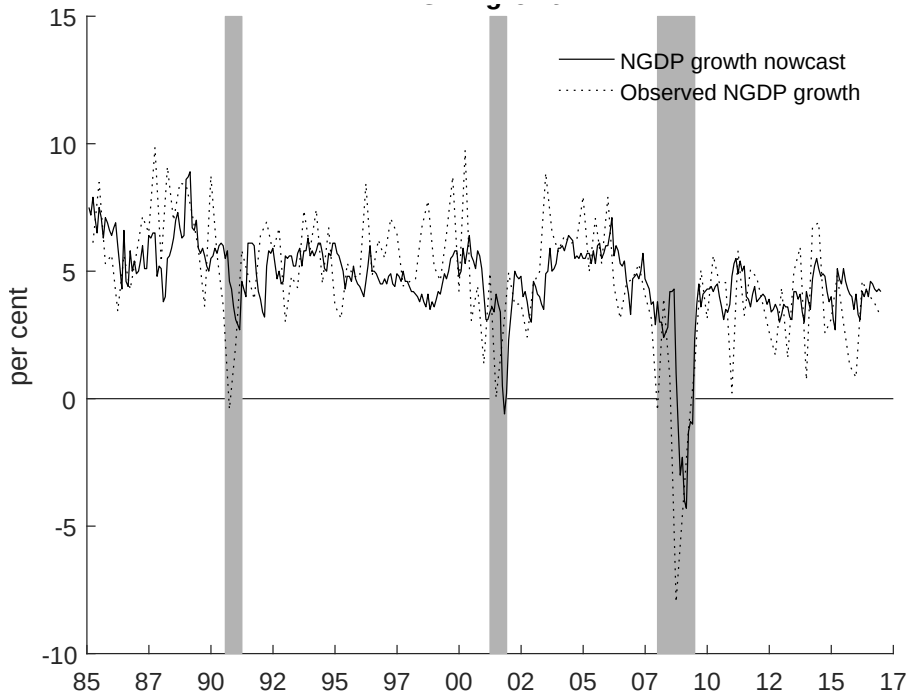
Table 1.2 EQUITY YIELDS PRINCIPAL COMPONENT ANALYSIS

Cumulative variance explained by:		
PC1	PC2	PC3
94.54	98.63	99.87

Note: The table shows the cumulative variance of US spot equity yields explained by the first three principal components. Monthly data on US spot equity yields are constructed following van Binsbergen et al. (2013) and using dividend swaps prices from Goldman Sachs Global Investment Research and dividend indices from Datastream, all based on the S&P 500. The sample period is from January 2010 to June 2017.

As a proxy for current-month nominal GDP growth, we add together survey-based measures of expected current-quarter real GDP growth and growth in the GDP deflator; specifically, we use the mean expected current-quarter growth rates in real GDP growth and the GDP deflator reported by respondents to monthly Blue Chip Economic Indicators surveys. This survey-based proxy measure of nominal GDP growth has two important advantages relative to official GDP data. First, the survey-based measure is available at a monthly frequency, rather than at the quarterly frequency with which official data are published. Second, as shown in Figure 1.2, the survey-based measure smoothes out much of the high-frequency volatility in official GDP data while still capturing the low-frequency variation. While the Kalman filter should in principle allow the model to determine how much of the variation in the official data represents genuine low-frequency movements in underlying GDP growth and how much reflects noise in the form of measurement error, preliminary analysis showed that when we attempt to estimate the models using official GDP data (at a quarterly frequency) they tend to suffer from one of two problems. In some cases,

Figure 1.2 NGDP GROWTH: OBSERVED AND NOWCAST



Note: Time series comparison of NGDP nowcasts and observed NGDP growth. NGDP nowcasts are from Wolters Kluwer Legal and Regulatory Solutions U.S. Blue Chip Economic Indicators. Observed NGDP is from FRED

the models failed to fit a material part of the variation in observed GDP growth—that is, they interpreted almost all of the variation in GDP growth, including the low-frequency variation, as measurement error. In turn, this implied that the loadings of GDP growth on the factors in equation (1.7) were extremely imprecisely estimated. In other cases, the models devoted a single factor to fitting nominal GDP growth extremely closely—that is, they interpreted essentially none of the variation as measurement error—with this "GDP growth factor" being only very weakly correlated with variation in observed asset prices. In turn, this implied that the $\mathbb{Q}$ dynamics of this factor were extremely imprecisely estimated. Thus, in both cases, predicted GDP-linked bond prices were often very imprecisely estimated and point estimates tended to be highly implausible. In practice, we found that using the smoother survey-based proxy resulted in much more plausible estimates of GDP risk premia.

The survey-based measures of longer-term GDP growth expectations are taken from the

Table 1.3 EQUITY YIELDS FITTING ERRORS

Maturities	1y	2y	3y	5y	7y	10y	g_t
Yields only	2.9	10.2	9.3	7.8	5.5	8.6	
With GDP growth	51.5	27.4	27.3	24.4	32.6	41.0	0.8

Note: The table shows the fitting errors on equity yields of (i) a model with yields only and (ii) a model with equity yields and NGDP growth (and surveys). All units are in basis points. Reported fitting errors are Root Mean Squared Errors (RMSEs). RMSEs for surveys (not reported) are around 30 bps on average (available upon request). Monthly data on US spot equity yields are constructed following van Binsbergen et al. (2013) and using dividend swaps prices from Goldman Sachs Global Investment Research and dividend indices from Datastream, all based on the S&P 500. The sample period is from January 2010 to June 2017.

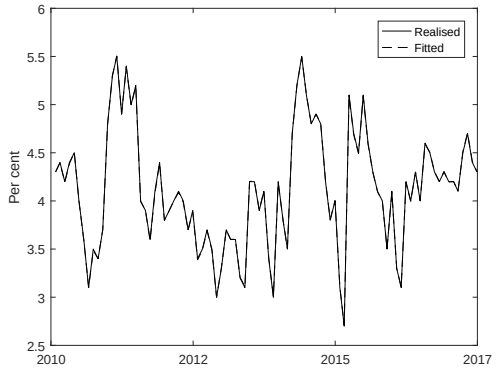
semi-annual Blue Chip Economic Indicators long-range surveys of nominal GDP. In March and October of each year, Blue Chip ask survey respondents to report their expectations of nominal GDP growth for future calendar years; we linearly interpolate between the mean responses to compute measures of expectations at fixed horizons. We then linearly interpolate over time in order to obtain a monthly series.

Finally, when we compute the breakevens between yields on conventional and GDP-linked bonds, we use estimates of zero-coupon conventional yields from the data set of Gurkaynak et al. (2007), which are updated by staff at the Board of Governors of the Federal Reserve System.

1.5 Results

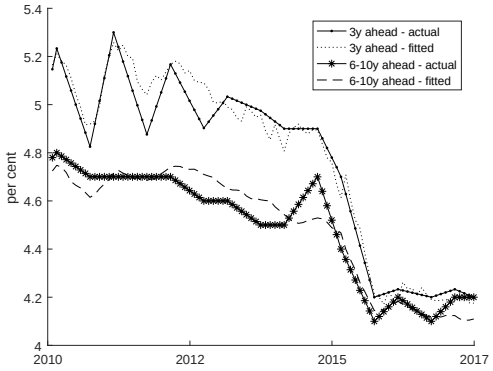
In this section we present results from the estimation of our joint model of GDP-linked bond yields and equity yields. In Section 1.5.1, we analyse the model fit of both equity yields and GDP growth. In Section 1.5.2 we analyse the contribution of different model factors to forecast error variance decompositions. In Section 1.5.3, we focus on GDP-linked bonds: we report results for their predicted yields, "breakevens" with respect to conventional government bonds, and the decomposition of the breakeven into GDP growth expectations and GDP risk premia.

Figure 1.3 FIT OF NGDP GROWTH NOWCAST



Note: Observed NGDP nowcasts and model fit of that series. NGDP nowcasts are from Wolters Kluwer Legal and Regulatory Solutions U.S. Blue Chip Economic Indicators.

Figure 1.4 FIT OF SURVEY-BASED NGDP GROWTH EXPECTATIONS



Note: Observed NGDP growth expectations at various horizons and model fit of those series. NGDP expectations (survey-based) are from Wolters Kluwer Legal and Regulatory Solutions U.S. Blue Chip Economic Indicators.

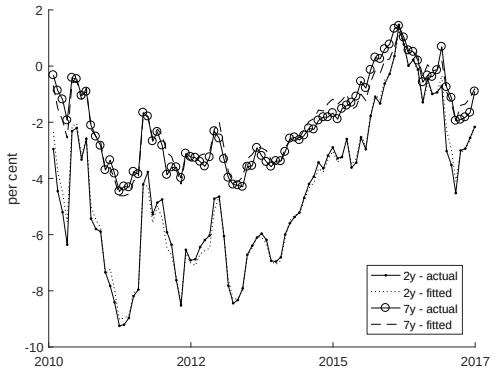
1.5.1 Impact of Including GDP growth

Table 1.3 shows root mean squared errors (RMSEs) between observed and model-implied equity yields, both for our joint model and for a simpler model estimated using only data on equity yields (that is, without using data on current and expected future GDP growth, and therefore not estimating the parameters g_0 and $\mathbf{g}_1$). A model estimated using only data on equity yields achieves a tight fit to the data, with RMSEs between about 3 and 10 basis points, depending on the maturity. Figures 1.3 and 1.4 show our joint model that includes data on current and expected future GDP growth closely matches the proxy for current GDP growth and the survey-based expectations of future NGDP growth. As we might expect, the inclusion of data on GDP growth—which are additional series to be matched with the same number of factors—worsens the fit of the model to equity yields, with RMSEs for equity yields rising to between about 25 and 50 basis points. Nevertheless, the model can still fit the broad movements in equity yields, as it can be seen in Figure 1.5, which shows the observed and model-implied equity yields at selected maturities.

1.5.2 Factor Analysis

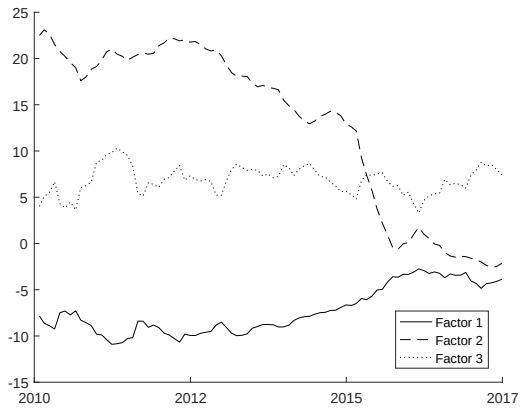
Figure 1.6 shows the time series of the joint model's three latent factors. In terms of the link between these factors and the observable series considered, Table 1.4 reports the loadings of all of the observable series on the factors and Table 1.5 shows the 1-month ahead forecast error variance decomposition of the series considered in our joint model. The overall variance of the forecast errors is split into the shares explained by each of the three factors. It can be seen that a large proportion of the variation in equity yields is explained by the first factor, on which yields of different maturities load evenly. This first factor also explains a large proportion of the variation in NGDP growth. The second factor seems to track long-term NGDP growth expectations relatively closely, while the third factor explains a non-negligible share of variation in NGDP growth and shorter-term NGDP expectations.

Figure 1.5 FIT OF EQUITY YIELDS



Note: Observed equity yields at various maturities and model fit of those series. Observed equity yields are constructed using dividend swaps prices from Goldman Sachs Global Investment Research and dividend indices from Datastream.

Figure 1.6 TIME SERIES OF MODEL FACTORS



Note: Estimated latent factors of joint model.

It is important to note that more than two thirds of the variation in NGDP growth are explained by the same factor that explains most of the variation in equity yields. This suggests that the majority of the information in NGDP growth should be spanned by equity yields, which lends support to the spanning assumption underpinning our identification

strategy.

Table 1.4 LOADINGS OF OBSERVABLES ON MODEL LATENT FACTORS

	Factor 1	Factor 2	Factor 3
1-y equity yield	2.90	0.49	0.54
2-y equity yield	2.48	0.43	0.27
3-y equity yield	2.15	0.37	0.18
5-y equity yield	1.65	0.29	0.11
7-y equity yield	1.32	0.23	0.08
10-y equity yield	0.98	0.17	0.05
NGDP	2.15	0.54	1.38
3-y expected NGDP	0.17	0.09	0.12
4-y expected NGDP	0.06	0.05	0.05
5-y expected NGDP	0.01	0.04	0.02
6 to 10-y expected NGDP	-0.01	0.02	0.00

Note: Loadings of observable series on estimated latent factors, corresponding to $\mathbf{B}_d$ and $\mathbf{S}_1$ in Section 1.4.2.

Table 1.5 FORECAST ERROR VARIANCE DECOMPOSITION - 1 MONTH AHEAD

y_t	Factor 1	Factor 2	Factor 3
1-y equity yield	0.94	0.03	0.03
2-y equity yield	0.96	0.03	0.01
3-y equity yield	0.96	0.03	0.01
5-y equity yield	0.97	0.03	0.00
7-y equity yield	0.97	0.03	0.00
10-y equity yield	0.97	0.03	0.00
NGDP growth	0.68	0.04	0.28
3-y expected NGDP growth	0.57	0.14	0.29
4-y expected NGDP growth	0.38	0.35	0.27
5-y expected NGDP growth	0.08	0.75	0.17
6 to 10-y expected NGDP growth	0.07	0.91	0.01

Note: Model-implied forecast error variance decomposition (one month ahead) for forecasted series, split by contributions from shocks to each of the three factors considered.

1.5.3 GDP-Linked Bond Yields and GDP Risk Premia

We now turn to the relative cost of borrowing using conventional and GDP-linked bonds, as measured by the breakeven rate between the two yields. To compute the breakeven, we subtract the model-implied GDP-linked bond yield from the observed government bond yield with the same maturity.[16] As explained in Section 1.2, we can decompose the breakeven rate into the expectation of average expected GDP growth over the life of the underlying bond and an additional GDP risk premium that compensates investors for exposure to GDP growth risk. Figure 1.7 shows the evolution of this breakeven rate at selected maturities over the sample. Breakeven rates are typically positive throughout; that is, predicted GDP-linked bond yields are lower than yields on conventional bonds.

Figure 1.7 GDP-LINKED BONDS BREAKEVEN RATES

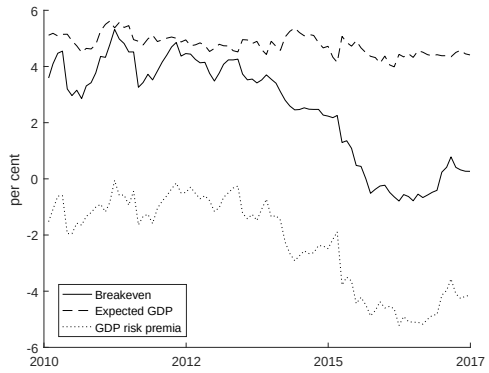


Note: Model-implied breakeven rate between GDP-linked bonds and nominal bonds at various maturities. Nominal bonds data used to compute breakevens come from the Federal Reserve Board.

To decompose the breakevens into expected average GDP growth and the GDP risk pre-

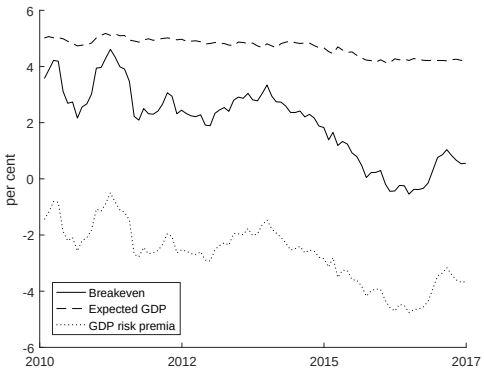
[16] Here, we use the estimated zero-coupon Treasury yields presented by Gurkaynak et al. (2007) and updated by the staff of the Board of Governors of the Federal Reserve System.

Figure 1.8 2-YEAR GDP-LINKERS BREAKEVEN RATE DECOMPOSITION



Note: Decomposition of fitted GDP-linked bonds breakeven rate into NGDP growth expectations and NGDP risk premia. Nominal bonds data used to compute breakevens come from the Federal Reserve Board

Figure 1.9 7-YEAR GDP-LINKERS BREAKEVEN RATE DECOMPOSITION



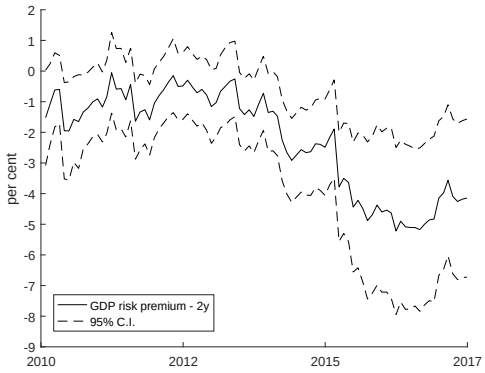
Note: Decomposition of fitted GDP-linked bonds breakeven rate into NGDP growth expectations and NGDP risk premia. Nominal bonds data used to compute breakevens come from the Federal Reserve Board

mium, we subtract the model-implied expected average GDP growth from the breakeven computed above.[17] Figures 1.8 and 1.9 show this decomposition for 2- and 7-year GDP-linked bonds respectively. Average GDP growth expectations are sensible, at around 4.5 percent, and are relatively stable over time. If anything, model-implied expected GDP growth displays a slight downward trend over the sample, with the average GDP growth across maturities falling from almost 5 percent to around 4.2 percent over the sample. Estimated GDP risk premiums are negative across maturities as expected, pushing up on the yield of GDP-linked bonds by between about 0.5 and 4.5 percentage points. It is worth noting that, despite substantial differences between our approach and previous attempts to quantify GDP risk premiums, average estimates from our exercise are similar to estimates from previous papers using US data (Kamstra and Shiller, 2009, Bowman and Naylor, 2016).

Figures 1.10 and 1.11 show the dynamics of GDP risk premiums. We follow Kim and Orphanides (2012) and use the Delta method to compute 95 percent confidence intervals for GDP risk premiums. The dynamics of GDP risk premiums are fairly similar across

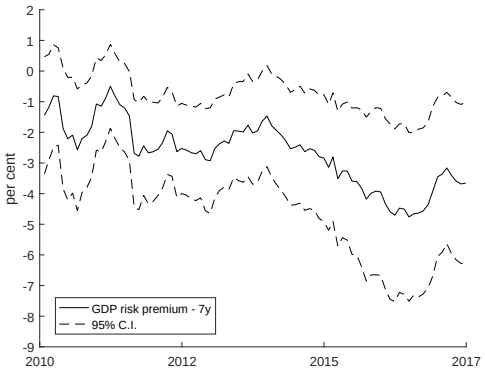
[17] GDP growth expectations can be easily solved for using equations (1.7) and (1.11).

Figure 1.10 2-YEAR GDP RISK PREMIUM



Note: GDP risk premium component of model-implied 2-year GDP-linked bond yields. Confidence intervals are estimated using the Delta method.

Figure 1.11 7-YEAR GDP RISK PREMIUM



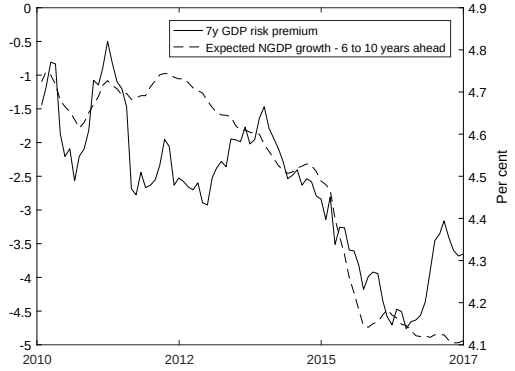
Note: GDP risk premium component of model-implied 7-year GDP-linked bond yields. Confidence intervals are estimated using the Delta method.

maturities, although the confidence intervals are relatively wide in both cases. In turn, Figure 1.12 shows that the trend down on GDP risk premia (which pushes up on the yield of GDP-linked bonds) coincides with a downward revision in expected nominal GDP growth at medium to long horizons. This decline in expected long-run growth could reflect increasing concerns of a persistent period of slow growth, sometimes referred to as "secular stagnation" (see, for example, Summers, 2015). Our results suggest that the premium that investors require to insure themselves against GDP risk increased in absolute value over the period, which seems intuitive.

Although it is helpful to see sample estimates of GDP risk premiums, prospective issuers of future GDP-linked bonds are likely more interested in the unconditional distribution of those risk premiums. Figure 1.13 shows the unconditional (population) mean of GDP risk premiums for a range of maturities. For these purposes, we assume that the unconditional average of the conventional yield curve is equal to its sample average from June 1961 to December 2017. The unconditional average term structure of GDP risk premiums is negative and upward sloping, that is, GDP risk premiums are more negative (making GDP-linked bond yields larger) at shorter maturities. This seems intuitive if we consider the relatively low persistence of shocks to NGDP growth, which should hence be less important over the lifespan of bonds with longer maturities. In terms of magnitudes,

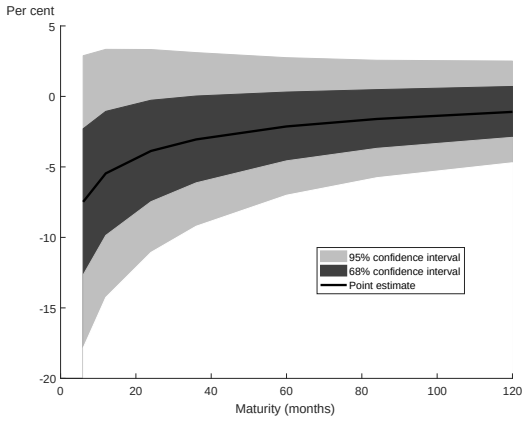
our model yields unconditional risk premia estimates in the region of -7 percent to -4 percent when considering maturities between 6 months and 2 years, and which decrease monotonically in absolute value, reaching -1 percent at the 10-year maturity. However, it should be noted that error bands around these point estimates are relatively wide.

Figure 1.12 GDP RISK PREMIUM AND EXPECTED NGDP GROWTH



Note: Time series of model-implied (7-year) GDP risk premium and expected NGDP growth 6 to 10 years ahead. Nominal bonds data used to compute breakevens come from the Federal Reserve Board.

Figure 1.13 TERM-STRUCTURE OF UNCONDITIONAL (POPULATION) MEAN OF NGDP RISK PREMIA



Note: Term-structure of model-implied unconditional (population) mean of NGDP risk premia. Nominal bonds data used to compute breakevens come from the Federal Reserve Board and cover the 1961-2017 period. Confidence intervals are estimated using the Delta method.

1.6 Conclusions

This paper uses a no-arbitrage term structure model of equity yields computed from the prices of dividend swaps to estimate the possible yields on hypothetical bonds with cash-flows indexed to the level of U.S. nominal GDP. This novel approach for estimating the relative cost of conventional and GDP-linked bonds avoids many of the pitfalls of previous approaches. In particular, our approach uses a flexible specification of investors' preferences which is known to capture the risk premiums on existing assets; it avoids the need to make possibly unrealistic assumptions about the covariance of returns on GDP-linked bonds with a market portfolio; and it provides an estimate of GDP risk premiums

that varies with maturity.

In short, our model predicts that U.S. nominal GDP-linked bonds would typically have yields lower than those on conventional Treasury bonds with the same maturity in our sample from 2010 to 2017. Positive expected future GDP growth lowers the yield on GDP-linked bonds relative to conventional bonds, which more than offsets the estimated GDP risk premium demanded by investors for holding GDP risk. GDP risk premia push up yields of hypothetical nominal GDP-linked bonds. The unconditional average of these premia is negative and upward sloping; that is, premia in short maturitity bonds push up yields by magnitudes in the range of 4 to 7 percentage points, decreasing monotonically in absolute value to reach approximately 1 percentage point at the 10-year maturity.

2 | Global Banks and Synthetic Funding: The Benefits of Foreign Relatives

This chapter is based on joint work with Matias Ossandon-Busch and Dennis Reinhardt.

Abstract

This paper examines the effect of dislocations in FX swap markets ('CIP deviations') on bank lending. Using data from UK banks we show that when the cost of obtaining swap-based funds in a particular foreign currency increases, banks reduce the supply of cross-border credit in that currency. This effect is increasing in the degree of banks' reliance on swap-based FX funding. Access to foreign relatives matters as banks employ internal capital markets to shield their cross-border FX lending supply from the described channel. Partial substitution occurs from banks outside the UK not affected by changes in synthetic funding costs.

Keywords: cross-border bank lending, covered interest rate parity deviations, FX swaps, internal capital markets.

JEL Codes: F34, G21.

2.1 Introduction

The international market for cross-border bank lending is characterised by the widespread origination of claims in currencies which are 'foreign' from the lenders' perspective. As of end-2016, around 82 percent of global cross-border claims in US dollars were originated outside the US, while 35 percent of euro claims came from jurisdictions outside the Euro Area.[1] This feature of the international financial landscape highlights the importance of FX funding markets, on which banks rely to fund the global supply of cross-border foreign-currency (FX) loans (Bruno and Shin, 2015, Ivashina et al., 2015, Correa et al., 2016).

One of these markets for FX funds, namely that of FX swaps (usually called 'synthetic' funding), has seen large dislocations in its pricing since the financial crisis, leading to the emergence of apparent arbitrage opportunities ('CIP deviations').[2] These dislocations have been the focus of a series of recent studies (Avdjiev et al., 2019, Du et al., 2018, Sushko et al., 2016, Cenedese et al., 2019, Cerutti et al., 2019), which have nevertheless largely focused on their causes but not the consequences for other variables of interest.[3]

In this paper, we expand the understanding of how dislocations in the market for FX swaps directly affect the stability of cross-border credit supply. We find that increases in the relative cost of synthetic FX funding lead to a reduction in the supply of cross-border credit denominated in the currency affected. Our analysis shows that these dynamics are not exclusive of crisis periods and that the effect on lending (intensive margin) is increasing in the size of the dislocation (as measured by CIP deviations). An important element of our identification strategy is to employ cross sectional variation in our sample to show that the lending of banks' with greater reliance on swap-based FX funding is more affected

[1] The number for the US is lower (i.e. 75 percent) when counting USD originated in the Cayman Islands towards US originated claims. See Figure 2.1 for data sources.

[2] FX swap markets allow banks with limited access to foreign currency funding markets to tap FX liquidity by swapping local currency funding without incurring foreign exchange risk.

[3] One exception is Liao (2019), who relates CIP deviations to corporate debt issuance.

than the lending of banks which are less reliant. We also show that the effect of these dislocations in FX swap markets on bank lending is particularly acute in combination with institutional frictions that prevent banks to access to alternative FX funding abroad. When these frictions are alleviated — for instance via access to networks of foreign 'relatives'— the lending effect of FX swap shocks weakens. The dataset we rely on to uncover these effects offers rich bank-level information for banks operating from the UK, an ideal vantage point given that the UK is the single largest global originator of cross-border bank credit, a large share of which is denominated in currencies other than sterling.

Why would we expect changes to the cost of swap-based FX funding to affect banks' lending decisions? At first glance, FX swaps are only one of several alternative FX funding channels banks can rely on to access FX liquidity. If these alternative FX funding channels are available for banks – i.e. in a world of frictionless and well integrated FX funding markets – changes to the costs of accessing FX swap markets should only alter banks' funding mix, without translating into disruptions in banks' credit supply in different currencies. In reality, however, some banks may face restrictions in accessing funding sources. If frictions existed and banks had limited access to on-balance-sheet FX funding, then these institutions may resort to swap-based FX funding as a way of overcoming geographical, regulatory or informational barriers. In this scenario, banks with large reliance on FX swap funding could be expected to adjust their balance sheet by more once funding shocks in FX swap markets occur. We test for this hypothesis by analysing heterogeneities in the reaction of bank lending to shocks to the cost of synthetic funding, particularly as a function of banks' access to alternative funding sources, including internal capital markets.

In order to measure funding shocks in FX swap markets we rely on the time series of deviations from the covered interest rate parity condition (in what follows CIP deviations) between sterling on the one side and US dollar and euro on the other, between 2003 and 2016. CIP deviations measure the difference between the 'cash' or money market interest

rate in a given foreign currency and the corresponding synthetic funding rate.[4] The well-established CIP principle in international finance states that such CIP deviations should tend to zero. We exploit violations in the CIP condition observed most markedly since 2008 to proxy for funding cost shocks – positive and negative – affecting the availability of FX swaps of sterling vis-á-vis US dollars and euros. For this purpose, we build on previous contributions documenting how CIP deviations reflect changing funding conditions in FX swap markets (see Ivashina et al., 2015).

The study of the effect of FX synthetic funding shocks on cross-border bank lending comes with strong data requirements. In particular, we base our analysis on an identification strategy that exploits balance sheet data on global banks operating from the UK, tracing their cross-border assets and liabilities (and other balance sheet characteristics) on a destination country-currency-quarter dimension. Adapting the established literature (e.g. Cetorelli and Goldberg, 2011; Ongena et al., 2015), we define the destination country-currency dimension as banks' relevant markets and estimate the effect of FX synthetic funding shocks on currency-specific cross-border lending, conditional on banks' ex-ante exposure to FX synthetic funding. The richness of the data allows us to saturate the empirical model with country-currency-time fixed effects, absorbing non-observable time-varying confounders such as borrowers' (currency-specific) demand shocks. By observing banks' on-balance-sheet FX liabilities, we can also explore heterogeneities in the response to FX synthetic funding shocks depending on banks' access to alternative FX funding markets. We implement this identification strategy on a sample that covers the activities of 106 banks lending to 70 countries between 2003 and 2016.

Our results suggest that shocks in global synthetic FX funding markets significantly affect the supply of cross-border FX lending by banks located in the UK. Importantly, the effect on lending we document is increasing in the degree of banks' reliance on synthetic

[4]This latter interest rate results from raising funds in banks' domestic currency and using the proceeds to buy foreign currency while hedging the FX risk of repayment by using an FX forward contract. Following convention, a negative CIP deviation of sterling vis-á-vis the US dollar reflects a situation in which direct US dollar funding in cash markets is cheaper than the synthetic alternative.

funding. In a second step, we explore whether banks' access to alternative (on-balance-sheet) FX funding sources shields their supply of FX cross-border lending. Indeed, we find that large access to alternative sources of FX funding shields banks' cross-border FX lending supply from synthetic FX funding shocks, but only if such access occurs via internal capital markets. We corroborate these findings by documenting how banks effectively draw FX funds from their internal (foreign) network in these events; that is, there are *advantages of having foreign relatives* in these instances.

In a final exercise, and in order to estimate the aggregate effect of shocks to the cost of synthetic funding, we explore potential substitution effects from borrowers into unaffected lenders. By aggregating data at the destination country-currency level, we find that banks from the relevant currency areas tend to step in and increase lending in the event of a retreat of UK banks when synthetic funding shocks hit, particularly in the case of the most affected markets. However, this does not typically lead to a full offset of the cut back in UK-originated lending.

2.1.1 Related Literature

Even though the reliance on synthetic FX funding as a share of total FX funding by banks has been significant over the past decades, the implications of funding shocks in these markets for cross-border lending have not yet been investigated to the best of our knowledge.[5] More generally, the literature on international banking has documented how liquidity shocks in global bank funding markets can have real effects via cross-border linkages (Schnabl, 2012, Ongena et al., 2015). Considering the large share of cross-border claims denominated in foreign currencies from source-countries' perspective, shocks to FX swap markets could play an important part in this transmission mechanism. By exploring the conditions under which global banks' reliance on FX swap funding affect their cross-border FX credit supply we are, to the best of our knowledge, the first to document

[5] Borio et al. (2017) come up with a figure for the share of US dollar synthetic funding in the neighborhood of 10 per cent.

the existence and functioning of a cross-border lending channel of funding shocks to the synthetic FX funding market.

Our work contributes to three strands of the literature. The first relates to studies documenting how market imperfections in bank funding markets affect credit supply in general, and the provision of cross-border credit by globally active banks in particular. Since early contributions by Peek and Rosengren (1997) and Peek and Rosengren (2000), which study the cross-border transmission of financial shocks by Japanese banks in the US, the literature has profusely documented how different types of liquidity shocks can affect banks' lending behavior provided that financial frictions exist. Previous studies have linked adjustments in (aggregate) cross-border credit supply to banking groups internal liquidity conditions during the crisis (Cetorelli and Goldberg, 2012a,b,c), to information asymmetries in the market for syndicated loans (De Haas and van Horen, 2012; Giannetti and Laeven, 2012), and to banking groups' exposure to wholesale interbank markets during the global financial crisis (De Haas and van Lelyveld, 2014). In particular, Cetorelli and Goldberg (2012a) show how global banks managed liquidity from a group-level perspective during the global financial crisis by exploiting their network of bank branches worldwide when facing liquidity shocks. Compared to these studies we are able to focus on a detailed channel of intragroup support in the form of specific currencies to address reliance on FX synthetic funding in times when such funding becomes more expensive. More specifically, compared to the work by Cetorelli and Goldberg, we find that this support channel is at work for both parent banks (as they find) but also for foreign affiliate branches. And compared to De Haas and van Lelyveld (2014) we find evidence for intragroup support to affiliates outside financial crisis times.[6] These studies do not focus on the FX composition of such lending and do not address the role of banks' reliance on FX synthetic funding for the stability of cross-border banking flows in particular foreign currencies.

A second strand of literature we relate to focuses specifically on the effect of FX funding

[6]They find that during the GFC parent banks did not act as significant providers of intragroup support.

costs on banks' credit supply. Acharya et al. (2017) find that after the collapse of the asset-backed commercial paper market in 2007 foreign banks in the US charged higher spreads for syndicated loans denominated in US dollars compared to non-US dollars loans. Correa et al. (2016) show that US branches of European banks were affected by a shock to wholesale deposits from US money market funds around the time of the European sovereign debt crisis and reduced their lending supply to US firms. The affected branches received additional funding from their parent banks, but not enough to offset the lost deposits. While these studies focus on the syndicated loan market within the US, we widen the scope and consider overall lending globally (albeit originated in the UK) with particular attention given to currencies of denomination. Also, our source of shocks is not restricted to periods of wide market dislocations, but have instead happened frequently since 2008. Therefore, and in comparison to previous studies, we concentrate on a different financial friction (namely global banks' reliance on FX synthetic funding as a mean to overcome fragmented FX funding markets) and look at the effect of shocks on a broader set of banks claims, denominated in a range of currencies and reaching a wide range of destinations globally.

Particularly noteworthy for our analysis is the study of Ivashina et al. (2015).[7] This article provides a theoretical framework in which a creditworthiness shock affects foreign banks' US dollar lending as US dollar wholesale funding in US markets is withdrawn. Banks respond to this shock by increasing their reliance on US dollar synthetic funding, putting pressure on the FX swap market, driving up costs and eventually leading to cuts in US dollar lending compared to lending in their domestic currency. In their empirical extension they show that European banks exposed to a creditworthiness shock reduced their supply of US dollar syndicated loans relative to euro loans both in Europe and the US at the height of the European debt crisis. Our work differs from this study in two central

[7] Brauning and Ivashina (2017) also present a model (and related empirics) of banks that can access synthetic funding. Their results suggest that internal capital markets are used by banks to exploit interest rate differentials caused by changes in monetary policy, eventually leading to a high demand for FX swaps and liquidity shortages in jurisdictions where this internal liquidity is reallocated. In contrast, we document that internal capital markets can also play a role in the opposite direction, offsetting shortages in the supply of FX swaps in a country that, like the UK, is a key supplier of cross-border FX-denominated loans.

dimensions. First, our empirical setup allows us to focus on the direct consequences of changes in CIP deviations, rather than analysing those as an intermediate channel of other shocks (e.g credit worthiness or monetary policy shocks). Importantly, the effect we find is (i) increasing in its intensive margin on the size of the underlying dislocations and (ii) also present in non-crisis periods. Second, we concentrate the analysis on cross-border lending in multiple FX currencies –US dollar and euro– while using banks' domestic currency – sterling– as a benchmark, even for particular banks. This allows us to compare lending in different currencies in the face of currency-specific synthetic funding shocks (rather than bank-specific shocks).

Finally, our paper is also related to the recent set of studies investigating the occurrence of CIP deviations.[8] In contrast to most of these, we focus on the side of 'liquidity takers' in these markets and take CIP deviations as given, instead focusing on the consequences of these in terms of cross-border bank lending. In Section 2.2.3 we discuss the potential endogeneity of these CIP deviations and the steps we take to mitigate resulting concerns.

The remainder of the paper proceeds as follows. Section 2.2 provides an overview of currency choice in cross-border banking, describes the dataset and discusses the theoretical framework behind using CIP deviations as a proxy for shocks in the synthetic funding market. Section 2.3 presents the identification strategy, reports our baseline results and robustness checks to these. Section 2.4 explores the role of access to alternative FX funding markets (including internal capital markets) in shielding banks from the channel sketched in our baseline results. Section 2.5 presents an extension of the baseline model that accounts for potential lender-substitution effects a/cross borrowers. Section 2.6 concludes.

[8] See, e.g., Abbassi and Brauning (2018), Du et al. (2018), Sushko et al. (2016), and Cenedese et al. (2019).

2.2 Data & Stylised Facts

In this section we first discuss stylised facts on currency choice in cross-border lending (Section 2.2.1) and describe our dataset containing information on balance sheet data from banks operating in the UK (Section 2.2.2). We then go on to describe the workings of the FX swap market, and the arbitrage condition linking the various ways in which borrowers can obtain FX funds. We also describe the breakup of that condition and discuss how this phenomenon constitutes currency-specific funding shocks affecting the stability of banks' FX funding (Section 2.2.3).

2.2.1 Currency Choice in Cross-Border Bank Lending

A distinct feature of the international financial system is the large share of cross-border banking claims denominated in 'foreign' currencies (i.e. not the domestic currency of the originator country). This share has been relatively stable around 60 percent of total cross-border banking claims in the period between 2003 and 2017 (Figure 2.1). Most significantly, as of end-2016, cross-border flows in US dollars originated outside the US represented around 40 percent of total (world-level) claims. In terms of geographic origin, cross-border banking claims' origination is dominated by the world's financial centres: Figure 2.2 shows that the UK is the largest lender by a wide margin.

Given the prominence of 'foreign currency' loans in cross-border bank lending, it follows that the supply of these loans depends to a large extent on global banks being able to access FX funding. Borio et al. (2017) discusses how these funding sources can be divided into four main channels: banks' FX deposit liabilities to non-banks, interbank FX liabilities (interbank and intragroup), international bonds, and net FX swaps. As of 2016, out of an estimated 10 trillion of non-US banks' US dollar liabilities, FX deposits were the largest funding source, accounting for 60 percent of the total. Deposits were followed by international bonds (25 percent), FX swaps (10 percent), and interbank liabilities (5

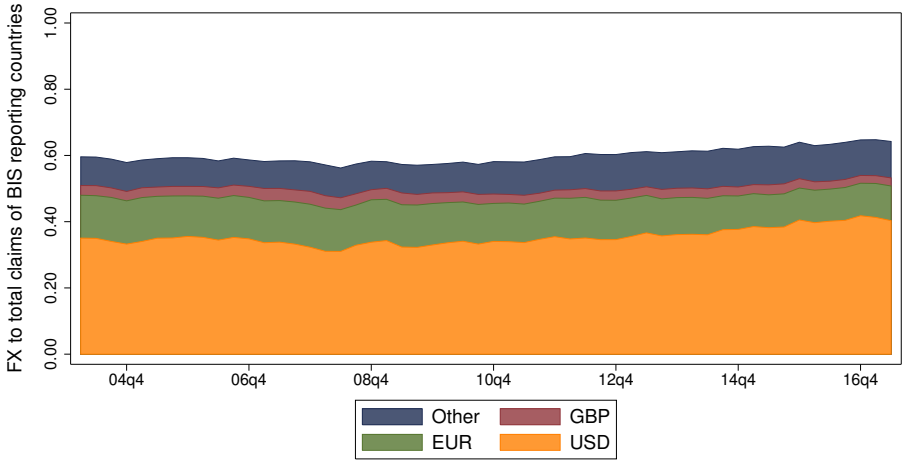


Figure 2.1 CROSS-BORDER BANK CLAIMS IN CURRENCIES OTHER THAN ORIGINATOR HOME CURRENCY

Notes: Authors' calculations based on the BIS Locational Banking Statistics. The figure shows the share of cross-border claims originated outside the currencies' domestic countries with respect to total currency-specific claims originated in all BIS reporting countries. The figure reports the breakdown for US dollar (USD), sterling (GBP), euro (EUR) and other currencies (Other). The figure shows that around 60 percent of cross-border claims originate outside the home countries of their currencies of denomination. Cross-border flows in US dollar originated outside the US represent around 40 percent of total (world-level) claims.

percent). This emphasizes the variety of sources potentially available for banks when choosing a given FX funding mix.

2.2.2 Banks Balance Sheet Data

In order to explore the effect of liquidity shocks in FX swap markets on cross-border bank lending in 'foreign' currencies we take the perspective of banks operating in the UK and providing cross-border FX loans in currencies different than sterling. In particular, we focus on banks lending abroad in US dollars and euros.

Our main data source is a panel of quarterly banks' balance sheet data constructed from selected regulatory fillings and statistical data forms submitted to the Bank of England by domestic and foreign banks operating in the UK.

We combine data contained in three of these forms. First, we obtain selected balance sheet variables from form BT, which reports a comprehensive picture of the structure of

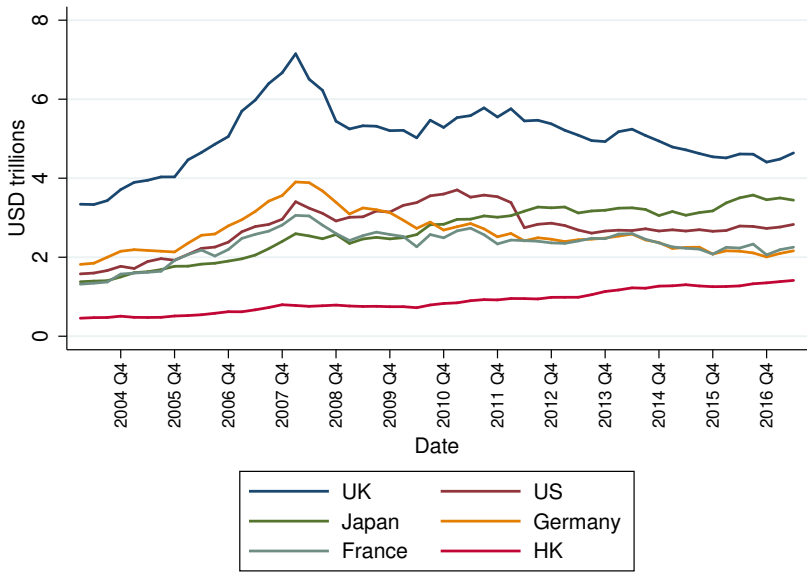


Figure 2.2 CROSS-BORDER BANK CLAIMS BY COUNTRY OF ORIGINATION

Notes: This figure depicts aggregate cross-border claims in US dollar trillions from 2004 to 2016 on a quarterly basis. The figure is based on data from the BIS Locational Banking Statistics. Each line represents the aggregate claims originated by banks located in the UK, the US, Japan, Germany, France and Hong Kong (HK). German data are interpolated when missing. These countries represent the major sources of cross-border banking claims.

each bank's balance sheet, including capitalization, funding structure and business model characteristics. Second, we use information reported in forms CC and CL, which provide detailed data on banks' international claims and liabilities. These data are reported on a bank-country-currency-quarter basis, tracing the balances outstanding of different types of assets held vis-á-vis borrowers located outside the UK. This source provides us with a currency breakdown for each asset position in sterling and other major currencies. These data have been used in previous papers, such as Aiyar et al. (2014) and Forbes et al. (2017).

Our baseline dependent variable measures the quarter-to-quarter growth rate in currency-specific international claims between bank i and all borrowers located in country j. We focus our analysis on different country-currency markets outside the UK. For each bank i we look at its cross-border claims vis-á-vis country j in two currencies, namely US dollars and euros. Further positions in yen, Swiss franc, and 'other currencies' are not

considered given the impossibility to trace back banks' reliance on synthetic funding in those currencies due to data limitations.[9] This latter exclusion should not be problematic given the small size of claims denominated in these currencies.

We start from a raw dataset containing information on 376 banks reporting cross-border claims in at least one quarter over 2003-2016. We implement a sampling procedure to focus on stable bank-country-currency relationships that can be observed throughout the period of analysis, as the identification strategy outlined below requires tracing bank-market relationships over time so as to pin-down the effect of funding shocks in FX swap markets. Also for identification purposes, only country-currency destination markets in which claims are held by at least two different banks in each quarter are considered. Our final quarterly dataset covers 106 banks over the 2003-2016 period. These banks lend to borrowers in 70 countries, creating a sample of 1,315 bank-country-currency relationships that can be traced over time, including claims in US dollars and euros.[10] Each bank lends to 10 different countries on average. Despite the demands of this procedure, the final sample covers on average 71.2 percent of US dollar and euro cross-border claims originated in the UK over the period of study.

Central to our analysis is the need to quantify banks' reliance on 'synthetic' funding in the currencies listed above (that is, funding obtained using FX swaps). Given the lack of detailed data on banks' derivatives positions, we follow Borio et al. (2017) and quantify banks' reliance on synthetic funding by residual; that is, we measure the difference between consolidated assets and liabilities in a given currency (as a share of total assets in that currency), and assume the 'missing' funding comes from FX swaps. [11] Algebraically:

[9] Specifically, the measure of reliance on synthetic funding requires information on domestic funding from 'BT' forms, which only contain data for assets and liabilities in sterling, euros and 'other', where 'other' is constituted mainly of US dollars.

[10] This dataset is 'final' in the sense that is consistent with the tightest set of fixed effects considered in our specifications. A detailed description of the steps required to obtain our final dataset can be found in Appendix B.1.2

[11] By construction this ratio of synthetic funding exposure can be either positive or negative. The latter case may reflect a situation in which a bank obtains relatively large amounts of foreign currency via deposits or FX money markets without using the proceedings to lend this FX liquidity. Since we are mainly interested in tracing a lending channel of positive synthetic funding exposures, we truncate the RSF variable

$$RSF_{i,k,t-l} = \frac{Claims_{i,k,t-l} - Liabilities_{i,k,t-l}}{Claims_{i,k,t-l}} \tag{2.1}$$

where $RSF_{i,k,t-l}$ is the reliance on synthetic funding of bank i in currency k at time $t-l$.

We can see from Table 2.1 that banks do indeed use synthetic funding. Their average reliance on this type of funding is approximately 9 percent of total assets in a given foreign currency, and there is heterogeneity across banks and over time (the standard deviation of this measure is 17 percent).

Table 2.1 reports descriptive statistics computed from the resulting baseline sample. The final panel includes 62,739 observations at the bank-country-currency-quarter level. Out of the 106 banks in the sample 95 are foreign-owned institutions (both branches and subsidiaries) and 11 correspond to UK-owned banks. The 70 destination countries correspond to the US, 13 Euro Area economies and 56 countries from the rest of the world. The first five columns of Table 2.1 report information on the whole sample. Thereafter the mean value for each variable in the pre-2008 sample is reported for two groups of banks: those with an average RSF ratio above the sample median ('high RSF') and those below that threshold ('low RSF').[12]

The motivation for analysing descriptive statistics split by reliance on synthetic funding is the need to compare a range of competing balance sheet characteristics that could be suspected of offering alternative explanations to our channel. That is, we look at balance sheet characteristics that could potentially be both correlated with reliance on synthetic funding and, by themselves, explain differences in cross-border lending supply by banks

by replacing negative RSF values by 0. Even though this approach is more consistent with the proposed research question, the main conclusions derived from the empirical analysis are unchanged if the negative values of RSF are included in the sample, as discussed in Section 2.3.3.

[12]We focus on the pre-2008 period given the lack of large liquidity shocks in FX swap markets, so that structural differences between high and low RSF banks can be observed before major dislocations in FX swap markets take place.

Table 2.1 BANK LEVEL DATASET – DESCRIPTIVE STATISTICS

						RSF		
	mean	**median**	**S.D.**	**min**	**max**	**large**	**low**	**Dif**
	I	II	III	IV	V	VI	VII	VIII
Dep. var.								
$\Delta L_{i,j,k,t}$	0.01	0.00	0.77	-3.15	3.30	0.05	0.05	0.01
Exposure var.								
RSF_{t-5}	0.09	0.00	0.17	0.00	0.70	0.09	0.01	0.081*
Control var.								
$Log\,assets_{t-1}$	17.68	17.78	1.83	13.33	19.83	17.47	17.52	-0.05
$Dep.\,ratio_{t-1}$	0.76	0.75	0.32	0.03	1.75	0.77	0.68	0.10
$Liq.\,ratio_{t-1}$	0.39	0.34	0.22	0.01	0.96	0.38	0.35	0.03
$Cap.\,ratio_{t-1}$	0.08	0.04	0.09	-0.06	0.38	0.08	0.06	0.03
$\Delta L^{\neq k}_{i,k,t}$	0.01	0.01	0.27	-0.90	0.95	0.06	0.06	0.00
CIP deviation								
GBP-CB	-0.07	-0.08	0.18	-0.76	0.41			
ΔCIP	0.00	0.00	0.14	-0.74	0.46			

NOTE: This table reports descriptive statistics for our main variables of interest. The dependent variable $\Delta L_{i,j,k,t}$ is computed as the quarter-to-quarter change in log total claims of bank i in country j, currency k and quarter t. The variable RSF represents the ratio of synthetic funding to assets at the bank-currency-quarter level. The table reports descriptive statistics for the following control variables: Banks' size ($Log\,Assets_{t-1}$), deposit-to-assets ratio ($Dep.\,ratio_{t-1}$), liquid-to-total assets ratio ($Liq.\,ratio_{t-1}$), and capital-to-assets ratio ($Cap.\,ratio_{t-1}$). The variable $\Delta Claims_{\neq k}$ represents the average change in log total claims of bank i in all currencies different than k. The table reports for each variable its sample average (mean), median, standard deviation (S.D.), and the minimum (Min.) and maximum (Max.) values. Columns VI and VII report the pre-2008 average for each variable for two subsamples: Banks with an average pre-2008 RSF ratio above (VI) and below (VII) the sample median. Column VIII shows the difference in means between large and low RSF banks. * indicates whether this difference is statistically significant by normalized differences (Imbens and Wooldridge, 2009). The last two rows report summary statistics for two measures of CIP deviations: GBP currency basis (level, GBP-CB) and the quarter-to-quarter change in the GBP currency basis (ΔCIP).

in the face of shocks to the cost of synthetic FX funding. These control variables include measures of banks' size (log of total assets), capitalization (capital-to-assets ratio), liquidity (liquid-to-total assets ratio), and deposits' reliance (total deposits to assets ratio). The final column in Table 2.1 reports a test of difference in means between both groups which uses the Imbens and Wooldridge (2009) test of normalized differences. We find that none

of the balance sheet items considered are significantly different across the two groups.[13] Importantly, we do not find evidence of both groups of banks reporting a different trend in the growth rate of cross-border claims before 2008. This result indicates that deviations in this growth rate after liquidity shocks in FX swap markets started occurring in 2008 should not be attributed to pre-existent differences in the behavior of banks differentially exposed to those shocks. In Section 2.3.3 we complement this analysis by running horse races in which we allow different balance sheet characteristics to 'compete' with RSF in explaining the heterogeneous reaction of bank lending in the face of shocks to the cost of synthetic funding.

In terms of the data going into our baseline specifications, both the dependent variable and all control variables are winsorized at the 1st and 99th percentiles [14]

2.2.3 The Covered Interest Rate Parity Condition and *Currency-Specific* Funding Shocks

The covered interest rate parity (CIP) condition states that the cost of obtaining funds in a given currency should be equalized across cash and FX swap markets. That is, from the point of view of a borrower looking for funds in a particular currency, it should be equally costly to pay the relevant cash-market interest rate, or, alternatively, to obtain funds in the cash market in a second currency and transform those proceeds into the target currency, locking-in the exchange rate at the moment of repayment via the use of an FX forward contract. Algebraically:

[13] If we instead look at the direct correlation between RSF and other balance sheet items in a linear way via the use of plain OLS regressions, we find that the only variable that is (weakly) positively correlated with RSF is total assets. We include this variable as a control in our benchmark specification and also run a robustness test dropping large banks from our sample.

[14] The exact definition of all these variables, and their corresponding entries in the relevant regulatory forms can be found in Appendix B.1.1

$$(1 + I^{USD}_{t,t+n})^n = \frac{S_t}{F_{t+n}}(1 + I^{GBP}_{t,t+n})^n \tag{2.2}$$

That is, it should be equivalent to borrow one US dollar at time t and pay back $(1 + I^{USD}_{t,t+n})^n$ at time $t + n$, and to borrow instead the S_t sterling needed to buy one dollar, transform those proceeds into one US dollar, and lock-in a given exchange rate (F_{t+n}) in the derivatives market to pay back the sterling debt at time $t + n$ at the relevant interest rate (that is, $(1 + I^{GBP}_{t,t+n})^n$).[15] If this condition did not hold, then an arbitrage opportunity would arise. Let us suppose, for the sake of argument, that the US dollar cash market interest rate (LHS of Equation 2.2) is lower than the FX-swap-implied interest rate (RHS of Equation (2.2)). If this was the case, an arbitrageur could make a positive risk-free profit by borrowing US dollars in the cash market and lending them via an FX swap in the derivatives market. It is worth noting that this profit would be risk-free, as all cash-flows (and exchange rates) are locked-in at the time trades are executed simultaneously.

The described CIP condition held remarkably well in the pre-GFC era (Figure 2.3). However, beginning in 2008, international financial markets witnessed the break-down of this once-thought unbreakable no-arbitrage relation. Figure 2.3 considers sterling as a base currency and shows that obtaining foreign currency funding in US dollar or euro via the FX swap market has been more expensive than doing so in cash markets during several periods.[16] It can be seen that this is not exclusively true for crisis periods.[17] This break-down in the CIP condition has been the subject of study of a series of recent papers, including Abbassi and Brauning (2018), Avdjiev et al. (2019), Du et al. (2018), Sushko et al. (2016), and Cenedese et al. (2019).

[15] In our baseline specification we rely on 3-month Libor interest rates and matching FX forward rates. In robustness checks (see Table B.8 in Appendix B.3) we repeat the baseline exercise using CIP deviations constructed using 1-month and 12-month interest rates instead, which lead to virtually unchanged results.

[16] See Figure B.1 in Appendix B.2 for a distinct view of CIP deviations in US dollar and euro markets.

[17] The wedge in funding costs across markets cannot be explained by counterparty risk. Du et al. (2018) document the existence of CIP deviations using risk-free securities denominated in different currencies.

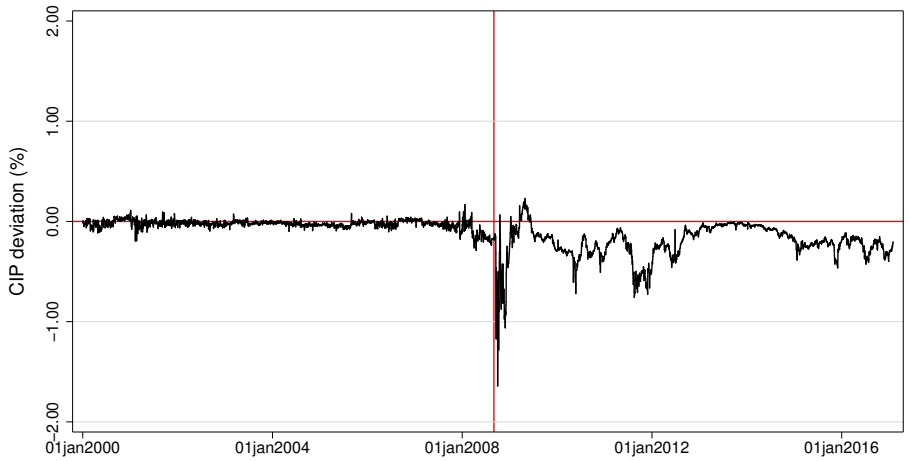


Figure 2.3 STERLING-BASED CIP DEVIATIONS (AVERAGE ACROSS CURRENCY PAIRS)

Notes: Authors' elaboration based on data from Bloomberg. The figure shows the average cross-currency basis between sterling (GBP) and four major currencies: US dollar (USD), Japanese yen (JPY), Swiss franc (CHF) and euro (EUR). The red vertical line marks September 1st 2008. A negative CIP deviation denotes a situation in which foreign currency funding is more expensive in FX swaps markets compared to cash markets.

A deviation from the CIP condition means that there exists a wedge in the cost of obtaining funds in a given currency in cash and FX swap markets. In the absence of frictions, borrowers (including banks) would then turn to the cheapest source of funding, rendering the more expensive alternative irrelevant. However, while FX derivatives can be readily accessible in international markets, access to cash markets (or insured deposits) for certain currencies is not automatic for some borrowers. In the case this fragmentation of funding markets was important, CIP deviations would constitute a funding shock to those borrowers with no access to FX cash markets or insured deposits, while the cost of funds for borrowers with access to both cash and derivatives markets would be unaffected (as they would turn to the cheapest alternative). Throughout the paper we will consider a *negative* change in CIP deviations as a situation in which cash market funding becomes cheaper in relation to synthetic funding via FX swaps. Algebraically:

$$CIP_{k,t} = y^{k}_{t,t+n} - y^{GBP}_{t,t+n} + \frac{1}{n}\left[log(F_{t,t+n}) - log(S_t)\right] \tag{2.3}$$

where $CIP_{k,t}$ is the sterling-based CIP deviation vis-a-vis currency k at time t; that is, the difference between the cost of obtaining funds in currency k via cash markets (at interest rate $y^k_{t,t+n}$) and doing so synthetically by borrowing sterling (at interest rate $y^k_{t,t+n}$) and locking in the exchange rate using spot (S_t) and forward ($F_{t,t+n}$) markets, as described above. Note that this equation is the wedge in the log version of Equation 2.2.

An important aspect of these funding shocks is that they are currency-specific. That is, from the point of view of a bank obtaining funds in a range of foreign currencies via FX swaps, differential changes in CIP deviations (when measured with respect to a common base currency) alter the relative cost of these currencies. In a world in which frictions such as the one described above are relevant, one could expect these changes in relative funding costs to have an impact on the FX composition of banks' lending.

It is worth noting that, from the point of view of a bank with no access to foreign currency cash markets, and which therefore obtains its FX funding via swaps, changes in CIP deviations only constitute a proxy of the relevant funding shocks it is subject to. In principle, one could focus on changes in the FX-swap leg of the CIP trade (only the RHS of Equation (2.2)), as this constitutes the effective funding cost via FX swaps. However, the price of FX swaps can change for two reasons: it can change due to supply and demand considerations (in tandem with some friction in the market), which is the shock we are actually interested in, but it can also change because of revisions to expected exchange rates in the future. The latter does not constitute necessarily a net funding shock: the differing cost of obtaining FX funds should be compensated by the fact that those funds are expected to change their value in terms of the domestic currency by the end of the contract. However, there is a way of abstracting from these cases: revisions to exchange rate expectations should be matched by changes in interest rate differentials across countries, leading to an unchanged CIP condition. Therefore, we use changes in CIP deviations as a proxy for friction-driven currency-specific funding shocks to banks securing foreign currency in swap markets.

Another possible confounding factor is the potential endogeneity of these CIP deviations to the balance sheet management of banks, considering this could affect both the supply and demand of FX swaps. Beginning by discussing supply considerations, the structure of the FX derivatives market is such that a relatively small group of big banks act as 'market makers' or 'dealers', concentrating a large portion of trades, while the rest of the banks usually operate whenever they have non-speculative needs to borrow or lend foreign currency. Recent papers, including Du et al. (2018) and Cenedese et al. (2019), point to a regulation-driven reduction in the balance sheet capacity of these market makers to engage in FX derivatives trades as one of the main reasons behind the existence of arbitrage possibilities (e.g. of a wedge in the CIP relation). If these big FX derivatives market makers engaged in cross-border lending in a systematic way linked in some form to their behaviour in FX derivatives markets, then this would constitute a problem for our specification. To guard against this possibility, we repeat our benchmark exercise excluding these big players from our sample, and find that results are virtually unchanged (Section 2.3.3).

In terms of potential demand considerations affecting CIP deviations, it could be argued a priori that banks of certain characteristics could rely more heavily on swaps for their FX funding, and, in periods in which this demand increased, be subject to monopolistic pricing from dealers, giving rise to CIP deviations. If this was the case, then there could be an omitted variable driving both changes in cross-border lending and deviations in the CIP condition. There are two considerations that suggest this is not an issue for our results. First, our findings are *currency-specific*; that is, if a bank's balance sheet or funding access was under stress and hence it had to cut back on lending and be subject to differential FX swap pricing, one would expect this to happen across currencies. However, our results are currency-specific in the sense that they link changes in the cost of, say, US dollar funding to US dollar lending, and actually disappear if we link euro CIP deviations to dollar lending and vice versa (Section 2.3.3). Complementarily, we also find that reliance on swap-based funding is uncorrelated to other balance sheet characteristics (Section 2.2.2).

Second, even if differential pricing did occur, existing research points to heterogeneities being relatively small in comparison to the magnitude of CIP deviations. For example, Abbassi and Brauning (2018) study German banks' pricing of dollar-euro forwards and find heterogeneity in prices that could reflect underlying balance sheet characteristics, but the effect seems to be small, and it can moreover be interpreted as complementary to our findings in that differential pricing would have differential consequences for cross-border lending, in line with our hypothesis. Therefore, even if banks were (endogenously) differentially affected by CIP deviations on the margin, they would all be exposed to a common underlying shock and adjust their currency-specific lending as a function of their exposure to the channel we sketch in this paper.

Finally, bank-level considerations aside, CIP deviations could be correlated with other dynamics at the macroeconomic level, including policy. For example, McGuire and von Peter (2012) document the use of central bank swap lines as a reaction to the emergence of CIP deviations. If these policy actions had an effect on cross-border bank lending, they would act like an omitted variable in our setup, potentially biasing our results. There are two considerations to be noted in this respect. First, one would need to think of reasons for which these policies would affect the cross-border lending of banks with high reliance on synthetic funding particularly strongly, which is not obvious. Second, these policy actions were only observed during crisis periods in our sample (the global financial crisis and the euro area crisis) and, as we show in Section 2.3.3, our results are robust to the exclusion of these periods.

2.3 The Effect of FX Swap Funding Shocks on Cross-Border Bank Lending

In this section we outline the identification strategy that allows us to estimate the causal effect of funding shocks in the FX swap market on banks' supply of cross-border lending in the currencies in question. We then present our benchmark specification, baseline results and a series of robustness checks.

2.3.1 Identification and Benchmark Specification

Our objective is to estimate the effect of currency-specific funding shocks originating in the FX swap market on UK banks' cross-border lending in those specific currencies. Hence, our variable of interest consist of percentage changes in UK banks' cross-border claims, denominated in both US dollars and euros. The 'shock' variable we consider (discussed in more detail in Section 2.2.3) is defined by quarter-to-quarter changes in sterling-based CIP deviations with respect to both euros and US dollars.[18] The sign convention is as follows: a negative change in this deviation reflects swap-based FX funding costs going up relative to the cash market costs.

The identification of the causal effect of FX funding shocks on banks' supply of currency-specific cross-border lending presents a series of challenges. In particular, a satisfactory specification needs to address two main concerns. First, there could be a third force driving both changes; that is, a third shock could push up on FX-specific funding costs and lead to reduced cross-border lending in that currency at the same time, therefore resulting in a misleading positive correlation between our variables of interest. Additionally, lending growth could as well be driven by changing demand. If borrowers increased demand

[18] In the baseline case we use quarterly averages of CIP deviations, but later check robustness to considering end-quarter observations.

for FX bank loans in the face of funding shocks in the FX swap market, then an increase in lending could just be a reflection of this increased demand and not of changes in banks' supply. Observing quantities is not enough to be able to isolate the effect of supply.

We exploit the richness of our dataset in a series of ways to address the concerns outlined above. In the hypothetical case an omitted third variable was driving both changes, then the correlation should not necessarily be stronger for banks with a higher exposure to our sketched mechanism. That is, banks with a high reliance on synthetic funding (i.e. relying on FX swaps) would have no reason to adjust lending particularly strongly in the face of shocks. We are able to test for this feature explicitly by incorporating balance sheet information on individual banks' reliance on synthetic funding.[19]

To control for demand constituting a confounding factor we leverage on the fact that we observe the lending of several banks in a particular currency into a particular destination country. This panel structure allows for adding currency-destination-time fixed effects, which allow us to control for unobserved changes in demand for funds in the spirit of Khwaja and Mian (2008).

A final consideration is that our results are driven by differences in bank-specific cross-border lending in different currencies (in the face of differential shocks to their funding costs in FX swap markets). Therefore, there are no grounds to expect that shocks at the bank level could be driving our results, as they would need to imply a differential reaction across the different currencies in a bank's lending portfolio. Despite this consideration, we add a series of time-varying bank level controls in our main specification, and also explore bank-time fixed effects in the robustness section to absorb relevant time-varying bank characteristics.

These design features result in the following benchmark specification:

[19] Additionally, we have shown in Section 2.2.2 that a range of other balance sheet characteristics are not correlated with banks' reliance on synthetic funding.

$$\Delta L_{i,j,k,t} = \alpha + \beta_1 RSF_{i,k,t-5} + \sum_{l=1}^{4} \beta_{2,l} \Delta CIP_{k,t-l} * RSF_{i,k,t-5} \tag{2.4}$$

$$+ \beta_3 \Delta L_{i,k,t}^{\neq k} + \beta_4 X_{i,t-1} + \gamma_{i,j,k} + \delta_{j,k,t} + \epsilon_{i,j,k,t}$$

where $\Delta L_{i,j,k,t}$ represents the percentage change in the cross-border claims of bank *i* to recipient country *j* in currency *k* at time *t*, $\Delta CIP_{k,t}$ is the first difference in the sterling-based CIP deviation of currency *k* at time *t* and $RSF_{i,k,t}$ is the reliance on synthetic funding of bank *i* in currency *k* at time *t* (see Equations (2.3) and (2.1), respectively). The focus on the *change* in claims rather than on their normalised stock responds to the need to avoid 'demand' fixed effects (country-currency-time) being affected by the composition of the pool of banks lending in a particular market.[20] $X_{i,t}$ represent bank-time specific controls and $\gamma_{i,j,k}$ and $\delta_{j,k,t}$ are bank-country-currency and country-currency-time fixed effects, respectively. The former allows us to control for time-invariant unobserved characteristics of banks lending to a particular country in a given currency, while the latter allow us to control for potential changes in country-specific demand for funds in a particular currency (hence constituting a key control variable). The bank-time controls include total assets, deposits ratio, liquidity ratio and capital ratio. We also consider the average cross-border lending in the currencies other than currency k ($\Delta L_{i,k,t}^{\neq k}$) which works as a benchmark and controls for banks overall lending behavior which might respond to factors other than changes in currency-specific synthetic funding costs.[21]

Following conventional use in the empirical banking literature (e.g., Kashyap and Stein,

[20] By focusing on changes in claims we obtain a comparable variable across banks, independent of the scale of their operations, which we can then try to 'clean' from demand effects by the use of the appropriate fixed effects. These fixed effects are estimated from comparable variables and go back to 'adjusting' them accordingly.

[21] Variable $L_{i,k,t}^{\neq k}$ includes lending in sterling, which is not analysed specifically in our baseline model because CIP deviations are measured with respect to Sterling (i.e., the CIP deviation of Sterling equals 0). We test the robustness of our results to including sterling lending on the dependent variable, matched with null CIP deviations to help improve the pinning down of the intercepts. Results are virtually unchanged.

2000), we consider the first four lags of our main object of interest: the interaction between ΔCIP and RSF. Using the fifth lag of RSF allows us to alleviate concerns that reliance on synthetic funding may react to the dynamics in ΔCIP, and it builds on the fact that this reliance is very sticky at the bank-currency level.[22] The interaction with RSF also emphasizes that the identification of the effect of CIP deviations operates over the distribution of RSF. Therefore, the model captures heterogeneous effects beyond banks' common exposure to –for example– reduced lending spreads in FX when CIP deviations become negative. We then focus our analysis on the sum of these four interaction terms. Moreover, the focus on the sum of the coefficients is important to trace banks' lending adjustment to ΔCIP over a time horizon of four quarters, recognizing the fact that this adjustment is likely to take place with a certain delay.

If higher synthetic funding costs in a particular currency resulted in reduced cross-border lending in that currency, and particularly so for banks with high reliance on this type of funding, we would expect coefficient β_2 to be positive and significant. This is our main coefficient of interest.

2.3.2 Benchmark Results

In this section we test whether banks with high reliance on synthetic FX funding adjust cross-border lending particularly strongly in the face of currency-specific synthetic funding shocks. Table 2.2 shows the results from bringing the benchmark specification outlined in Equation (2.4) to the dataset described in Section 2.2.1. For each regression we report the sum of the coefficients corresponding to the lags considered in Equation (2.4). Standard errors are clustered at the time (quarter) and bank levels.[23]

We find strong evidence that banks adjust currency-specific cross-border lending in the

[22] The relevant autocorrelation coefficient is 0.92.

[23] In our tightest specification we include bank-country-currency and country-currency-time fixed effects, leaving bank-time as the dimension in which errors could be correlated. With this in mind, we cluster standard errors at the bank and quarter levels.

face of funding shocks to the same currency in the FX swap market.

Table 2.2 BENCHMARK RESULTS

	I	II	III	IV	V
Joint ΔCIP x RSF_{t-5}		0.745**	0.678***	0.617***	0.605***
		(0.287)	(0.251)	(0.195)	(0.176)
Joint ΔCIP	0.108**	0.0259	0.0224	-0.0241	
	(0.0506)	(0.0912)	(0.0836)	(0.0811)	
RSF_{t-5}		-0.022	-0.024	0.007	0.020
		(0.015)	(0.017)	(0.021)	(0.031)
Interaction terms:					
ΔCIP_{t-1} x RSF_{t-5}		0.306**	0.287**	0.204*	0.192**
		(0.127)	(0.122)	(0.110)	(0.087)
ΔCIP_{t-2} x RSF_{t-5}		0.278*	0.257*	0.271**	0.261**
		(0.142)	(0.137)	(0.122)	(0.107)
ΔCIP_{t-3} x RSF_{t-5}		0.190	0.178	0.192	0.170
		(0.117)	(0.118)	(0.130)	(0.126)
ΔCIP_{t-4} x RSF_{t-5}		-0.029	-0.045	-0.050	-0.018
		(0.116)	(0.105)	(0.098)	(0.083)
Controls:					
$Log\,assets_{t-1}$			0.001	-0.013	-0.013
			(0.002)	(0.010)	(0.010)
$Dep.\,ratio_{t-1}$			-0.002	0.004	0.008
			(0.012)	(0.014)	(0.017)
$Liq.\,ratio_{t-1}$			-0.016	-0.033	-0.037
			(0.018)	(0.044)	(0.046)
$Cap.\,ratio_{t-1}$			0.035	-0.096	-0.093
			(0.041)	(0.088)	(0.087)
$\Delta L_{i,k,t}^{\neq k}$			0.107***	0.076***	0.084***
			(0.022)	(0.023)	(0.022)
Constant	0.011***	0.012*	0.001	0.262	0.256
	(0.003)	(0.007)	(0.023)	(0.180)	(0.183)
No. of Banks	106	106	106	106	106
Fixed effects	None	None	None	i + j,t	i,j,k + j,k,t
Obs	62,739	62,739	62,739	62,739	62,739
R^2	0.000	0.000	0.002	0.060	0.108

NOTE: This table reports the results from estimating Equation (2.4) for different specifications of the model. All constitutive terms of the interactions are included in the regressions. Coefficients for $\Delta CIP_{k,t}$ are not reported. Col. I reports the results of regressing $\Delta L_{i,j,k,t}$ only on the four lags of $\Delta CIP_{k,t}$, showing the respective joint coefficient in the upper row (Joint ΔCIP). In Col. II we add the four lags of the interaction term between $\Delta CIP_{k,t}$ and $RSF_{i,k,t-5}$. Column III further includes our set of control variables. Column IV adds both bank (i) and country-quarter (j,k) fixed effects. Finally, Column V reports our preferred benchmark specification including both bank-country-currency (i,j,k) and country-currency-time fixed effects (j,k,t). This latter model absorbs any variation that is specific to banks serving a particular country-currency market, as for instance borrowers' credit demand in that currency. Robust standard errors clustered at the bank- and quarter-level are reported between parentheses. Variables are winsorized at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in Appendix B.1.1. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Column I in Table 2.2 reports the results of a plain specification that does not factor in bank heterogeneity in terms of reliance of synthetic funding, but instead looks at average common variation in cross-border bank lending in the face of changes in CIP deviations. This estimation, although lacking a sharp identification, allows us to get a first idea of the empirical relationship between the growth rate in cross-border claims and currency-specific funding shocks in FX swap markets. It can be seen that an increase in the funding cost of using FX swaps is associated with a decrease in banks' currency-specific lending growth. In the remainder of the analysis we do incorporate bank heterogeneity in their exposure to shocks to the cost of FX swaps by considering their reliance on this type of funding (as described in Section 2.3.1).

The specification underlying results in column II factors in this bank heterogeneity, and delivers results which are in line with the unconditional correlation reported in column I. That is, the table shows that in the face of, say, an increase in the cost of synthetic funding, it is banks with a high reliance on this type of funding that cut back currency-specific lending particularly sharply. In column III we add a series of bank balance sheet items as further controls, and in column IV we further tighten the specification by adding bank and country-time fixed effects. This setting allows us to absorb confounding factors related to banks' time-invariant characteristics and country-specific trends affecting banks operating in that market, which are then ruled-out as a driver of our results. For instance, this setting captures borrowers' demand shocks that are homogeneous across currencies but specific to each destination country. Our results are robust to this fixed effects setting. In our final specification (column V) we allow these potential demand shocks (and other potential confounding factors) to be currency-specific by including country-currency-time fixed effects combined with the bank-country-currency time-invariant fixed effects. Our main findings hold after saturating the model with this structure. It is reassuring to see that the joint coefficient of the four lags of the interaction between ΔCIP and RSF (β_2) remains fairly stable across the different specifications of the model, working as evidence of the regularity of the empirical relationship documented in this paper.

The effect of currency-specific funding shocks on banks' cross-border credit supply is not only statistically significant but also economically meaningful. Consider the case of a bank that has a ratio of US dollar synthetic funding relative to total US dollar assets that is one standard deviation above the sample mean; that is, 17 percentage points above the sample mean of 9 per cent. Based on the results from our benchmark model, a negative CIP deviation of 14 basis points in the sterling-US dollar basis (i.e., the standard deviation of its changes) leads the bank in consideration to cut back US dollar lending by 1.4 per cent in comparison to the behaviour of a bank with average synthetic funding exposure. These estimates are conservative considering the existence of banks with 70 per cent reliance on synthetic funding and observed changes CIP deviations above 40 basis points.

Another useful exercise to calibrate the economic magnitude of our baseline effect is to focus on a particular point in time and develop an alternative hypothetical scenario.[24] Consider the second quarter of 2012, when the sterling-US dollar basis widened by 7 basis points.[25] In this quarter, the group of banks in our sample with positive reliance on synthetic funding cut back cross-border US dollar lending (to all destinations) by 184 billion US dollars. By making use of our benchmark results, we can estimate the hypothetical lending behaviour of these banks had they not been exposed to the shock to the cost of synthetic funding; i.e., if these banks had not relied on synthetic funding at all. In order to do this we calculate a bank-specific lending adjustment that arises from mapping a hypothetical reduction of their reliance on synthetic funding to zero into their lending behaviour, in the context of the observed shock.[26] By doing this we calculate that, had these banks had zero reliance on synthetic funding, they would have cut back lending by 160 billion US dollars instead; that is, the fall in lending would have been 24 billion US dollars (i.e. 13%) smaller.

[24] This exercise is an adaptation of a calculation presented in Cornett et al. (2011) in the context of liquidity risk in the global financial crisis.

[25] We consciously avoid using the global financial crisis and the height of the European debt crisis as case studies, despite larger widenings in the relevant basis, given potential confounding factors taking place at those times.

[26] The calculation we do for each bank is: $\Delta CIP * \Delta RSF * \beta_2$, where ΔRSF is the distance between their observed reliance on synthetic funding and zero. We then add up these adjustments across banks.

Our benchmark results are unchanged when considering a battery of robustness checks, described in detail in the next section.

2.3.3 Robustness Tests

In this section we run a number of robustness tests to assess the sensitivity of our findings to different specifications of the model.

We first examine whether our baseline findings can respond to or be biased by important individual events which in turn are time-clustered with the CIP deviations we use to quantify funding shocks in the FX swap market. Figure 2.3 shows that, although CIP deviations do occur at different periods throughout our sample, these are particularly large during the 2008-2009 global financial crisis, and later during the euro area crisis. Our results may therefore be driven by the fact that banks largely exposed to FX synthetic funding are also generally more exposed to international financial markets, which were hit severely during these crises. In order to address this concern, we re-estimate our benchmark specification after alternatively dropping the 2008-2009 and 2011-2012 periods from our sample. Results, reported in columns (1) and (2) in Table B.1 in Appendix B.2, confirm that excluding the potential biases induced by crisis periods does not alter our findings. Moreover, the size of the coefficient of interest remains fairly stable. It is also worth noting that result are almost unchanged when dropping the pre-2008 portion of the sample, in which virtually no shocks are observed (and hence only helps pin down the coefficients of intercepts and control variables).[27]

One additional potential issue is that CIP deviations could be contemporaneous to (or even a reflection of) other market-wide dynamics, which could be the 'true shocks' bank lending is reacting to. We conduct two robustness checks to address these concerns. First, we emphasise the currency specific nature of our story by considering a 'placebo' FX

[27] These results are not reported for space reasons but available upon request.

swap funding shock by assigning US dollar CIP deviations to euro lending and euro deviations to US dollar lending. The fact that we do not find any results when performing this experiment (column 3 in Table B.1) is reassuring and addresses concerns that CIP deviations only reflect tensions in financial markets. Relatedly, we also explore the possibility of CIP deviations being a reflection of US dollar strength (Avdjiev et al., 2019), which could in turn affect bank lending via alternative channels. When replacing CIP shocks with changes in the US dollar index (col. 4), we see that results cease to be significant. This result lends additional support to our hypothesis relating bank lending to specific shocks in the synthetic FX funding market.

Another concern relates to the workings of the FX swap market. So far we have analysed banks as 'liquidity takers' which tap FX swaps markets when in need of (synthetic) FX funds. However, some institutions necessarily have to 'make markets' and take the other side of the trades. If these 'market makers' engage in cross-border lending, while also having the capacity to influence the price of FX swaps given the relative concentration of the market, then our results could be biased if their behaviour differed from the mechanisms sketched so far. In order to guard our results against such possibility, we estimate our benchmark specification after excluding the top-5 banks in FX derivatives' trading volume.[28] Results, reported in column (5) and (6) in Table B.1, show that our findings remain in place when excluding this group of 'market makers'.

A further concern relates to a potential correlation between reliance on synthetic funding and other bank traits. For example, a high value of RSF may also reflect a relatively high exposure to short-term interbank market debt. Provided that this latter type of liabilities was especially affected during periods of financial distress in our sample, the channel that we identify may capture banks' overall exposure to financial contagion. Even though both (i) the time-varying controls and fixed-effects included in Equation (2.4) and (ii) the currency-specific nature of our results should prevent a bias via such confounding factors,

[28] We identify these banks from *Euromoney 2016 FX rankings*. We consider the top 5 banks in overall market share, which account for around 60% of the market on average.

we implement a set of further robustness tests that shed light on the role of bank characteristics. First, we run a set of regressions in which we replace the fixed-effects structure in Equation (2.4) by alternative structures including bank-quarter fixed effects. This test aims at changing the dimension of the identification from within (country-currency) relevant markets to a within bank estimation that absorbs both observed and unobserved bank traits that could be correlated with RSF. The results, reported in Table B.2 in Appendix B.2, show that our findings remain in place once we control for both observed and unobserved time-varying bank characteristics captured by bank-quarter fixed effects under different specifications.[29]

A related exercise entails running 'horse races' in which we replace our quantification of banks' exposure to shocks to synthetic funding markets with other balance sheet characteristics which we would expect to be unrelated to our story. It is reassuring to see that shocks to the cost of synthetic funding particularly affect the lending of banks with high reliance on this type of funding, but not that of banks with particularly high values of other balance sheet characteristics considered (see Table B.3 in Appendix B.2).

Finally, we also test the robustness of our results to more mechanical modifications of our baseline setup (all tables reported in Appendix B.3). Our results are robust to (i) considering alternative swap maturities and end-of-quarter observations for measuring CIP deviations, (ii) truncating our left-hand-side variable, increasing the winsorisation threshold and replacing aggregate lending with a narrower measure of loan growth, (iii) modifying the clustering of standard errors to bank and currency-time units, (iv) considering alternative measures of banks' reliance on synthetic funding, (v) adding sterling flows to our panel with corresponding null CIP deviations to help anchor the baseline, and (vi) excluding the US and euro area as destination countries and, separately, US and euro area banks lending from the UK as originators. The robustness of our results and

[29] We run this exercise both with and without our preferred set of credit-demand controls via fixed-effects. In the latter case we find the coefficients of Joint ΔCIP x RSF_{t-5} to be slightly smaller than in the benchmark model. These smaller coefficients reflect that currency-specific credit supply and demand shocks are negatively correlated, so that not controlling for credit demand leads to an underestimation of the actual size of the (credit-supply-driven) coefficient. This latter fact further underpins the validity of our identification.

stability of the magnitudes involved across this battery of checks speak to the tightness of our identification strategy.

2.4 The Benefits of Foreign Relatives

In the previous section we document an effect on cross-border bank lending arising from funding shocks in FX swap markets. Banks with a high reliance on synthetic FX funding adjust their currency-specific cross-border lending particularly strongly in the face of changes in the cost of funds in FX swap markets. This feature is by no means obvious: if banks had access to alternative sources of funding at similar cost, then changes in the cost of swap-based FX funding need not necessarily lead to shifts in lending behavior, but only to a change in the source of those funds.

In this section, we extend our baseline model to test whether the documented effect of synthetic funding shocks on bank lending reflects banks' capacity to access alternative FX funding. We test for this hypothesis by considering a series of alternative measures that could shed light on banks' capacity to tap FX funds. We first analyse whether the effect of synthetic funding shocks on cross-border lending differs across banks' organisational structures, focusing on the differences between branches, which have frictionless access to their parents abroad, and other banks. We then consider effective access to alternative sources of on-balance-sheet FX funding in general, and internal capital markets (ICM) in particular, and test whether this access shields banks' lending from synthetic funding shocks. Finally, we also analyse whether banks' actual liability management in the event of synthetic funding shocks goes in line with our hypothesis.

One possible interpretation of these tests is that they are suggestive of traces of institutional frictions in international FX funding markets, which can help to explain the dynamics of cross-border FX credit supply. Previous literature suggests that a reallocation of FX funding sources may be impaired by such institutional frictions (Buraschi et al., 2014).

Banks with limited institutional access to alternative FX markets are arguably less able to prevent the credit supply effects documented in Section 2.3.2. Relevant institutional frictions in international capital markets may relate, for instance, to ring-fencing regulations and capital controls that prevent banks from efficiently reallocating internal liquidity from a consolidated perspective when they benefit from a local presence via bank affiliates in foreign funding markets (see, e.g., Allen and Gale, 2004; Cetorelli and Goldberg, 2012a; Acharya et al., 2017). More generally, market segmentation and differences in regulatory regimes may impair global banks' capacity to pledge future cash flows when issuing paper abroad, further limiting their access to foreign FX markets even in an arms'-length fashion (see, e.g., Darrell et al., 2007; Brunnermeier and Pedersen, 2009.)

2.4.1 Banks Organisational Structure

At first glance, the hypothesis that alternative FX funding sources can provide a cushion against synthetic funding shocks seems easily testable *a priori*; however, measuring access to funding sources is not straightforward: banks could have access in case of need, without this ever materializing in the balance sheet data we observe. One alternative is to consider banks' organisational structure, relying on the idea that UK-regulated banks and foreign branches could have a differential access to FX markets given different intragroup links, regulatory arrangements and, more generally, different informational frictions. Therefore, as a first step in exploring heterogeneities in the effect of synthetic funding shocks on bank lending we test whether there are differential effects for UK-regulated banks on the one hand and foreign branches on the other.

Foreign-owned branches providing cross-border FX credit from the UK are especially interesting for our analysis. It has been profusely documented that branches tend to have tighter links with their banking groups (see, e.g., Cerutti et al., 2007; Dell'Ariccia and Marquez, 2010). This phenomenon relates to the fact that branches have no separate legal standing but form an integral part of the parent's balance sheet, thus in most cases

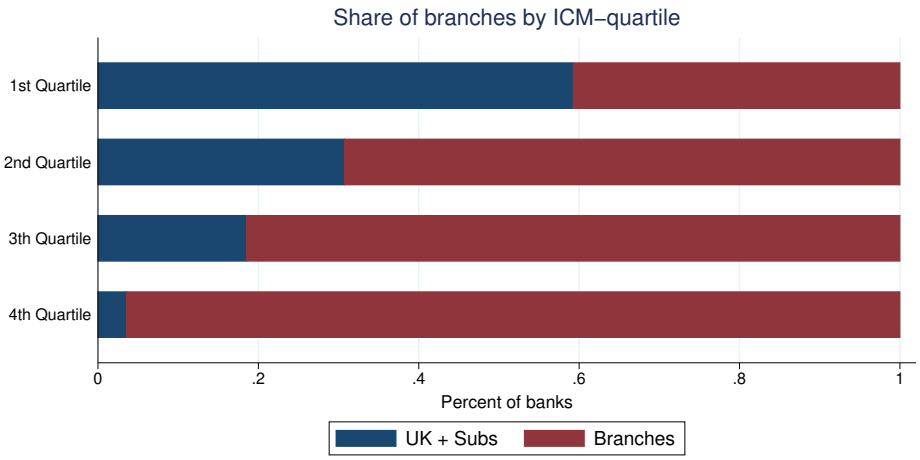


Figure 2.4 SHARE OF BRANCHES BY ICM-QUARTILE

Notes: The graph shows the share of foreign branches (red area) and UK-regulated banks (blue area) as a share of the total number of banks in the four quartiles of the distribution of the ratio of ICM liabilities to assets. ICM stands for the ratio of internal capital market liabilities from abroad (currency-specific) to total bank assets. The figure is constructed from the working sample used for the econometric analysis and based on regulatory data from the Bank of England.

enjoying a more direct and frictionless access to intragroup funding. This stylized fact is also present in our sample of UK-based banks. Figure 2.4 depicts the share of branches in each quartile of the distribution of banks by their ratio of internal capital market funding (ICM) to assets. This figure reveals a clear pattern in which higher quartiles of the ICM distribution report a higher presence of branches. However, branches are not special in terms of their reliance on synthetic funding (RSF), the key dimension of heterogeneity behind our identification strategy. Replicating the same exercise for the quartiles of the RSF distribution (Figure 2.5) shows that branches are evenly distributed across quartiles. These charts highlight the distinctive aspects of banks' FX liquidity management captured by RSF and ICM.[30]

The pattern outlined above suggests that branches can be used as a quasi-control group in

[30] In our sample, branches report on average a higher ratio of on-balance-sheet FX funding to total assets (0.42) compared to the group of UK-regulated banks (0.29). Most importantly, this difference stems mostly from internal capital markets (ICM) funding from abroad (ratio to total assets is 0.13 versus 0.04). On the contrary, the ratio of non-ICM FX funding from abroad to assets does not vary much between these two groups (0.29 vs. 0.24). Despite these differences, branches report on average a similar RSF compared to other banks, suggesting that synthetic funding reliance and access to ICM represent two distinct dimensions of banks' FX liquidity management. These descriptive statistics are reported in Table B.5 in Appendix B.3

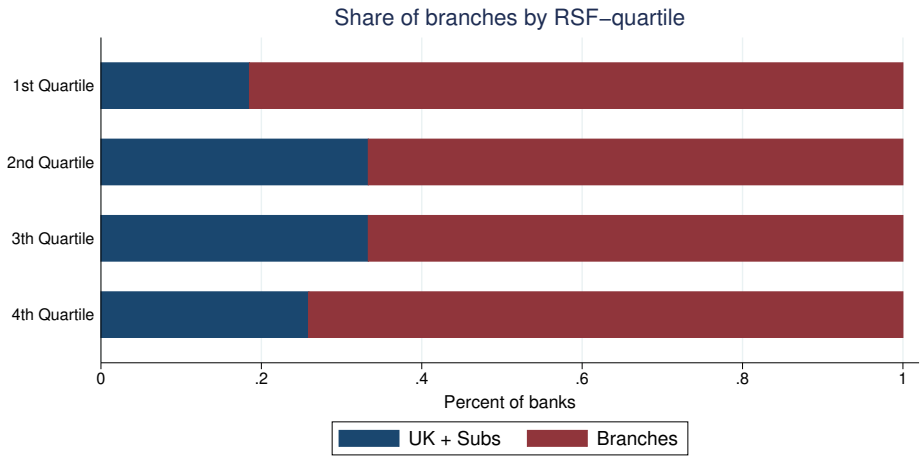


Figure 2.5 SHARE OF BRANCHES BY RSF-QUARTILE

Notes: The figure shows the share of foreign branches (red area) and UK-regulated banks (blue area) as a share of the total number of banks in the four quartiles of the RSF distribution. RSF represents the ratio of synthetic funding to assets. The figure is constructed from the working sample used for the econometric analysis and based on regulatory data from the Bank of England.

the context of our analysis, considering that they typically share a similar RSF exposure but, simultaneously, a larger access to ICM on average compared to other banks.[31] Considering this setup we test whether non-branches' low institutional access to alternative markets via ICM affects the adjustment of their credit supply following synthetic funding shocks. To operationalise this test we adjust Eq. (2.4) by adding a triple-differences' term which equals 1 if a bank in the sample is a branch and 0 otherwise. We then focus the analysis on the joint coefficient of the triple interaction (ΔCIP x RSF_{t-5} x $Branch_{t-5}$) after saturating the model with our preferred fixed-effects structure.

Results are reported in Table 2.3. We find that, for the same level of dependence on synthetic funding, foreign branches adjust their cross-border FX lending by around two-thirds less than other banks (col. II). In cols. III and IV we tighten the analysis by identifying those foreign branches owned by banking conglomerates headquartered in the Euro Area and the US. The rationale for this exercise is that, in the event of system-

[31] In unreported results, we find that benchmark results can be replicated both for the subsamples of branches and UK-regulated banks. This finding confirms that a large heterogeneity in the use of synthetic funding exists, even within the group of the arguably Â´well integrated' branches. These results are available upon request.

wide shocks to the cost of obtaining a particular foreign currency using FX swap markets, branches of banking groups headquartered in the relevant currency area will have more direct access to cash funding in that particular currency than other banks. With this in mind, we replicate the previous exercise by defining a new dummy variable that takes the value of 1 if a bank is (i) a foreign branch and (ii) owned by a bank headquartered in one of these currency areas. This test, reported in column IV in Table 2.3, shows that these particular branches are behind the 'shielding' effect identified in column III. On the contrary, when we define as branches only those entities owned by banks headquartered in regions different than the Euro Area or the US, the branches do not seem to be shielded any more (see column V in Table 2.3).

Taken together, these results show that branches – a group of banks that we would expect to be less exposed to the institutional frictions affecting FX funding access – are less affected by synthetic funding shocks. Most importantly, the capacity of branches to compensate for the loss in synthetic funding seem to be fueled by their advantage to obtain liquidity via their headquarters abroad, as long as these headquarters operate in the relevant currency areas. These findings highlights how banks' organisational structures can shape the dynamics of cross-border credit flows in a world of synthetic funding shocks.

2.4.2 Alternative FX Funding Sources: Internal Capital Markets

Starting from the differential effect of synthetic funding shocks on branches' cross-border FX lending, in this subsection we explore a dimension that could be expected to be behind this finding; namely, their differential access to alternative sources of FX funding. We conjecture that if institutional frictions related to banks' capacity to tap alternative FX funding markets matter, then wide access to these alternative sources should indeed lead to a smaller effect of synthetic funding shocks on cross-border lending, both for branches and non-branches. In particular, we look at banks' on-balance-sheet FX funding in general, and the split between ICM and non-ICM funding in particular. Looking at effective

Table 2.3 ACCESS TO FX FUNDING: FOREIGN BRANCHES

		Triple interaction term ($Trait_{t-5}$):		
	None	Branch	CA Branch	Non-CA Branch
	I	II	III	IV
Joint ΔCIP x RSF_{t-5} x $Trait_{t-5}$		-0.522**	-0.795**	0.194
		(0.246)	(0.390)	(0.479)
Joint ΔCIP x RSF_{t-5}	0.605***	0.813***	0.793***	0.594***
	(0.176)	(0.227)	(0.238)	(0.170)
Joint ΔCIP x $Trait_{t-5}$		0.0379	0.0800	-0.0445
		(0.107)	(0.0761)	(0.108)
RSF_{t-5} x $Trait_{t-5}$		0.061	0.005	0.124*
		(0.066)	(0.072)	(0.069)
$Trait_{t-5}$		0.000	0.211***	-0.228***
		(0.000)	(0.035)	(0.030)
RSF_{t-5}	0.020	-0.012	0.019	-0.003
	(0.031)	(0.043)	(0.040)	(0.032)
Controls:				
$Log\,assets_{t-1}$	-0.013	-0.013	-0.022**	-0.020**
	(0.010)	(0.011)	(0.009)	(0.009)
$Dep.\,ratio_{t-1}$	0.008	0.010	0.010	0.013
	(0.017)	(0.018)	(0.017)	(0.018)
$Liq.\,ratio_{t-1}$	-0.037	-0.031	-0.031	-0.024
	(0.046)	(0.046)	(0.045)	(0.046)
$Cap.\,ratio_{t-1}$	-0.093	-0.075	-0.138*	-0.119*
	(0.087)	(0.082)	(0.081)	(0.071)
$\Delta L^{\neq k}_{i,k,t}$	0.084***	0.084***	0.082***	0.083***
	(0.022)	(0.023)	(0.022)	(0.022)
Constant	0.256	0.245	0.333**	0.428**
	(0.183)	(0.190)	(0.154)	(0.169)
Observations	62,739	62,739	62,739	62,739
R^2	0.108	0.108	0.108	0.108

Note: This table reports the results from estimating Equation (2.4) by adding an interaction term between ΔCIP x RSF_{t-5} and variables measuring banks' different organizational structure and access to global FX funding. All constitutive terms of the interactions are included in the regressions. The variable $Trait_{t-5}$ represents the respective interaction term in each column lagged in five quarters. Col. I replicates the benchmark results from Col. V in Table 2.2. Columns II to IV include triple interactions with a foreign branch dummy (Branch, Col. II); a dummy for foreign branches from the US or Euro Area (CA Branch, Col. III); and a dummy for foreign branches with a headquarter in currency areas different than the US or the Euro Area (Non-CA Branch, Col. IV). Robust standard errors clustered at the bank and quarter level are reported between parentheses. All regressions include the full set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorized at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in Appendix B.1.1. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

access to on-balance-sheet FX funds provides a complementary intensive margin angle to the extensive margin view represented by branches' organisational structure. In fact, we may expect also subsidiaries and especially UK-owned banks – given their role as bank headquarters – also to benefit from access to alternative sources of FX funds.

In order to test for this conjecture, we compute a ratio of on-balance-sheet FX funds to total assets at the bank-currency-quarter level. We then zoom into the type of funds by computing the ratios of foreign ICM and non-ICM funds to total assets over the same panel dimension. ICM funds represent *FX-specific* intrabank liabilities from abroad vis-à-vis related entities within the same banking conglomerate. [32] For completeness, we compute non-ICM funds as the net liabilities when subtracting ICM from total FX funds.[33] In order to arrive at a discrete proxy for large and small access to *FX-specific* intragroup funding in the extensive margin that can be compared with the branch dummy calculated in the previous section, we assign observations above the 75th percentile of the respective ratio to a group of 'high access' banks and use a dummy based on this categorization to introduce a triple interaction term in Eq. (2.4).[34] These dummies enter the model with the same 5-lag structure as the RSF variable. Making use of this structure we assess whether the effect of synthetic funding shocks on lending is smaller for those banks with large access to alternative funding sources. [35]

The results from this exercise are reported in Table 2.4. We find that the aggregate access

[32] Ideally we would have bilateral intragroup links to specific currency areas; however, such data starts only in 2014 and is hence too short for our analysis

[33] Note that the level of on-balance-sheet funding is not mechanically correlated with the reliance on synthetic funding: a bank with a given level of reliance on synthetic funding can have low or high on-balance-sheet funding (if overall FX operations are small or large, respectively). In effect, the correlation of these two variables in our sample is negative but low.

[34] We split observations at the 75th percentile to properly capture the skewness of the ICM ratio distribution. As it can be seen in Figure B.2 in Appendix B.3, the low median (red vertical line) in the ratio's distribution implies that many low-ICM observations would be assigned to the high ICM group if using a median split. For consistency, we follow the same definition when generating splits in the other relevant ratios throughout the analysis.

[35] Due to data limitations we restrict this analysis to the period from 2008Q1 to 2016Q1, as the information on banks' internal capital markets' funding is not available for earlier periods. This does not impose a big constraint on the exercise given that we are left with the period of non-negligible synthetic funding shocks in any case.

to on-balance-sheet FX funding *per se* does not shield banks' lending from the effect of dislocations in synthetic funding markets (col. II). However, when zooming in into the different types of on-balance-sheet funding (cols. III and IV) we see that a high ex-ante ICM ratio does indeed reduce the effect of synthetic funding shocks on FX credit supply. On the contrary, access to non-ICM funds does not have a similar shielding effect. We therefore conclude that, for the full set of banks in the sample, a large access to ICM does shield banks' FX lending from the effect of shocks to the cost of synthetic funding.

Interestingly, when we replicate the exercise separately for the subsamples of branches and UK-regulated institutions (columns V and VI), we find the effect of a higher marginal ICM-access to be stronger in the case of non-branches. This is consistent with the fact that branches have a generally high level of ICM (see Figure 2.4) and hence it is difficult to tease out differential effects. For non-branches of course the relevance of ICM access will capture to a great extent the access of banks to their branches located in key currency areas. [36]

We interpret these latter results as providing further evidence that access to funding markets via intragroup links helps banks offset shocks arising in synthetic funding markets. This also points to the possible role played by institutional frictions to the extent that they may prevent some banks from making full use of their internal capital markets.

2.4.3 Zooming-In: Changes in Banks' FX Foreign Liabilities.

The results above are suggestive of the notion that UK-based banks that are less constrained by institutional frictions can tap intragroup FX liquidity sources which, in turn, reduces the pass-through of synthetic funding shocks to FX cross-border lending. However, it is still to be seen whether banks actually increase their internal FX funding when institutional frictions are low, or whether the findings described above merely reflect that

[36] Reinhardt and Riddiough (2015) show that intragroup funding to parent banks from foreign affiliates has been most stable during the global financial crisis and in the face of increases in the VIX index.

Table 2.4 ACCESS TO FX FUNDING: ON-BALANCE-SHEET FX-FUNDING

	Triple interaction term ($Trait_{t-5}$):					
	Branch	Total FX	ICM rat.	Non-ICM rat.	ICM rat.: Branches	ICM rat.: UK-regulated
	I	II	III	IV	V	VI
Joint ΔCIP x RSF_{t-5} x $Trait_{t-5}$	-0.522**	-0.795	-1.263***	2.367	-1.720	-2.574**
	(0.246)	(1.783)	(0.395)	(3.318)	(1.364)	(1.231)
Joint ΔCIP x RSF_{t-5}	0.813***	0.693**	1.059***	0.518**	0.726**	1.013*
	(0.227)	(0.299)	(0.328)	(0.223)	(0.327)	(0.535)
Joint ΔCIP x $Trait_{t-5}$	0.0379	0.0101	0.0979	-0.175**	-0.00375	1.083**
	(0.107)	(0.108)	(0.174)	(0.0825)	(0.192)	(0.391)
RSF_{t-5} x $Trait_{t-5}$	0.061	-0.070	0.039	0.108	0.078	-0.011
	(0.066)	(0.226)	(0.055)	(0.262)	(0.113)	(0.120)
$Trait_{t-5}$	0.000	-0.018	-0.009	-0.055***	-0.014	-0.000
	(0.000)	(0.025)	(0.022)	(0.013)	(0.022)	(0.080)
RSF_{t-5}	-0.012	0.056	0.038	0.042	0.004	0.142*
	(0.043)	(0.039)	(0.032)	(0.037)	(0.054)	(0.077)
Controls:						
$Log\,assets_{t-1}$	-0.013	-0.019	-0.019	-0.023*	-0.018	-0.059
	(0.011)	(0.014)	(0.014)	(0.012)	(0.016)	(0.065)
$Dep.\,ratio_{t-1}$	0.010	0.030	0.029	0.020	0.055**	-0.028
	(0.018)	(0.025)	(0.023)	(0.023)	(0.024)	(0.055)
$Liq.\,ratio_{t-1}$	-0.031	-0.045	-0.049	-0.041	-0.082*	-0.018
	(0.046)	(0.041)	(0.040)	(0.037)	(0.048)	(0.116)
$Cap.\,ratio_{t-1}$	-0.075	-0.022	-0.019	-0.036	-0.111	0.017
	(0.082)	(0.139)	(0.133)	(0.139)	(0.167)	(0.272)
$\Delta L_{i,k,t}^{\neq k}$	0.084***	0.062**	0.063**	0.060**	0.065*	0.059
	(0.023)	(0.026)	(0.026)	(0.025)	(0.035)	(0.044)
Constant	0.245	-0.070	0.039	0.108	0.078	-0.011
	(0.190)	(0.226)	(0.055)	(0.262)	(0.113)	(0.120)
Observations	62,739	36,573	36,573	37,887	21,318	14,503
R^2	0.108	0.112	0.112	0.112	0.138	0.227

Note: This table reports the results from estimating Equation (2.4) by adding an interaction term between ΔCIP x RSF_{t-5} and variables measuring banks' different degree of access to on-balance-sheet FX funding. The sample period is restricted to 2008Q1 to 20016Q1. The variable $Trait_{t-5}$ represents the respective interaction term in each column lagged in five quarters. For comparison, col. I replicates the exercise using triple differences with the branch dummy reported in col. III in Table 2.3. Columns II to IV report triple interaction regressions with dummies equal to one for banks above the 75th percentile of the respective variable. The variables of interest (i.e. $Trait_{t-5}$) are the ratio of (FX-specific) FX funding to total assets (Total FX, col. II); the ratio of (FX-specific) internal FX funding (ICM) to total assets (ICM rat., col. III); and the ratio of non-ICM funding to total assets (Non-ICM rat., col. IV). Columns V and VI replicate the exercise from col. III for the subset of foreign branches (col. V) and UK-regulated banks (col. VI). Robust standard errors clustered at the bank and quarter level are reported between parentheses. All regressions include the full set of fixed effects specified in Eq. (2.4). Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in Appendix B.1.1. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

better connected banks have an overall better market perception that allows them to raise FX liquidity when needed.

We explore this angle by analysing whether branches and UK-regulated banks with large ICM-access do indeed increase their internal funding in the face of synthetic funding shocks. To implement this test, we adjust the structure of our panel as follows. First, we compute the quarterly growth rate in (exchange rate adjusted) ICM liabilities at the bank-currency-quarter level given data on intragroup liabilities from specific countries are only available for a short period. Therefore, we exclude the destination country dimension used in the previous regressions. The resulting panel can be used to test whether high-RSF banks with a better ICM-access ex-ante do indeed increase their ICM liabilities in the context of synthetic funding shocks. The new structure of our panel means that we cannot implement our preferred set of country-currency-time fixed effects as in Eq. 2.4. We therefore run regressions saturated with bank and currency-time fixed effects.

Results are reported in Table 2.5. In a first exercise (cols. II and III), we look at whether branches are more active in using their ICM funding networks in the event of synthetic funding shocks. Results show that this is indeed the case, as branches draw more ICM funding when compared to non-branches, even though the coefficient of interest losses statistical significance when including currency-time fixed effects. The latter may not be surprising given data limitations, namely that we observe intragroup funding from related entities across the rest of the world rather than directly from the parent entity. We then turn to the subsample of UK-regulated banks, for which intragroup links were found to be particularly important, and explore whether those with high ex-ante access to ICM do make use of this channel conditional on the occurrence of synthetic funding shocks. The results, reported in columns IV and V, confirm that within this group of banks a larger ICM-access ex-ante allows banks to draw more liquidity from internal sources abroad in the event of shocks.

In sum, the exercises in this subsection allow us to link the role of ex-ante access to ICM

Table 2.5 ACCESS TO FX FUNDING: INTERNAL FUNDING GROWTH

	Triple interaction term ($Trait_{t-5}$):				
	None	Branch	Branch	ICM rat.	ICM rat.
	I	II	III	IV	V
Joint ΔCIP x RSF_{t-5} x $Trait_{t-5}$		-3.532**	-2.161	-2.085*	-3.258*
		(1.859)	(2.087)	(1.216)	(1.852)
Joint ΔCIP x RSF_{t-5}	-0.624	1.519	0.522	1.334	0.850
	(1.694)	(1.093)	(1.432)	(1.447)	(1.662)
Joint ΔCIP x $Trait_{t-5}$		-0.0269	-0.460	0.784*	1.132*
		(0.166)	(0.435)	(0.445)	(0.600)
RSF_{t-5} x $Trait_{t-5}$		-0.449***	-0.490***	-0.112	-0.125
		(0.142)	(0.143)	(0.146)	(0.213)
RSF_{t-5}	0.138	0.510***	0.541***	0.467**	0.480**
	(0.139)	(0.122)	(0.123)	(0.182)	(0.202)
Controls:					
$Log\,assets_{t-1}$	-0.020	-0.020	-0.024	0.008	-0.008
	(0.036)	(0.036)	(0.039)	(0.008)	(0.008)
$Dep.\,ratio_{t-1}$	-0.064*	-0.067*	-0.071	-0.026	-0.036
	(0.035)	(0.038)	(0.042)	(0.061)	(0.083)
$Liq.\,ratio_{t-1}$	-0.135	-0.144	-0.144	-0.508	-0.452
	(0.142)	(0.141)	(0.146)	(0.350)	(0.378)
$Cap.\,ratio_{t-1}$	0.021	-0.037	0.019	0.890	0.621
	(0.322)	(0.311)	(0.330)	(0.633)	(0.759)
$\Delta L^{\neq k}_{i,k,t}$	0.089**	0.089**	0.084**	0.157	0.156
	(0.036)	(0.036)	(0.035)	(0.120)	(0.131)
Constant	0.492	0.416	0.493	-0.168	0.131***
	(0.585)	(0.558)	(0.591)	(1.564)	(0.039)
Fixed effects	None	i+k	i + k,t	i+k	i + k,t
Observations	4,214	4,214	4,214	1,019	1,019
R^2	0.018	0.021	0.034	0.037	0.082

Note: This table reports the results from estimating an adjusted version of Equation (2.4) with a panel structured at the bank-currency-quarter dimension. The dependent variable is the quarterly growth rate in internal FX funding liabilities. Col. I reports the result of a simple model replicating the double interaction structure of Equation (2.4). Columns II to V report the results of triple-interaction models in which ΔCIP x RSF_{t-5} is further interacted with variables measuring banks' ex-ante access to internal funding from abroad (i.e. $Trait_{t-5}$). Columns II and III use a branch dummy, while columns IV and V use a dummy equal to one for banks with a ratio of (currency-specific) FX internal liabilities to total assets (ICM rat.) above the 75th percentile. Columns II and IV include bank and currency fixed effects ($i + k$), whereas columns III and V include bank and currency-quarter fixed effects ($i+k, t$). Robust standard errors clustered at the bank and quarter level are reported between parentheses. Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in Appendix B.1.1. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

in shaping the effect of synthetic funding shocks on bank lending, with an active management of internal FX liabilities in the event of a shock. The important role played by internal capital markets reveals how geographical funding market structures can shape the stability of cross-border banking flows worldwide, especially in the presence of institutional frictions potentially preventing the reallocation of funding sources when liquidity conditions change.

2.5 The Macroeconomic Dimension: Substitution Across Banks and Countries

The results of our analysis provide compelling evidence of an effect on cross-border bank lending from shocks to the cost of synthetic funding. However, this does not necessarily mean that such dynamics should have aggregate consequences: borrowers in the recipient countries could offset this credit supply shock by shifting their demand for credit to less affected banks, either based in the UK or in other countries. Exploring this question is important both to calibrate the macroeconomic consequences of shocks to the cost of synthetic funding and, relatedly, to assess whether stronger access to global (intrabank) liquidity channels helps limit the pass-through of the identified effect on lending to the real economy.

In this section we analyse whether this substitution across banks or originator countries indeed takes place. We divide this analysis in two steps. We first assess the existence of substitution in credit supply in the cross-section of UK-based banks, as less affected banks could step in when affected banks cut back their lending in the face of synthetic funding shocks. However, a more potent source of substitution might be banks outside the UK which are less affected by synthetic funding shocks. We thus assess secondly substitution of borrowers shifting demand out of affected UK banks into banks outside the UK, importantly into banks located in the US or the Euro Area. Taken together, these

tests can shed light on the potential consequences for aggregate credit volumes of shocks to the cost of synthetic funding, and whether banks' access to internal capital markets has a role in these considerations.

To conduct these tests, we adjust our baseline empirical setting as follows. First, we aggregate our left-hand side variable at the country-currency level and compute the aggregate growth rate in cross-border credit by all UK-based banks. Then, we re-compute all bank-level variables as the market-share-weighted average of all banks within a country-currency market. For example, the synthetic funding reliance variable (RSF) is computed as the average RSF of all banks in a country-currency pair weighted by their respective market shares in that specific market.[37]

To explore the substitution of credit across origination countries we implement a second set of tests in which we replace the dependent variable by the (exchange rate adjusted) growth rate in total cross-border credit to the country-currency pair in consideration from the 'rest of the world' (i.e. world ex UK) or from the currency areas of the currencies we consider; that is, the US and Euro Area. We compute these series using data from the BIS Locational Banking Statistics.

In order to operationalise this setting, we run an adjusted version of Equation (2.4) using a panel at the country-currency-quarter level. This adjusted empirical model is formalized by Equation (2.5):

$$\Delta L_{j,k,t} = \alpha + \beta_1 RSF_{j,k,t-5} + \sum_{l=1}^{4} \beta_{2,l} \Delta CIP_{k,t-l} * RSF_{j,k,t-5} \tag{2.5}$$

$$+ \beta_3 X_{j,t-1} + \gamma_{j,k} + \delta_t + \epsilon_{j,k,t}$$

[37] For this exercise we employ the full dataset without the filters imposed on the data in our baseline specification to allow for a potential substitution across all UK-based banks active in a given market abroad.

In Equation (2.5) we study the cross-border lending growth rate in country j and currency k during quarter t ($\Delta L_{j,k,t}$). As in our baseline specification, the variable of interest is the interaction between a country-level proxy for the exposure to synthetic funding in currency k by banks operating in country j (RSF) and the deviations in the CIP condition (ΔCIP). We consider country-currency and time fixed effects. Although this specification does not allow for the type of credit demand control implemented in Equation (2.4), we can still absorb demand shocks that spread similarly across countries and currencies.[38] To ensure consistency, the country-currency level panel used to run the estimation of Eq. (2.4) is matched to this country-currency specification, including the same group of 70 countries.

Table 2.6 reports the results of testing for substitution of credit across UK-based banks with different exposures to synthetic FX funding. Column I reports a positive and statistically significant joint coefficient for the interaction term of interest, suggesting that markets with a large presence of UK-based banks largely exposed to synthetic funding experience a drop in aggregate credit from the UK when synthetic funding shocks occur. We interpret this result as evidence against a potential substitution of credit across UK-based banks with different exposures to synthetic funding. Interestingly, despite not speaking directly to substitution dynamics, columns II-V show that, in periods of synthetic market strain, aggregate lending from the UK does not fall in destination markets with large share of lending originated from UK-based branches (cols. II-III) or UK banks with large use of internal capital markets (cols. IV-V). [39] This result - which goes in line with our findings from Section 2.3.2 at the bank-level - could imply that either there is more active substitution or that the original credit supply does not fall initially given the

[38] Richer fixed effect structures such as receiving country-time fixed effects are difficult to implement in our core specification measuring substitution across originator countries. This is because of stronger data restrictions in the cross-country BIS International Banking Statistics compared to the UK micro-banking data used in our baseline specification: for reasons for confidentiality or an actual lack of data there are often for example no observations on lending in euros to countries in Latin America or for lending in dollars to countries in Central or Eastern Europe.

[39] For this exercise we split the sample according to the 75th percentile of the pre-2008 distribution of the share of UK-based branches in total claims from the UK.

large presence of banks that can undo the effect of synthetic funding shocks by relying on their internal capital markets.[40]

Table 2.6 MACROECONOMIC DIMENSION – SUBSTITUTION ACROSS UK BANKS

		Share of UK branches in total claims:		Share of large ICM ratio:	
Sample:	Full	Low	High	Low	High
	I	II	III	IV	V
Joint ΔCIP x RSF_{t-5}	1.159**	1.326**	0.646	1.688*	-1.096
	(0.461)	(0.618)	(0.936)	(0.848)	(1.181)
RSF_{t-5}	-0.057	-0.099**	0.081	-0.110	0.047
	(0.037)	(0.041)	(0.065)	(0.078)	(0.095)
Controls:					
$Log\,assets_{t-1}$	0.008	0.007	0.009*	0.009	-0.007
	(0.006)	(0.007)	(0.005)	(0.011)	(0.014)
$Dep.\,ratio_{t-1}$	-0.021	-0.059	0.080*	-0.019	0.222*
	(0.036)	(0.045)	(0.046)	(0.062)	(0.114)
$Liq.\,ratio_{t-1}$	0.244***	0.316***	0.119	0.309**	-0.093
	(0.066)	(0.080)	(0.106)	(0.136)	(0.137)
$Cap.\,ratio_{t-1}$	0.434***	0.503***	0.039	0.013	1.185***
	(0.151)	(0.184)	(0.204)	(0.207)	(0.279)
Constant	-0.237**	-0.227*	-0.275**	-0.266	-0.157
	(0.102)	(0.120)	(0.108)	(0.196)	(0.202)
Obs	6,576	4,896	1,680	2,856	980
R^2	0.036	0.041	0.061	0.038	0.064

Note: This table reports the results from estimating Equation (2.5) at the country-currency level. The dependent variable is the quarterly change in log total claims to country j in currency k by all UK-based banks in the original sample ($\Delta L_{j,k,t}$), before including sample filters. The independent variables (with the exception of ΔCIP) are computed as market-share weighted averages of the respective underlying bank-level variables in each country-currency pair. Column I reports the results for the full sample. Columns II and III report a sample split exercise according to the 75th percentile of the pre-crisis average share of UK-based branches in total claims to each j, k pair. Columns IV and V replicate the sample split exercise according to the 75th percentile of the pre-crisis share of large ICM-ratio banks in total claims in each j, k pair. Large ICM-ratio banks are those with a ratio of (currency-specific) FX internal liabilities to total assets (ICM ratio) above the 75th percentile of the banks' distribution. All constitutive terms of the interactions are included in the regressions. Regressions include country-currency and time fixed effects. Standard errors (in parentheses) are clustered at the currency and quarter level. Variables are winsorised at the 1st and 99th percentiles. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Next, we re-estimate Eq. (2.5) by replacing the dependent variable $\Delta L_{j,k,t}$ by the growth

[40] As in Section 2.4.3 and due to data limitations, this exercise is restricted to the period 2008-2016.

rate in cross-border claims from the 'rest of the world' (all countries ex-UK) in general, and, alternatively, from the corresponding currency areas of the flows in consideration (i.e., the US and Euro Area). The latter is motivated by these regions being the 'home areas' for the currencies we consider, i.e. the US dollar and the euro, and hence less exposed to shocks to the cost of obtaining these currencies synthetically. The results from this analysis are reported in Table 2.7. While in these regressions we keep the focus on the joint coefficient of the interaction term ($\Delta CIP_{k,t-l} * RSF_{j,k,t-5}$), which still reflects the weighted reliance of synthetic funding of UK banks active in the relevant market, we would expect, in contrast to our baseline results, a negative sign if a substitution across origination countries takes place; that is, we would expect lending from these areas to increase in the face of shocks to sterling-based synthetic FX funding in their respective currencies (which we have seen to reduce UK lending).

Given the change in the dataset used to measure cross-border lending from Bank of England regulatory data to BIS Locational Statistics, in Column I we report a repeat of the exercise on UK lending shown in Table 2.6, but estimated on BIS data. Reassuringly, results hold and the magnitudes of effects are very similar. Turning to cross-country substitution, column II shows that this does not take place between the UK and the world considered as a whole, as the rest of the world does not increase lending to affected countries in the event of sterling-based synthetic funding shocks. However, the result changes when considering only cross-border flows originated in the US and the Euro Area (column III), in which case estimating Eq. (2.5) results in a negative and statistically significant coefficient. This is intuitive if synthetic funding shocks are not exclusive to sterling but also shared across other non-US dollar/euro currencies. As a further exercise we look separately at markets with a high and low market share of UK-based banks, as a proxy for their exposure to sterling-based synthetic funding shocks (columns IV and V).[41] It can be seen that it is indeed the case that the increase in credit supply from US and Euro Area based banks only happens in those markets particularly affected by our shock, that is, in

[41] This sample split follows the same definition as in Table 2.4.

Table 2.7 MACROECONOMIC DIMENSION – SUBSTITUTION ACROSS SOURCE COUNTRIES

Claims from:	UK	Rest of world	Home CA		
			Share UK claims:		
Sample:	Full	Full	Full	Low	High
	I	II	III	IV	V
Joint ΔCIP x RSF_{t-5}	1.039**	-0.499	-0.959*	-0.651	-1.694**
	(0.415)	(0.403)	(0.541)	(0.661)	(0.769)
RSF_{t-5}	-0.084	-0.048	0.021	-0.041	0.079
	(0.052)	(0.033)	(0.041)	(0.051)	(0.069)
Controls:					
$Log\,assets_{t-1}$	0.013**	-0.001	0.003	0.002	0.004
	(0.005)	(0.002)	(0.002)	(0.003)	(0.006)
$Dep.\,ratio_{t-1}$	-0.008	-0.006	0.052	0.034	0.035
	(0.087)	(0.035)	(0.074)	(0.080)	(0.134)
$Liq.\,ratio_{t-1}$	0.239***	0.019	0.097*	0.119*	0.083
	(0.062)	(0.033)	(0.050)	(0.063)	(0.086)
$Cap.\,ratio_{t-1}$	0.434**	-0.050	-0.270*	-0.290*	-0.329
	(0.176)	(0.089)	(0.141)	(0.151)	(0.271)
Constant	-0.334***	0.025	-0.072	-0.045	-0.088
	(0.073)	(0.032)	(0.049)	(0.061)	(0.103)
Obs	6,546	6,546	5,695	2,999	2,696
R^2	0.039	0.076	0.035	0.043	0.048

Note: This table reports the results from estimating Equation (2.5) at the country-currency level. The dependent variable is the quarterly change in log total claims to country j in currency k computed using data from the BIS Locational Banking Statistics ($\Delta L_{j,k,t}$). The independent variables (with the exception of ΔCIP) are computed as market-share weighted averages of the underlying bank-level variables in each country-currency pair. The table reports regressions in which we compute $\Delta L_{j,k,t}$ using flows originated in three regions: UK (col. I), all countries different than the UK (Rest of world, col. II); and the US and Euro Area as the home currency areas of the currencies in which claims are denominated (Home CA, cols. III to V). In columns IV and V we report a sample split exercise according to the median of the pre-crisis average share of claims from the UK in total claims to each j, k market. All constitutive terms of the interactions are included in the regressions. Regressions include country-currency and time fixed effects. Standard errors are clustered at the currency and quarter level. Variables are winsorised at the 1st and 99th percentiles. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

markets where UK-based banks have a larger presence ex-ante and where a larger share of them is largely exposed to synthetic funding.

How large is such cross-country substitution? The answer is nuanced. We indeed see currency area banks increasing lending to affected markets, but it is yet to be determined

whether that increase in lending is enough to offset the fall in lending coming from the UK. This net effect will depend on the relative importance of lending from UK banks and lending from currency area banks and has to be considered on a case-by-case basis. As an illustrative example, we can go back to the case study considered in Section 2.3.2. During the second quarter of 2012, the sterling-based US dollar basis widened by 7 basis points (making it more expensive to secure US dollars synthetically). In order to illustrate heterogeneities in the degrees of substitution in cross-border lending let us consider two cases: Singapore, which receives around 30% of its US dollar funding from the UK, and South Africa, for which the share of dollars coming from UK is close to 50%. The market-weighted reliance on synthetic funding of UK banks active in these markets is very similar, at around 20%. Using the coefficients displayed in Table 2.7, it can be calculated that, in the face of the CIP shock considered, the increase in cross-border lending from the US offsets around two-thirds of the fall in UK lending for Singapore, but that this figure was smaller, at around one third, for South Africa, given the larger reliance on the UK for its US dollar funding.

In sum, the analysis of credit supply from affected and non-affected banks in the event of synthetic funding shocks suggests that (i) substitution does not take place within the sample of UK-based banks, but (ii) other banks, namely those based in the US and Euro Area, do step in and increase their lending to particularly affected recipient countries. The net effect depends on initial levels of lending coming from the UK and the respective currency area. This result highlights the effects on the geographical distribution of cross-border lending that arise as a consequence of global banks' limited access to alternative FX funds in a context of significant dislocations in synthetic FX funding markets.

2.6 Conclusion

This article documents the existence of a cross-border bank lending channel arising from funding shocks in FX swap markets. By looking at balance sheet data from banks operat-

ing in the UK we show that banks cut cross-border lending in specific foreign currencies whenever the cost of obtaining funds in these currencies goes up in FX derivatives markets. These instances are reflected in deviations in the covered interest rate parity (CIP) condition, which have drawn much attention in the post financial crisis era.

By exploiting the richness of our dataset we are able to control for a series of confounding factors, and to tightly identify a causal link going from the cost of 'synthetic' FX funding to the supply of cross-border FX loans. When further dissecting these results we find that banks with higher reliance on synthetic funding cut back lending by a greater extent in the face of synthetic funding shocks, and that the effect is alleviated for those banks that have access to on-balance-sheet FX funds coming from abroad via internal capital markets. The effects we find are highly statistically significant and economically meaningful. We interpret our results as evidence of the relevance of institutional frictions in the workings of global banking activities.

When exploring the degree of borrower substitution towards other lenders, we do not find evidence of an increase in lending from unaffected UK banks, but do see an increase in lending originating from the corresponding currency areas, particularly towards destination countries with initial high reliance on UK lending. However, this increased lending does not work as a full offset in many cases, pointing to the macroeconomic consequences of the mechanisms outlined in the paper.

Our results could inform policy discussions related to international financial fragmentation and the need for regulatory cooperation to tackle the drivers of fragmentation. Specifically, it may contribute to the debate on the future of global banking and potential restrictions on global bank operations. Since the outset of the latest financial crisis several countries have introduced policies aimed at restricting the ability of domestic banks and foreign bank affiliates to participate in internal (and external) capital markets, including geographic ring-fencing policies.[42] These policies attempt to protect the interests of

[42] See OECD (2017) for a recent survey of the structural banking reform measures implemented in most

domestic stakeholders, limiting the transmission of foreign shocks.[43] Our analysis highlights a potential unintended drawback of this drive: by restricting global banks' capacity to manage internal liquidity on a global scale, these policies may entail the risk of reducing banks' access to FX liquidity, affecting thereby the stability of cross-border banking flows. In this context, international regulatory cooperation may be important in addressing the financial stability concerns behind potentially fragmenting policies.

of the countries surveyed in the aftermath of the crisis. This report highlights that a key issue being increasingly monitored since the crisis concerns liquidity and many financial requirements are liquidity related.

[43] Previous studies have argued that these policies may provide a cushion against financial contagion (Anginer et al., 2017) at the cost of increasing banks' capital and liquidity needs (Makarova et al., 2010). See also Beck et al. (2015). See Fiechter et al. (2011) for a discussion on the financial stability implications of branches vs. subsidiary based models of international banking.

3 | Dollar Shortage Shocks and Central Bank Swap Lines

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.

Keywords: central bank swap lines, liquidity facilities, dollar shortages, uncovered interest rate parity condition, financial frictions.

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

3.1 Introduction

Despite having been a defining feature of the three largest financial crises of the last decades, surprisingly little is known about the macroeconomic effect of 'dollar shortage' shocks affecting non-US banking systems, and about the role of the observed monetary policy response in the form of central bank swap lines in attenuating these effects. This gap is the more noticeable to the extent that swap line arrangements have by now become part of the permanent monetary 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 financial 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 monetary 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 financial 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. We show that the impact of the shock on macro variables is significant from a quantita-

tive perspective, and that the observed drawing from dollar swap lines is not enough to attenuate these dynamics (but an uptake in line with maxima set by the Federal Reserve would). 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.

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 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 Andries 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 Queralto, 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.[1] Second, we incorporate central bank swap lines into the picture. 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 3.2 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 3.3 describes the basic features of our baseline model and its calibration, including the mechanisms surrounding central bank swap lines. In Section 3.4 we analyse the dynamics of the model in the face of a 'dollar shortage' shock under various exchange rate arrangements and multiple scenarios for the use of swap lines. Section 3.5 concludes.

3.2 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.

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

3.2.1 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).

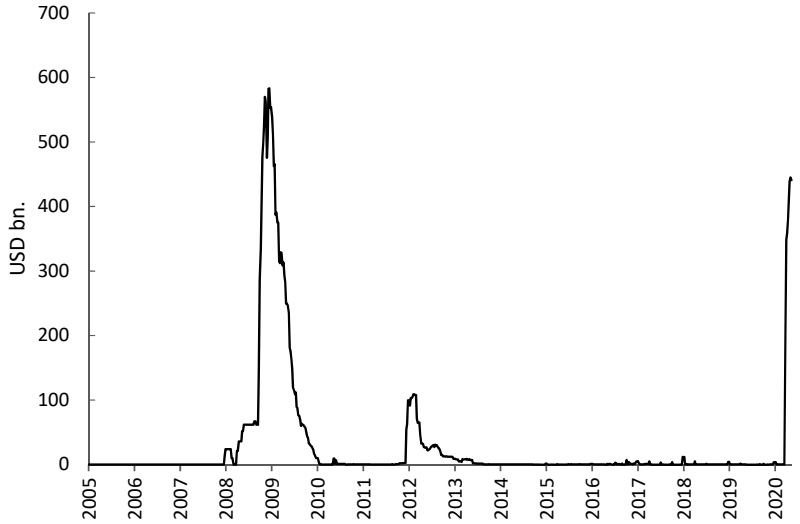
In terms of the model outlined in Section 3.3, the key feature of central bank swap lines is that they represent an additional source of foreign currency for the domestic economy, which the domestic central bank channels on to the domestic banking system under collateral requirements that are similar to those of its other lending facilities and overall conditions typically more favourable than those banks would face in the market.

3.2.2 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).[2] 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

[2] 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 3.1 CENTRAL BANK LIQUIDITY SWAPS HELD BY THE FEDERAL RESERVE



Source: FRED.

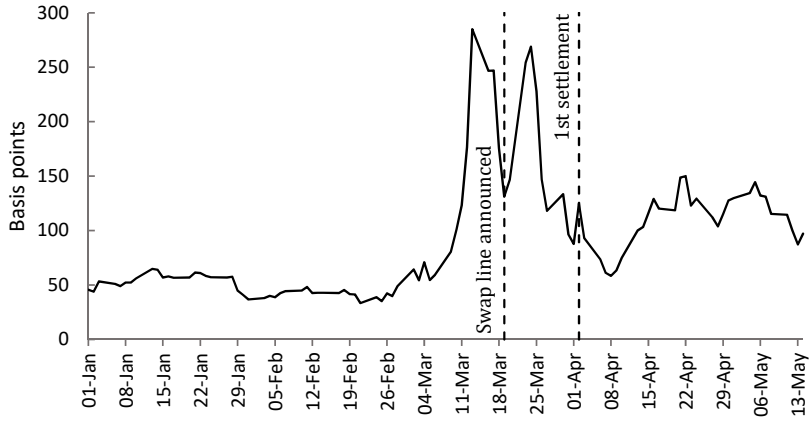
became significantly less frequent on the back of less active foreign exchange intervention policies and an increase in the use of foreign exchange reserves for this purpose, before being formally phased out in the early 1990s.

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 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.[3] Second, other central banks set up swap line arrangements of their own,

[3]Namely, Brazil, Singapore, South Korea and Mexico, for which a swap line was already in place in the

Figure 3.2 KOREAN WON-US DOLLAR 3-MONTH CIP DEVIATIONS



Source: Bloomberg and author's calculations.

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).[4]

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 3.1). 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.[5] The main motivation cited was to '*help lessen*

context of the trilateral US-Canada-Mexico relationship.

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

[5]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,

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.'[6]

Figure 3.2 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 as those in Bahaj and Reis (2018).

3.3 Model

Our baseline model is a two-country version of the canonical open economy New Keynesian model as in Erceg et al. (2007), with financial frictions in the spirit of Akinci and Queralto (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 Queralto, 2019, Aoki et al., 2018). We allow for this differential friction when borrowing in foreign currency to evolve stochastically over time.

Singapore and Sweden.

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

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.

3.3.1 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

$$C_t + D_t \leq \frac{W_t}{P_t}L_t + R_t D_{t-1} + \Xi_t \tag{3.1}$$

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).[7] This choice is motivated by the findings in Boz et al. (2020), who report a globally dominant role for the US dollar in international trade invoicing.[8] For completeness, Appendix C.3 reports the main results of the paper under the more standard producer currency pricing (PCP) paradigm. In our baseline case, 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 $\epsilon_t = e_t P^*_t / P_t$.

[7] 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.

[8] In particular, they report a share of exports invoiced in US dollars of more than 80% for Korea, our calibration target.

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

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 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).

3.3.2 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):

$$q_t S_{i,t} = D_{i,t} + \epsilon_t D^*_{i,t} + N_{i,t} \tag{3.2}$$

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:

$$q_t S_{i,t} + R_t D_{i,t-1} + R^*_t \epsilon_t D^*_{i,t-1} \leq R_{K,t} q_{t-1} S_{i,t-1} + D_{i,t} + \epsilon_t D^*_{i,t} \tag{3.3}$$

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

[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.

$$R_{K,t} = \frac{Z_t + (1-\delta)q_t}{q_{t-1}} \tag{3.4}$$

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

Combining (3.2) and (3.3) we can obtain the law of motion of a continuing bank's net worth:

$$N_{i,t+1} = (R_{K,t+1} - R_{t+1})q_t S_{i,t} + (R_{t+1} - R^*_{t+1}\epsilon_{t+1}/\epsilon_t)\epsilon_t D^*_{i,t} + R_{t+1}N_{i,t} \tag{3.5}$$

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

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:

$$\Theta(x_{i,t}, \gamma_t) = \theta(1 + \frac{\gamma_t}{2}x^2_{i,t}) \tag{3.6}$$

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:

$$\gamma_t = (\gamma_{t-1})^{\rho_\gamma}(\gamma^{ss})^{(1-\rho_\gamma)}u^\gamma_t \tag{3.7}$$

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 Queralto (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:

$$V_{i,t} = \max_{S_{i,t}, D^*_{i,t}} \quad (1-\sigma_b)E_t(\Lambda_{t,t+1}N_{i,t+1}) + \sigma_b E_t(\Lambda_{t,t+1}V_{i,t+1}) \tag{3.8}$$

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 (3.5) and

$$V_{i,t} \geq \Theta(x_{i,t}, \gamma_t) q_t S_{i,t} \tag{3.9}$$

which constitutes an incentive compatibility constraint.

The optimum behaviour of banks is characterised by two first order conditions.[13] The

[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).

[13] See Appendix C.1.1 for a derivation.

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:

$$\mu_t^* = \left(\frac{\Theta(x_t, \gamma_t)}{\Theta'(x_t, \gamma_t)} - x_t\right)^{-1} \mu_t \tag{3.10}$$

where 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:

$$\mu_t = E_t\left[\Omega_{t+1}(R_{K,t+1} - R_{t+1})\right] \tag{3.11}$$

$$\mu_t^* = E_t\left[\Omega_{t+1}(R_{t+1} - \frac{\epsilon_{t+1}}{\epsilon_t} R_{t+1}^*)\right] \tag{3.12}$$

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:

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

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

Optimality condition (3.10) 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:

$$\phi_t = \frac{\nu_t}{\Theta(x_t, \gamma_t) - (\mu_t + \mu_t^* x_t)} \tag{3.13}$$

Optimality condition (3.13) 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 C.1.1 for a derivation).

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

3.3.3 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:

$$Y_t = \left(\int_0^1 Y_{i,t}^{\frac{1}{1+\theta_p}} di \right)^{(1+\theta_p)} \tag{3.14}$$

The price level of domestic final output is given by $P_{Dt} = \left(\int_0^1 P_{Dit}^{-\frac{1}{\theta_p}} \right)^{-\theta_p}$, 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:

$$Y_{i,t} = \left(\frac{P_{Di,t}}{P_{Dt}} \right)^{-\frac{1+\theta_p}{\theta_p}} Y_t \tag{3.15}$$

Each differentiated intermediate good is produced according to:

$$Y_{i,t} = K_{i,t}^{\alpha} L_{i,t}^{1-\alpha} \tag{3.16}$$

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:

$$E_t\Big\{\sum_{j=0}^{\infty}\Lambda_{t,t+j}\xi_p^j\Big[(P_{Di,t}-\zeta_{i,t+j})Y_{i,t+j}\Big]\Big\} \tag{3.17}$$

subject to (3.15) and (3.16), 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

$$E_t\Big\{\sum_{j=0}^{\infty}\Lambda_{t,t+j}\Big[q_{t+j}I_{t+j} - p_{D,t}\phi_{I,t}\Big]\Big\} \tag{3.18}$$

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

$$\phi_{I,t} = \frac{\psi_I}{2}(I_t/I_{t-1}-1)^2 I_t \tag{3.19}$$

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

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

3.3.4 Market Clearing

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

$$Y_t = C_{Dt} + I_{Dt} + \frac{\xi^*}{\xi}(M_{Ct}^* + M_{It}^*) + \phi_{It} \tag{3.20}$$

where $\frac{\xi^*}{\xi}$ is the relative size of the foreign economy. Market clearing for claims on capital

(entirely owned by domestic banks) implies:

$$S_t = K_{t+1} \tag{3.21}$$

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

$$K_{t+1} = (1 - \delta)K_t + I_t \tag{3.22}$$

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

$$\epsilon_t D_t^* = \epsilon_t R_t^* D_{t-1}^* - NX_t \tag{3.23}$$

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

$$NX_t = p_{dt} Y_t - C_t - I_t - p_{dt} \phi_{It} \tag{3.24}$$

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

3.3.5 Policy

3.3.5.1 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:

$$R_{t+1}^n = \left(R_t^n\right)^{\gamma_r} \left(\beta^{-1} \pi_t^{\frac{1-\gamma_e}{\gamma_e}} \left(e_t / e_{t-1}\right)^{\frac{\gamma_e}{1-\gamma_e}}\right)^{(1-\gamma_r)} u_t^r \tag{3.25}$$

where u_t^r constitutes an exogenous shock. The functional form draws from Akinci and Queralto (2019) and Gali and Monacelli (2016), but considers *changes* in the nominal exchange rate rather than deviations from steady state. This is motivated by two main reasons. First, policymakers do not observe equilibrium exchange rate levels, and hence tend to focus on exchange rate changes instead. Second, financial stability considerations in policymaking are typically cast in exchange rate volatility space, which is more directly related to exchange rate changes. In this respect, even countries with allegedly freely floating exchange rate regimes acknowledge a role for monetary policy in smoothing exchange rate changes, without aiming to influence its level in the medium term.[14]

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 3.3.7.1, 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 effect, the Bank of Korea has recently explicitly stated that it has "*devoted efforts to achieve financial and foreign exchange market stability*" in response to the turmoil resulting from the Covid-19 pandemic.[15]

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.

3.3.5.2 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 3.2.1, 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

[14] See, for example, Bank of Korea's Monetary Policy Report from March 2020.
[15] See page 37 in their March 2020 Monetary Policy Report.

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.[16]

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).

$$F_t = \phi^F(\mu_t^* - \mu_{ss}^*) \tag{3.26}$$

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 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 deals with 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 3.2.1, 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 terms of the

[16]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.

model, $D_t^{*,s}$ 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. However, central bank supplied foreign currency funds still require collateral θ, matching that of local currency funds supplied by domestic households.[17] [18]

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

$$\epsilon_t D_t^{*,s} + \epsilon_t F_{t-1}(R_t^* + fp_t) = T_t + \epsilon_t F_t + R_t^s \epsilon_t D_{t-1}^{*,s} \tag{3.27}$$

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).[19]

After demanding $D_t^{*,s}$ foreign currency funds from the domestic central bank the balance sheet of domestic banks changes from (3.2) to:

$$q_t S_{i,t} = D_{i,t} + \epsilon_t D_{i,t}^* + \epsilon_t D_{i,t}^{*,s} + N_{i,t} \tag{3.28}$$

and the evolution of its net worth from (3.5) to:

$$N_{i,t} = R_{K,t} q_{t-1} S_{i,t-1} - R_t D_{i,t-1} - \epsilon_t R_t^* D_{i,t-1}^* - \epsilon_t R_t^{*,s} D_{i,t-1}^{*,s} \tag{3.29}$$

[17] This responds to the fact that, in reality, central banks require the same collateral for the allocation of swap-acquired foreign currency as they do for the rest of their lending facilities in domestic currency. See Bahaj and Reis (2018).

[18] 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.

[19] Future work could aim to make this spread endogenous to the dynamics of the model in order to deliver an interior solution to the choice of swap-based foreign currency funding by banks. In practice, empirical analysis shows no clear correlation between the spreads charged and the amount of swaps demanded in operations conducted since 2007.

The optimisation problem of the domestic banks is analogous to the one laid out in Section 3.3.2, but now there is an additional choice variable $D_t^{*,s}$ and an additional constraint:

$$D_t^{*,s} \leq F_t \tag{3.30}$$

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

Appendix C.1.2 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:

$$D_t^{*,s} = F_t \tag{3.31}$$

The conditions that characterise the optimal choice of banks in Section (3.3.2) change as follows. Condition (3.10) becomes

$$\mu_t^* = \left(\frac{\Theta(x_t, \gamma_t)}{\Theta'(x_t, \gamma_t)} - x_t - sw_t\right)^{-1} \mu_t \tag{3.32}$$

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 (3.13) becomes:

$$\phi_t = \frac{\nu_t}{\Theta(x_t, \gamma_t) - \mu_t - \mu_t^* sw_t - \mu_t^* x_t} \tag{3.33}$$

We can see from equation (3.33) 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 (3.23) to:

$$\begin{aligned} \epsilon_t D_t^* + \epsilon_t F_t = \\ \epsilon_t R_t^* D_{t-1}^* + \epsilon_t (R_t^* + fp_t) F_{t-1} - NX_t \end{aligned} \tag{3.34}$$

3.3.6 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:

$$R_{t+1}^{n,*} = (R_t^{n,*})^{\gamma_r} (\beta^{*-1} \pi_t^{*\gamma_\pi})^{(1-\gamma_r)} u_t^{r*} \tag{3.35}$$

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

3.3.7 Calibration

Our calibration of the core part of the model follows Akinci and Queralto (2019) for the most part, which in turn draws significantly from Justiniano et al. (2010). The financial frictions and monetary policy rule are chosen to match characteristics of Korea, our calibration target. 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, lead-

ing 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 Queralto (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.[20] 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

[20]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.

a ratio of foreign currency debt of 0.2. This is achieved by setting $\theta = 0.27$, $\xi_b = 0.07$ and $\gamma^{ss} = 3$. This calibration choice results in a non-negligible currency mismatch in the domestic economy, motivated by the fact that Chui et al. (2016) report a sizeable currency mismatch in the balance sheet of Korea's non-official sector between 2006 and 2014. [21]

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 Queralto (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.

3.3.7.1 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.

Figure 3.2 suggests an increase of approximately 215 basis points between the pre-stress period and the peak of the stress.[22] This level of CIP deviations was reached before swap lines were announced, and hence the the 'dollar shortage' shock is calibrated so

[21] Their estimates of the net foreign assets of the sector are approximately -20% of exports on average.

[22] 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).

as to deliver the observed stress under no (swap) policy action, that is, $\phi^F = 0$. We then calibrate ϕ^F in 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).[23] 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 C.1 in Appendix C.2.1 lists the chosen parameter values.

3.4 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 3.3.7.1. However, we do not allow the home central bank to draw US dollars from its swap line. We explore the model dynamics under three

[23] Data sources and transformations can be found in Appendix C.2.2.

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.

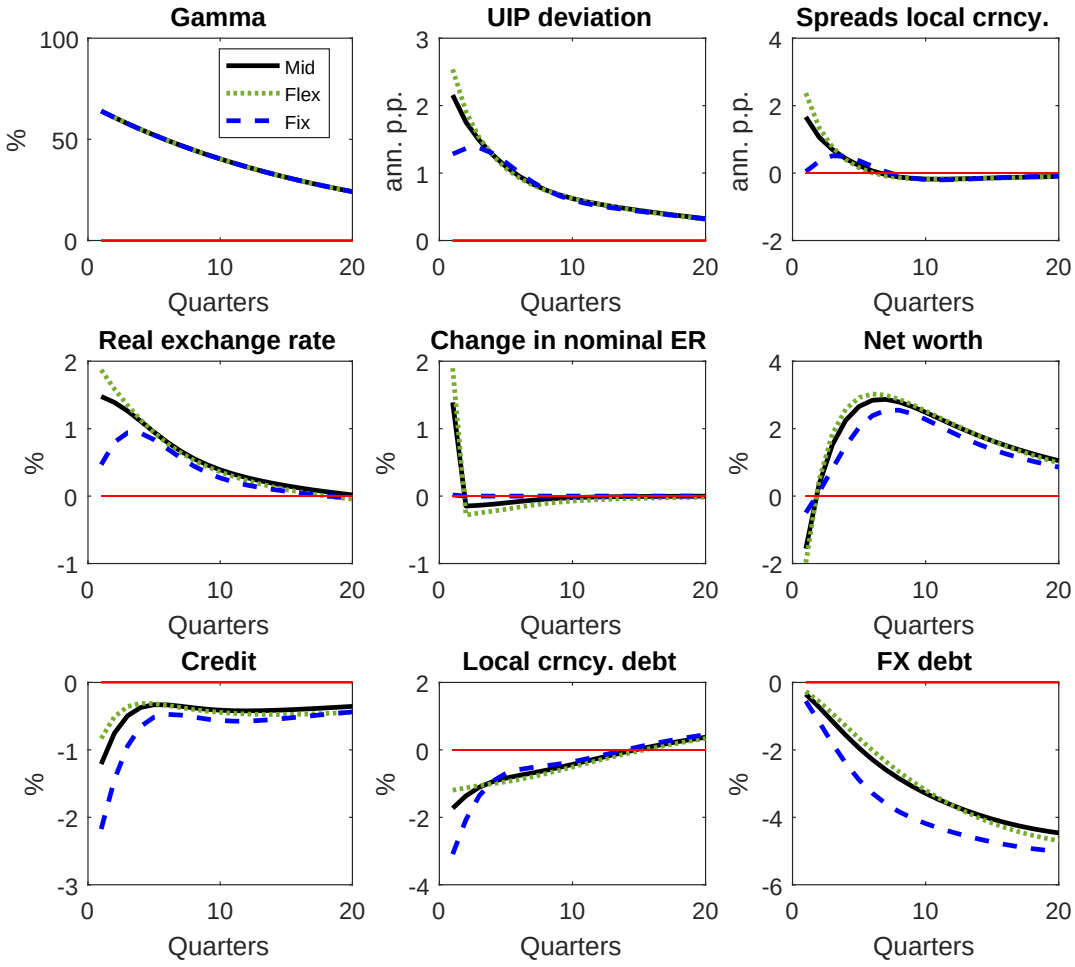
Secondly, we focus on the intermediate exchange rate arrangement (which best characterises the monetary policy of emerging markets such as Korea) and introduce the possibility for the home central bank to draw from its US dollar swap line with the Fed. We explore three different scenarios: a baseline 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 3.3.7.1).

3.4.1 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 3.3). 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,

Figure 3.3 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 ($\gamma_e = 0.99$).

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 inter-

est rates observed in Figure 3.4. 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 3.4), leading to a sharper contraction in bank lending.

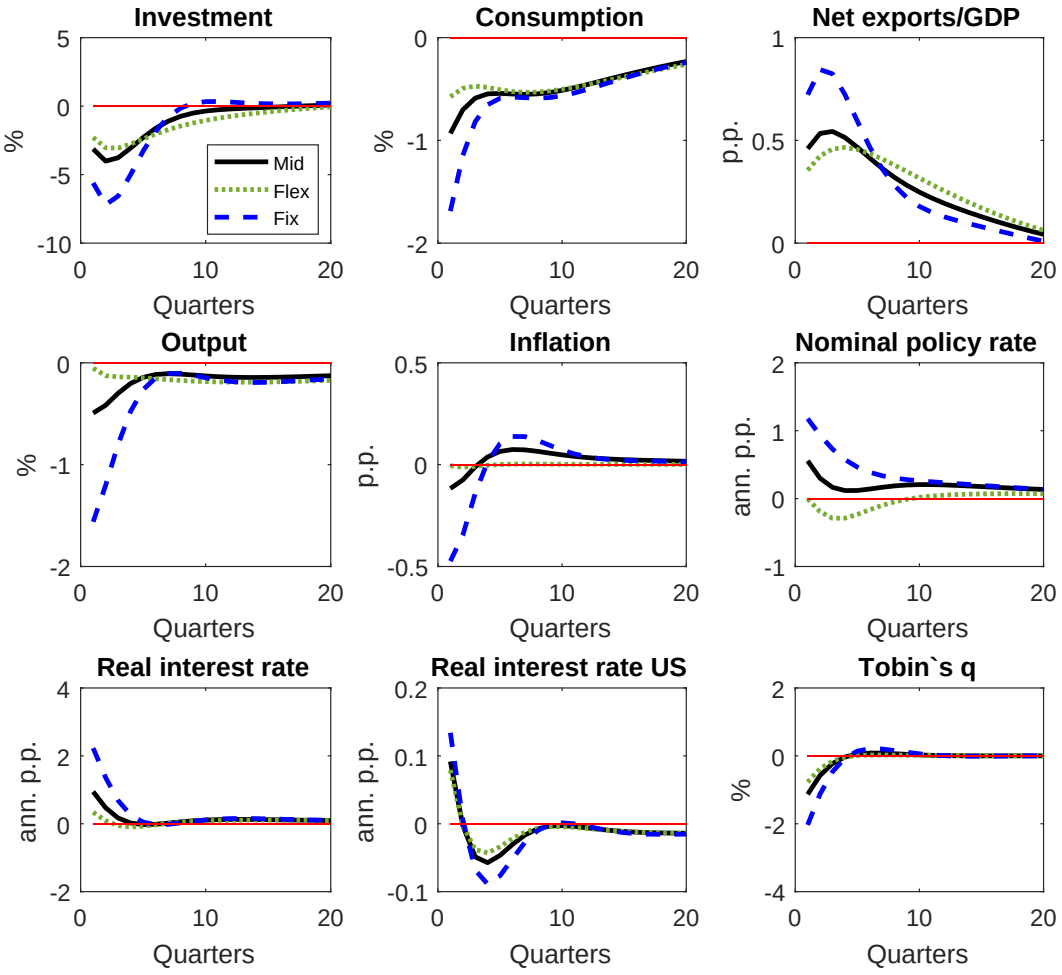
On the real economy side, the fall in the price of capital and the contraction in bank lending coincide with a fall in investment, while the negative wealth effect (and the more expensive imports) results in consumption also falling, which combine into a contraction in output (Figure 3.4). Net exports 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.[24]

The starkest heterogeneity across exchange rate regimes can be seen in the reaction of the policy rate and inflation (Figure 3.4). 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 expense of some domestic deflation. This is of course more extreme in the case of the quasi-fixed exchange rate regime.

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 quantitative perspective: investment falls by nearly 4%, consumption by nearly 1% and output by 0.5% under the intermediate exchange rate regime.

[24] Akinci and Queralto (2019) explore the inferiority of fixed exchange rate arrangements in more detail in a similar model in the face of US monetary policy shocks.

Figure 3.4 MODEL DYNAMICS AFTER 'DOLLAR SHORTAGE' SHOCK, MACRO VARIABLES



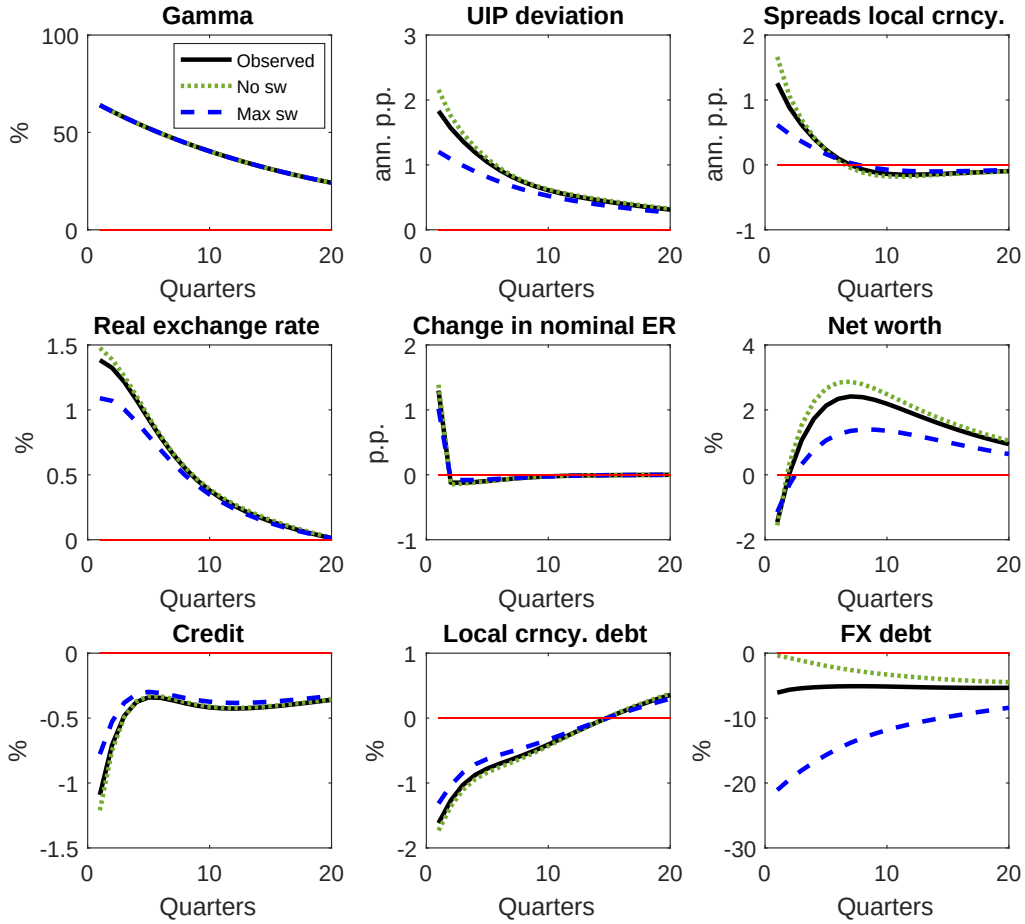
Note: Impulse response functions of model following a 'dollar shortage' shock (an increase in γ_t). Black solid lines correspond to scenario of an intermediate degree of exchange rate targeting ($\gamma_e = 0.4$), green dotted lines to scenario of flexible exchange rates ($\gamma_e = 0.05$) and blue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

Model dynamics are qualitatively very similar under produce currency pricing. See Appendix C.3.1.

3.4.2 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

Figure 3.5 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).

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 3.4.1). See Section 3.3.7.1 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 3.5). 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 3.2), 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 3.6). The milder contraction in credit shown in Figure 3.5, and 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

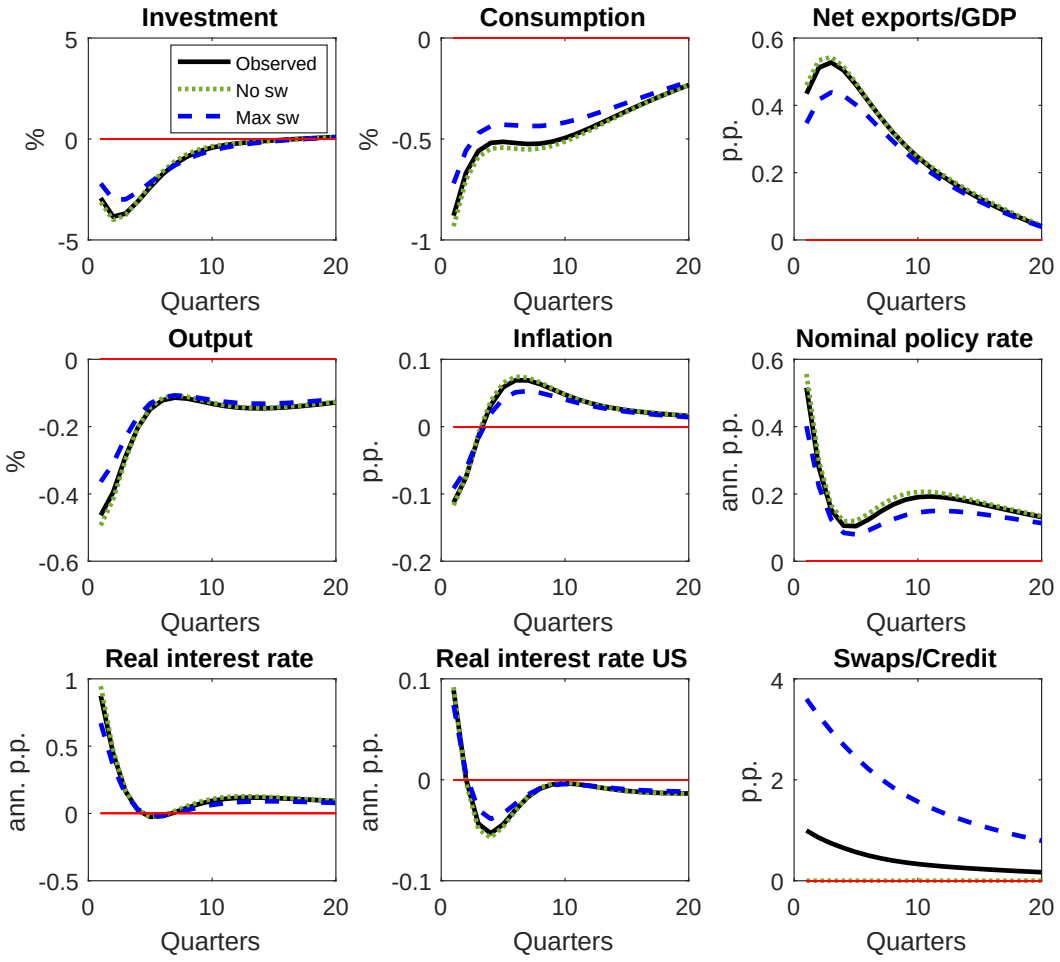
(and milder import contraction) lead to less of an increase in net exports, and a smaller improvement in current account balances. Once more, the effect of intervention is only quantitatively important in the case of maximum swap uptake, while an uptake matching that observed during the Covid-19 pandemic 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.

Model dynamics are qualitatively very similar under produce currency pricing. See Appendix C.3.2.

3.5 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.

Figure 3.6 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).

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A | Appendix to Chapter 1 - No-Arbitrage Pricing of GDP-Linked Bonds

A.1 Solution for GDP-Linked Bond Yields

In this appendix we derive the solution for yields on GDP-linked bonds in equations (1.14)-(1.16). We guess that the solution for prices takes the form

$$P_{t,g}^{(k)} = \exp\left(a_{k,g} + \mathbf{b}_{k,g}'\mathbf{x}_t\right).$$

Substituting this equation into equation (1.12) gives

$$\exp\left(a_{k,g} + \mathbf{b}_{k,g}'\mathbf{x}_t\right) = \mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(-r_t + g_{t+1}\right)\exp\left(a_{k-1,g} + \mathbf{b}_{k-1,g}'\mathbf{x}_{t+1}\right)\right]$$

Taking logs and combining with equations (1.7), (1.9), and (1.13) gives

$$\begin{aligned}
a_{k,g} + \mathbf{b}_{k,g}'\mathbf{x}_t &= \log\mathbb{E}_t^{\mathbb{Q}}\begin{bmatrix}\exp\left(-\rho_0 - \rho_1'\mathbf{x}_t + g_0 + \mathbf{g}_1'\left(\mu^{\mathbb{Q}} + \mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\right)\\ \exp\left(a_{k-1,g} + \mathbf{b}_{k-1,g}'\left(\mu^{\mathbb{Q}} + \mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\right)\end{bmatrix}\\
&= -\rho_0 - \rho_1'\mathbf{x}_t + g_0 + a_{k-1,g} + \log\mathbb{E}_t^{\mathbb{Q}}\begin{bmatrix}\exp\left(\mathbf{g}_1'\mu^{\mathbb{Q}} + \mathbf{g}_1'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{g}_1'\mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\\ \exp\left(\mathbf{b}_{k-1,g}'\mu^{\mathbb{Q}} + \mathbf{b}_{k-1,g}'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{b}_{k-1,g}'\mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\end{bmatrix}\\
&= -\rho_0 - \rho_1'\mathbf{x}_t + g_0 + a_{k-1,g} + \mathbf{g}_1'\mu^{\mathbb{Q}} + \mathbf{g}_1'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{b}_{k-1,g}'\mu^{\mathbb{Q}} + \mathbf{b}_{k-1,g}'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t\\
&\quad + \log\mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(\left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}\right)'\mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\right]\\
&= -\rho_0 - \rho_1'\mathbf{x}_t + g_0 + a_{k-1,g} + \left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}\right)'\mu^{\mathbb{Q}} + \left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}\right)'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t\\
&\quad + \frac{1}{2}\left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}\right)'\mathbf{\Sigma}\mathbf{\Sigma}'\left(\mathbf{g}_1 + \mathbf{b}_{k-1,g}\right).
\end{aligned}$$

Matching coefficients gives equations (1.15) and (1.16) in the main text. The boundary conditions $a_{0,g} = 0$ and $\mathbf{b}_{k,g} = \mathbf{0}$ follow from the fact that the time-t price of a zero-period bond paying one dollar at maturity must be one dollar.

A.2 Solution for Equity Yields

In this appendix we derive the solution for equity yields in equations (1.20)-(1.22). We guess that the solution for prices takes the form

$$\frac{P_{t,d}^{(k)}}{D_t} = \exp\left(a_{k,d} + \mathbf{b}_{k,d}'\mathbf{x}_t\right).$$

Substituting this equation into equation (1.18) gives

$$\exp\left(a_{k,d} + \mathbf{b}_{k,d}'\mathbf{x}_t\right) = \mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(-r_t + \Delta d_{t+1}\right)\exp\left(a_{k-1,d} + \mathbf{b}_{k-1,d}'\mathbf{x}_{t+1}\right)\right]$$

Taking logs and combining with equations (1.19), (1.9), and (1.13) gives

$$\begin{aligned}
a_{k,d} + \mathbf{b}_{k,d}'\mathbf{x}_t &= \log \mathbb{E}_t^{\mathbb{Q}}\left[\begin{array}{c} \exp\left(-\rho_0 - \rho_1'\mathbf{x}_t + \delta_0 + \delta_1'\left(\mu^{\mathbb{Q}} + \mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\right) \\ \exp\left(a_{k-1,d} + \mathbf{b}_{k-1,d}'\left(\mu^{\mathbb{Q}} + \mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\right)\end{array}\right] \\
&= -\rho_0 - \rho_1'\mathbf{x}_t + \delta_0 + a_{k-1,d} + \log \mathbb{E}_t^{\mathbb{Q}}\left[\begin{array}{c} \exp\left(\delta_1'\mu^{\mathbb{Q}} + \delta_1'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \delta_1'\mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right) \\ \exp\left(\mathbf{b}_{k-1,d}'\mu^{\mathbb{Q}} + \mathbf{b}_{k-1,d}'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{b}_{k-1,d}'\mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\end{array}\right] \\
&= -\rho_0 - \rho_1'\mathbf{x}_t + \delta_0 + a_{k-1,d} + \delta_1'\mu^{\mathbb{Q}} + \delta_1'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \mathbf{b}_{k-1,d}'\mu^{\mathbb{Q}} + \mathbf{b}_{k-1,d}'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t \\
&\quad + \log \mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(\left(\delta_1 + \mathbf{b}_{k-1,d}\right)'\mathbf{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}}\right)\right] \\
&= -\rho_0 - \rho_1'\mathbf{x}_t + \delta_0 + a_{k-1,g} + \left(\delta_1 + \mathbf{b}_{k-1,g}\right)'\mu^{\mathbb{Q}} + \left(\delta_1 + \mathbf{b}_{k-1,g}\right)'\mathbf{\Phi}^{\mathbb{Q}}\mathbf{x}_t \\
&\quad + \frac{1}{2}\left(\delta_1 + \mathbf{b}_{k-1,d}\right)'\mathbf{\Sigma}\mathbf{\Sigma}'\left(\delta_1 + \mathbf{b}_{k-1,d}\right).
\end{aligned}$$

Matching coefficients gives equations (1.21) and (1.22) in the main text. The boundary conditions $a_{0,d} = 0$ and $\mathbf{b}_{k,d} = \mathbf{0}$ follow from the fact that the time-t price of a zero-period equity paying D_t dollars at maturity must be D_t dollars.

A.3 Alternative Solution for Equity Yields

In this appendix, we show how to derive the equivalent solution of zero-coupon equities provided in Section 1.3.2.

Note from equations (1.21) and (1.22) that we can write the short-term equity yield in the form taken in equation (1.24), where

$$\rho_{0,d} = \rho_0 - \delta_0 - \delta_1'\mu^{\mathbb{Q}} - \frac{1}{2}\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1 \text{ and} \tag{A.1}$$

$$\rho_{1,d} = \rho_1 - \boldsymbol{\Phi}^{\mathbb{Q}\prime}\delta_1. \tag{A.2}$$

Next, we define $M_{d,t+1} = M_{t+1}\frac{D_{t+1}}{D_t}$. Taking logs and substituting in equations (1.19) and (1.8) gives

$$\log M_{t+1,d} = -r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} + \delta_0 + \delta_1'\mathbf{x}_{t+1}.$$

Substituting in equation (1.11) gives

$$\log M_{t+1,d} = -r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} + \delta_0 + \delta_1'\left(\mu + \boldsymbol{\Phi}\mathbf{x}_t + \boldsymbol{\Sigma}\varepsilon_{t+1}\right)$$

Using the mapping between the $\mathbb{P}$ and $\mathbb{Q}$ measures, that is, $\mu = \mu^{\mathbb{Q}} + \boldsymbol{\Sigma}\lambda_0$ and $\boldsymbol{\Phi} = \boldsymbol{\Phi}^{\mathbb{Q}} + \boldsymbol{\Sigma}\boldsymbol{\Lambda}_1$, gives

$$\begin{aligned}\log M_{t+1,d} &= -r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} + \delta_0 + \delta_1'\left(\mu^{\mathbb{Q}} + \boldsymbol{\Sigma}\lambda_0 + \left(\boldsymbol{\Phi}^{\mathbb{Q}} + \boldsymbol{\Sigma}\boldsymbol{\Lambda}_1\right)\mathbf{x}_t + \boldsymbol{\Sigma}\varepsilon_{t+1}\right) \\ &= -r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} + \delta_0 + \delta_1'\mu^{\mathbb{Q}} + \delta_1'\boldsymbol{\Sigma}\lambda_0 + \delta_1'\boldsymbol{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \delta_1'\boldsymbol{\Sigma}\boldsymbol{\Lambda}_1\mathbf{x}_t + \delta_1'\boldsymbol{\Sigma}\varepsilon_{t+1}\end{aligned}$$

Substituting in the definition of the short rates in equations (1.9) and (1.24) gives

$$\begin{aligned}
\log M_{t+1,d} &= -\rho_0 - \rho_1'\mathbf{x}_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} + \rho_0 - \rho_{0,d} - \delta_1'\mu^{\mathbb{Q}} - \frac{1}{2}\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1 + \delta_1'\mu^{\mathbb{Q}} + \delta_1'\boldsymbol{\Sigma}\lambda_0 \\
&\quad +\delta_1'\boldsymbol{\Phi}^{\mathbb{Q}}\mathbf{x}_t + \delta_1'\boldsymbol{\Sigma}\boldsymbol{\Lambda}_1\mathbf{x}_t + \delta_1'\boldsymbol{\Sigma}\varepsilon_{t+1} \\
&= -\rho_{0,d} - \left(\rho_{1,d}' + \delta_1'\boldsymbol{\Phi}^{\mathbb{Q}}\right)\mathbf{x}_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} - \frac{1}{2}\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1 + \delta_1'\boldsymbol{\Sigma}\lambda_0 + \delta_1'\boldsymbol{\Phi}^{\mathbb{Q}}\mathbf{x}_t \\
&\quad +\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Lambda}_1\mathbf{x}_t + \delta_1'\boldsymbol{\Sigma}\varepsilon_{t+1} \\
&= -\rho_{0,d} - \rho_{1,d}'\mathbf{x}_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} - \frac{1}{2}\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1 + \delta_1'\boldsymbol{\Sigma}\lambda_0 + \delta_1'\boldsymbol{\Sigma}\boldsymbol{\Lambda}_1\mathbf{x}_t + \delta_1'\boldsymbol{\Sigma}\varepsilon_{t+1} \\
&= -r_{t,d} - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} - \frac{1}{2}\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1 + \delta_1'\boldsymbol{\Sigma}\lambda_0 + \delta_1'\boldsymbol{\Sigma}\boldsymbol{\Lambda}_1\mathbf{x}_t + \delta_1'\boldsymbol{\Sigma}\varepsilon_{t+1}
\end{aligned}$$

And substituting in the definition of the price of risk $\lambda_t = \lambda_0 + \boldsymbol{\Lambda}_1\mathbf{x}_t$ gives

$$\log M_{t+1,d} = - - r_{t,d} - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} - \frac{1}{2}\delta_1'\boldsymbol{\Sigma}\boldsymbol{\Sigma}'\delta_1 + \delta_1'\boldsymbol{\Sigma}\lambda_t + \delta_1'\boldsymbol{\Sigma}\varepsilon_{t+1}$$

If we further define $\lambda_{t,d} = \lambda_t - \boldsymbol{\Sigma}'\delta_1$ (that is $\lambda_{t,d} = \lambda_{0,d} + \boldsymbol{\Lambda}_{1,d}\mathbf{x}_t$ where $\lambda_{0,d} = \lambda_0 - \boldsymbol{\Sigma}'\delta_1$

and $\mathbf{\Lambda}_{1,d} = \mathbf{\Lambda}_1$) and substitute this into the previous equation we obtain

$$\begin{aligned}
\log M_{t+1,d} &= -r_{t,d} - \frac{1}{2}\left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right)'\left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right) - \left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right)'\varepsilon_{t+1} - \frac{1}{2}\delta_1'\mathbf{\Sigma}\mathbf{\Sigma}'\delta_1 \\
&\quad + \delta_1'\mathbf{\Sigma}\left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right) + \delta_1'\mathbf{\Sigma}\varepsilon_{t+1} \\
&= -r_{t,d} - \frac{1}{2}\left(\lambda_{t,d}' + \delta_1'\mathbf{\Sigma}\right)\left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right) - \left(\lambda_{t,d}' + \delta_1'\mathbf{\Sigma}\right)\varepsilon_{t+1} - \frac{1}{2}\delta_1'\mathbf{\Sigma}\mathbf{\Sigma}'\delta_1 \\
&\quad + \delta_1'\mathbf{\Sigma}\left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right) + \delta_1'\mathbf{\Sigma}\varepsilon_{t+1} \\
&= -r_{t,d} - \frac{1}{2}\left(\lambda_{t,d}'\left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right) + \delta_1'\mathbf{\Sigma}\left(\lambda_{t,d} + \mathbf{\Sigma}'\delta_1\right)\right) - \lambda_{t,d}'\varepsilon_{t+1} - \delta_1'\mathbf{\Sigma}\varepsilon_{t+1} \\
&\quad - \frac{1}{2}\delta_1'\mathbf{\Sigma}\mathbf{\Sigma}'\delta_1 + \delta_1'\mathbf{\Sigma}\lambda_{t,d} + \delta_1'\mathbf{\Sigma}\mathbf{\Sigma}'\delta_1 + \delta_1'\mathbf{\Sigma}\varepsilon_{t+1} \\
&= -r_{t,d} - \frac{1}{2}\left(\lambda_{t,d}'\lambda_{t,d} + \lambda_{t,d}'\mathbf{\Sigma}'\delta_1 + \delta_1'\mathbf{\Sigma}\lambda_{t,d} + \delta_1'\mathbf{\Sigma}\mathbf{\Sigma}'\delta_1\right) - \lambda_{t,d}'\varepsilon_{t+1} - \delta_1'\mathbf{\Sigma}\varepsilon_{t+1} \\
&\quad - \frac{1}{2}\delta_1'\mathbf{\Sigma}\mathbf{\Sigma}'\delta_1 + \delta_1'\mathbf{\Sigma}\lambda_{t,d} + \delta_1'\mathbf{\Sigma}\mathbf{\Sigma}'\delta_1 + \delta_1'\mathbf{\Sigma}\varepsilon_{t+1} \\
&= -r_{t,d} - \frac{1}{2}\lambda_{t,d}'\lambda_{t,d} - \lambda_{d,t}'\varepsilon_{t+1}.
\end{aligned}$$

Thus, $M_{d,t+1}$ takes an analogous form to M_{t+1}. We can therefore equivalently price zero-coupon equities according to

$$\frac{P_{t,d}^{(n)}}{D_t} = \mathbb{E}_t^{\mathbb{Q}_d}\left[\exp\left(-r_{t,d}\right)\frac{P_{t+1,d}^{(n-1)}}{D_{t+1}}\right], \tag{A.3}$$

where the factors follow the law of motion in equation (1.25) under the probability measure $\mathbb{Q}_d$, with

$$\begin{aligned}
\mu^{\mathbb{Q}_d} &= \mu - \mathbf{\Sigma}\lambda_{0,d} \\
&= \mu^{\mathbb{Q}} + \mathbf{\Sigma}\left(\lambda_0 - \lambda_{0,d}\right) \\
&= \mu^{\mathbb{Q}} + \mathbf{\Sigma}\mathbf{\Sigma}'\delta_1
\end{aligned}$$

and

$$\begin{aligned}\boldsymbol{\Phi}^{\mathbb{Q}_d} &= \boldsymbol{\Phi} - \boldsymbol{\Sigma}\boldsymbol{\Lambda}_{1,d} \\ &= \boldsymbol{\Phi}^{\mathbb{Q}} + \boldsymbol{\Sigma}\left(\boldsymbol{\Lambda}_1 - \boldsymbol{\Lambda}_{1,d}\right) \\ &= \boldsymbol{\Phi}^{\mathbb{Q}}.\end{aligned}$$

Finally, we guess the solution for equity yields takes the form

$$\frac{P_{t,d}^{(k)}}{D_t} = \exp\left(a_{k,d}^* + \mathbf{b}_{k,d}^{*\prime}\mathbf{x}_t\right).$$

Substituting this into equation (A.3) gives

$$\exp\left(a_{k,d}^* + \mathbf{b}_{k,d}^{*\prime}\mathbf{x}_t\right) = \mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(-r_{t,d}\right)\exp\left(a_{k-1,d}^* + \mathbf{b}_{k-1,d}^{*\prime}\mathbf{x}_{t+1}\right)\right]$$

Taking logs and combining with equations (1.24) and (1.25) gives

$$\begin{aligned}a_{k,d} + \mathbf{b}_{k,d}^{\prime}\mathbf{x}_t &= \log\mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(-\rho_{0,d} - \rho_{1,d}^{\prime}\mathbf{x}_t\right)\exp\left(a_{k-1,d}^* + \mathbf{b}_{k-1,d}^{*\prime}\left(\mu^{\mathbb{Q}_d} + \boldsymbol{\Phi}^{\mathbb{Q}_d}\mathbf{x}_t + \boldsymbol{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}_d}\right)\right)\right] \\ &= -\rho_0 - \rho_1^{\prime}\mathbf{x}_t + a_{k-1,d}^* + \log\mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(\mathbf{b}_{k-1,d}^{*\prime}\mu^{\mathbb{Q}_d} + \mathbf{b}_{k-1,d}^{*\prime}\boldsymbol{\Phi}^{\mathbb{Q}_d}\mathbf{x}_t + \mathbf{b}_{k-1,d}^{*\prime}\boldsymbol{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}_d}\right)\right] \\ &= -\rho_0 - \rho_1^{\prime}\mathbf{x}_t + a_{k-1,d}^* + \mathbf{b}_{k-1,d}^{*\prime}\mu^{\mathbb{Q}_d} + \mathbf{b}_{k-1,d}^{*\prime}\boldsymbol{\Phi}^{\mathbb{Q}_d}\mathbf{x}_t + \log\mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(\mathbf{b}_{k-1,d}^{*\prime}\boldsymbol{\Sigma}\varepsilon_{t+1}^{\mathbb{Q}_d}\right)\right] \\ &= -\rho_0 - \rho_1^{\prime}\mathbf{x}_t + a_{k-1,g}^* + \mathbf{b}_{k-1,g}^{*\prime}\mu^{\mathbb{Q}_d} + \mathbf{b}_{k-1,g}^{*\prime}\boldsymbol{\Phi}^{\mathbb{Q}_d}\mathbf{x}_t + \frac{1}{2}\mathbf{b}_{k-1,d}^{*\prime}\boldsymbol{\Sigma}\boldsymbol{\Sigma}^{\prime}\mathbf{b}_{k-1,d}^{*}.\end{aligned}$$

Matching coefficients gives equations (1.27) and (1.28) in the main text.

B | Appendix to Chapter 2 - Global Banks and Synthetic Funding: The Benefits of Foreign Relatives

B.1 Data

B.1.1 Variable Definitions

Table B.1 describes the variables used in the analysis. These variables are divided into the following categories: dependent variables, main variables of interest, bank-level controls, and additional variables.

Table B.1 VARIABLES DEFINITIONS

Variable	Definition	Source
Dep. vars:		
$\Delta L_{i,j,k,t}$	Exchange-rate adjusted growth rate in cross-border claims of bank i to country j in currency k at time t in percent.	BoE
$\Delta L_{j,k,t}$	Aggregated exchange-rate adjusted growth rate in cross-border claims of all UK banks to country j in currency k at time t in percent. Alternatively, the variable is computed from total cross-border claims originated in the BIS reporting countries from the BIS Locational Banking Statistics.	BoE,BIS
Main vars:		
$\Delta CIP_{k,t-l}$	Quarter-to-quarter change in the cross-currency basis between sterling and currency k.	BBG
$RSF_{i,k,t-l}$	Ratio of synthetic funding in currency k by bank i relative to total liabilities in currency k. Synthetic funding in k is proxied by the difference between total assets and liabilities denominated in currency k.	BoE
Joint ΔCIPxRSF_{t-5}	Joint coefficient of 4-lags of interactions between RSF and CIP for lags t=-1 to t=-4.	BoE& BBG
Dif_{t-5}	Dummy equal to 1 if the respective claims are denominated in EUR. Alternatively, the variable equals to 1 if ΔCIP is negative.	BBG
Control vars:		
$Log\,assets_{t-1}$	Log of total assets at the UK-bank level (excludes assets of foreign affiliates).	BoE
$Dep.\,ratio_{t-1}$	Ratio of total retail (sight + savings) deposits to total assets at the bank level.	BoE
$Liq.\,ratio_{t-1}$	Ratio of liquid assets (cash + BoE deposits) to total assets at the bank level.	BoE

Table B.1 VARIABLES DEFINITIONS (CONTINUED)

Variable	Definition	Source
$Cap.ratio_{t-1}$	Ratio of total equity to total assets	BoE
$\Delta L_{i,k,t}^{\neq k}$	Average growth rate of bank i's claims in non-k currencies to all countries but j.	BoE
Additional vars:		
Branch	Dummy variable equal to one if a bank in the sample is a branch of a foreign banking conglomerate operating in the UK.	C&VH
CA branch	Dummy variable equal to one if a foreign bank branch in the sample is owned by a bank headquartered either in the US or the Euro Area. These jurisdictions represent the home currency areas (CA) of the currencies in which cross-border claims are denominated (i.e. USD and EUR).	C&VH
Non-CA branch	Dummy variable equal to one if a foreign bank branch in the sample is owned by a bank headquartered outside the US or the Euro Area. These jurisdictions represent the home currency areas (CA) of the currencies in which cross-border claims are denominated (i.e. USD and EUR).	C&VH
Total FX	Ratio of total on-balance-sheet liabilities in a given FX currency to total bank assets. FX currencies are represented by either USD or EUR. In the analysis the variable enters the empirical model as a dummy equal to one for banks with a ratio above the 75th percentile, and 0 otherwise.	BoE
ICM ratio	Ratio of foreign internal liabilities in a given FX currency to total bank assets. FX currencies are represented by either USD or EUR. Internal liabilities represent liabilities vis-à-vis correspondent entities within the same banking conglomerate located outside the UK. In the analysis the variable enters the empirical model as a dummy equal to one for banks with a ratio above the 75th percentile, and 0 otherwise. This variable is only available for the period 2008-2016.	BoE
Non-ICM ratio	Ratio of Non-ICM liabilities in a given FX currency to total bank assets. FX currencies are represented by either USD or EUR. Non-ICM liabilities correspond to total on-balance-sheet liabilities minus ICM liabilities as described in the variable ICM rat.. In the analysis the variable enters the empirical model as a dummy equal to one for banks with a ratio above the 75th percentile, and 0 otherwise. This variable is only available for the period 2008-2016.	BoE

Table B.1 VARIABLES DEFINITIONS (CONTINUED)

Variable	Definition	Source
Additional vars:		
Rest of World	Dummy variable equal to one for countries different than the UK, and 0 otherwise.	Own
Home CA	Dummy variable equal to one for the US and the Euro Area countries, and 0 otherwise. These countries represent the home currency area (CA) of the currencies in which cross-border claims are denominated (i.e. USD and EUR).	Own
Share of UK branches	Average pre-2008 (2003-2007) share of UK branches in total claims from banks operating in the UK to a given country-currency market i, j. In the analysis the variable is used as a dummy equal to one for markets with a share above the 75th percentile of the distribution, and 0 otherwise.	BoE
Share of large ICM rat.	Share of large-ICM ratio banks in total claims from banks operating in the UK to a given country-currency market i, j. Large-ICM ratio banks are banks with a ratio of internal liabilities from abroad (ICM) to assets above the 75th percentile of the variable's distribution. The share is computed as of 2008Q1, the first available observation. In the analysis the variable is used as a dummy equal to one for markets with a share above the 75th percentile of the distribution, and 0 otherwise.	BoE
Share of UK claims	Average 2003-2007 share of UK-originated cross-border claims in total claims to a given country-currency market i, j originated in the BIS reporting countries. In the analysis the variable is used as a dummy equal to one for markets with a share above the sample median, and 0 otherwise.	BIS

NOTES: This table reports the definitions and sources of the variables used in the analysis. The sources include the Bank of England (BoE), Bloomberg (BBG), the Claessens and Van Horen (2014) Bank Ownership Database (C&VH), the Locational Banking Statistics reported by the Bank of International Settlements (BIS), and the authors' own construction (own).

B.1.2 Dataset Cleaning

To explore the effect of liquidity shocks in FX swap markets on cross-border credit supply we rely on regulatory data provided by the Bank of England covering the cross-border operations of all banks active in the UK. Both domestics as well as foreign-owned banks are included in the sample. We merge bank-level data from two main different sources. The first one reports balance-sheet information for banks located on the UK irrespective of whether they perform cross-border lending operations or not. These data reports the balance sheet of those banks as a UK jurisdictional entity. Therefore, it does not include the assets and liabilities of affiliated banks abroad. For each item in the balance sheet we can observe banks' positions in US dollar, euro and sterling. The second source provides us with information on banks' cross-border assets and liabilities for the aforementioned currencies. These data reports banks' cross-border positions per country and currency on a quarterly basis, following a panel with a bank-country-currency-time structure. For the purpose of our study we merge these two sources of data to generate a panel that reports banks' cross-border assets and liabilities in each country-currency pair (i.e. the relevant market in our setting) together with the domestic balance-sheet characteristics of banks in the UK.

We implement several filters to ensure that the structure of the dataset fulfills the identification requirements of our research question. This screening procedure is as follows. First, we restrict the original sample of 376 banks reporting some cross-border to those banks active throughout the sample period. This filter leaves us with 115 banks which represent the largest and historically more established banks provided cross-border banking services from the UK. We implement this first filter avoid the confounding effect of banks entering and exit the sample and to ensure that we compare the same banks over time. Moreover, focusing on the large players in the cross-border lending market reduces

the within-bank volatility in the sample, which is important considering our focus on the intensive margin of the cross-border transmission of FX swap liquidity shocks. For instance, banks only seldomly active in cross-border lending can lead to abnormal growth rates in our left-hand side variable, polluting the sample with outliers.

As a second step we focus on our sample of relevant markets and keep for each bank only country-currency pairs that are reported throughout the sample period. This filter rules-out the effect of entries and exits from these markets and allows us to center the analysis on cross-border flows' disruptions affecting otherwise rather stable funding channels between banks in the UK and borrowers abroad. This filter leaves us with a sample of 3,589 bank-country-currency pairs (i.e. our unit of observation) out of the original 13,722 pairs. Despite of this drop in the number of observations, the sample still covers 71.2% of global cross-border claims in US dollar and euro from UK-based banks on average during the sample period. This latter filter also drops 9 banks that do not report a constant cross-border relationship with any of the country-currency bins in which they report some degree of activity. Therefore, the final sample comprises 106 banks active in 69 countries between 2003Q1 and 2016Q4.

This filtering process is important in order to fulfill the identification requirements imposed by the fixed effects structure of Equation (2.4). The country-currency-time fixed effects imply that we need to observe at least two banks holding cross-border claims in US dollar and euro in a given country over time. Since this feature of Equation (2.4) represents the core of our identification strategy – as it absorbs borrower demand confounders that can bias our estimates – we require the data to ensure that sufficient variation within each country-currency bin exists. Moreover, this setting is consistent with our focus on the intensive rather than on the extensive margin of the FX swap lending channel.

B.2 Additional Results

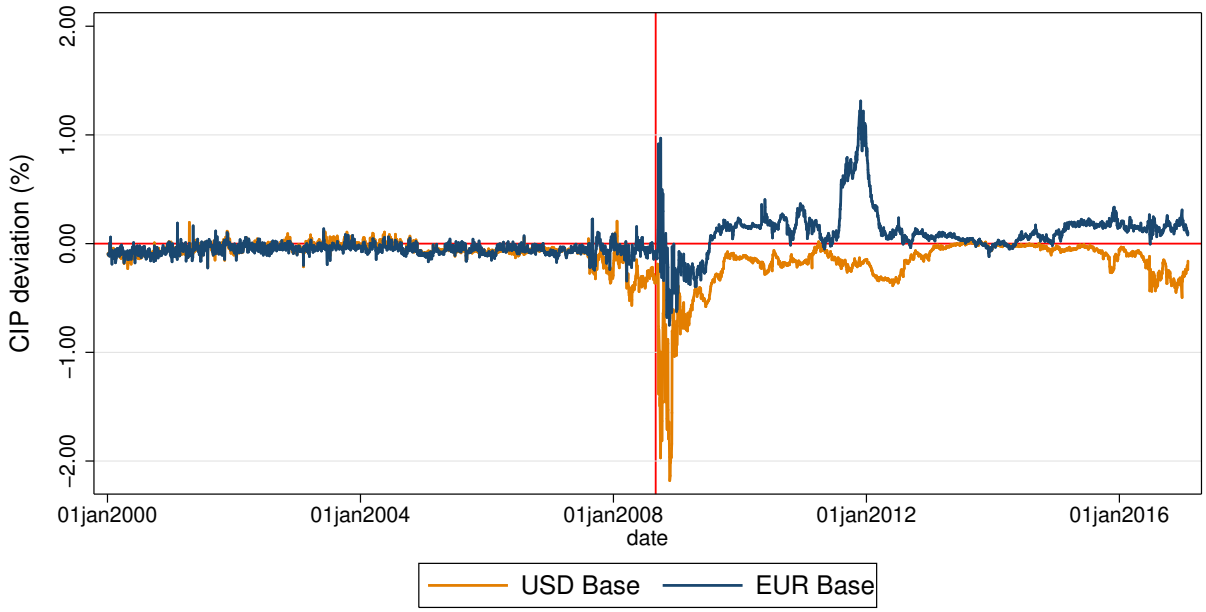


Figure B.1 Sterling-based CIP deviations by currency

Notes: Authors' elaboration based on data from Bloomberg. The figure depicts the cross-currency basis between GBP, on the one hand, and USD and EUR, on the other. A negative CIP deviation denotes a situation in which foreign currency funding is more expensive in FX swaps markets compared to cash markets.

Table B.1 ROBUSTNESS TESTS – EMPIRICAL SETTING

Specification:	Base	Exclude 08-09	Exclude 11-12	Placebo: ΔCIP	Placebo: ΔUSD	Top 5 trader: Yes	Top 5 trader: No
	I	II	III	IV	V	VI	VII
ΔCIP x RSF_{t-5}	0.605***	0.588**	0.744***	0.395	-1.805	1.248	0.475**
	(0.176)	(0.261)	(0.224)	(0.339)	(1.223)	(0.884	(0.232)
RSF_{t-5}	0.020	-0.003	0.012	0.021	0.027	0.159*	-0.012
	(0.031)	(0.030)	(0.035)	(0.032)	(0.029)	(0.069)	(0.032)
Controls:							
$Log\ assets_{t-1}$	-0.013	-0.004	-0.014	-0.013	-0.014	-0.080**	-0.009
	(0.010)	(0.013)	(0.011)	(0.010)	(0.010)	(0.026)	(0.011)
$Dep.\ ratio_{t-1}$	0.008	0.017	-0.002	0.007	0.006	0.009	0.010
	(0.017)	(0.019)	(0.022)	(0.017)	(0.017)	(0.073)	(0.020)
$Liq.\ ratio_{t-1}$	-0.037	-0.032	-0.024	-0.036	-0.037	-0.218	-0.024
	(0.046)	(0.054)	(0.057)	(0.045)	(0.046)	(0.129)	(0.045)
$Cap.\ ratio_{t-1}$	-0.093	-0.012	-0.062	-0.093	-0.096	0.276	-0.049
	(0.087)	(0.087)	(0.103)	(0.087)	(0.087)	(0.420)	(0.084)
$\Delta L^{\neq k}_{i,k,t}$	0.084***	0.082***	0.077***	0.085***	0.084***	0.302**	0.063***
	(0.022)	(0.025)	(0.026)	(0.023)	(0.023)	(0.085)	(0.022)
Constant	0.256	0.087	0.276	0.257	0.268	1.590**	0.165
	(0.183)	(0.233)	(0.188)	(0.184)	(0.184)	(0.472)	(0.184)
Obs	62,739	48,348	47,057	62,739	62,739	11,015	50,032
R^2	0.108	0.110	0.112	0.108	0.108	0.343	0.110

NOTE: This table reports the results from estimating Equation (2.4) under alternative specifications. All constitutive terms of the interactions are included in the regressions. Coefficients for $\Delta CIP_{k,t}$ and for its interactions with RSF_{t-5} are not reported. Column I replicates the benchmark results from column V in Table 2.2. Column II excludes the years 2008 and 2009 (i.e. global financial crisis) from the analysis, whereas column III excludes the years 2011 and 2012 (i.e. European sovereign debt crisis). In column IV we replace ΔCIP by a 'placebo' FX swap funding shock by assigning US dollar CIP deviations to euro lending and euro deviations to US dollar lending. In column IV we replace ΔCIP by a 'placebo' FX swap funding shock defined by quarterly changes in the BIS USD price index. In columns VI and VII we report regressions of sample splits according to whether banks belong to the group of top-5 banks in FX swaps' trading volume in the sample. Banks on column VI are within that group, whereas banks on column VII are outside the group. Robust standard errors clustered at the bank and quarter level are reported between parentheses. All regressions include a set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in Appendix B.1.1. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.2 ROBUSTNESS TESTS – ALTERNATIVE FE SPECIFICATIONS

	I	II	III	IV	V	VI
Joint ΔCIP x RSF_{t-5}	0.605***	0.347**	0.365**	0.408*	0.499**	0.499**
	(0.176)	(0.178)	(0.178)	(0.239)	(0.227)	(0.230)
RSF_{t-5}	0.020	0.011	0.022	0.033	0.045	0.045
	(0.031)	(0.016)	(0.028)	(0.032)	(0.033)	(0.034)
Controls:						
$Log\,assets_{t-1}$	-0.013					
	(0.010)					
$Dep.\,ratio_{t-1}$	0.008	0.010	0.019**	0.022**	0.026**	0.026**
	(0.017)	(0.007)	(0.010)	(0.010)	(0.010)	(0.010)
$Liq.\,ratio_{t-1}$	-0.037					
	(0.046)					
$Cap.\,ratio_{t-1}$	-0.093					
	(0.087)					
$\Delta L^{\neq k}_{i,k,t}$	0.084***	-1.886***	-1.888***	-1.894***	-1.901***	-1.901***
	(0.022)	(0.076)	(0.076)	(0.076)	(0.073)	(0.074)
Constant	0.256	0.025***	0.017**	0.014*	0.010	0.010
	(0.183)	(0.005)	(0.007)	(0.007)	(0.007)	(0.008)
Fixed effects:	i,j,k	i,t	i,j,k	i,j,k	i,j,k	i,j,k
	j,k,t		i,t	i,t	i,t	i,t
				j,t	j,k,t	j,k,t
						HC,t
Obs.	62,739	62,355	62,355	62,355	62,355	62,355
R^2	0.108	0.154	0.158	0.213	0.255	0.255

NOTE: This table reports the results from estimating Equation (2.4) using alternative fixed effects (FE) specifications. All constitutive terms of the interactions are included in the regressions. Coefficients for $\Delta CIP_{k,t}$ and for its interactions with RSF_{t-5} are not reported. Column I replicates the benchmark results from Column V in Table 2.2 without changes to the empirical setting. This regression includes bank-country-currency (i,j,k) and country-currency-time (j,k,t) FE. The regression reported in column II includes only bank-time (i,t) FE. Columns III and IV add to column II bank-country-currency (i,j,k) and country-time (j,t) FE. Column V further adds country-currency-time (j,k,t) FE. In column VI we further add to the regression on column V home country-time FE (HC,t). We define home country as the country in which a given bank operating from the UK is headquartered. Robust standard errors clustered at the bank and quarter level are reported between parentheses. In columns II and VI only the coefficients for the control variables $Dep.\,ratio_{t-1}$ and $\Delta L^{\neq k}_{i,k,t}$ are reported, which vary over the bank-currency-time dimension. Other control variables are absorbed by bank-time FE. All regressions include a set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in Appendix B.1.1. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.3 ROBUSTNESS TESTS – HORSE-RACE AGAINST RSF

	Triple interaction term (Int_{t-5}):				
	None	Asset	Dep.	Liq.	Cap.
	I	II	III	IV	V
ΔCIP x RSF_{t-5}	0.605***	0.577**	0.706***	0.588***	0.608***
	(0.176)	(0.254)	(0.273)	(0.210)	(0.183)
ΔCIP x Int_{t-5}		0.00377	-0.153	-0.0579	-0.103
		(0.0193)	(0.137)	(0.115)	(0.472)
RSF_{t-5}	0.020	0.018	0.011	0.002	0.017
	(0.031)	(0.032)	(0.032)	(0.033)	(0.029)
Int_{t-5}		-0.015	0.018	0.015	-0.043
		(0.010)	(0.021)	(0.039)	(0.098)
Controls:					
$Log\,assets_{t-1}$	-0.013		-0.012	-0.014	-0.012
	(0.010)		(0.011)	(0.010)	(0.010)
$Dep.\,ratio_{t-1}$	0.008	0.008		0.006	0.008
	(0.017)	(0.018)		(0.017)	(0.017)
$Liq.\,ratio_{t-1}$	-0.037	-0.039	-0.038		-0.037
	(0.046)	(0.045)	(0.045)		(0.046)
$Cap.\,ratio_{t-1}$	-0.093	-0.084	-0.095	-0.096	
	(0.087)	(0.080)	(0.088)	(0.092)	
$\Delta L^{\neq k}_{i,k,t}$	0.084***	0.083***	0.084***	0.085***	0.085***
	(0.022)	(0.022)	(0.022)	(0.023)	(0.022)
Constant	0.256	0.281	0.235	0.257	0.230
	(0.183)	(0.178)	(0.196)	(0.186)	(0.183)
Obs.	62,739	62,739	62,738	62,739	62,739
R^2	0.108	0.108	0.108	0.108	0.108

NOTE: This table reports the results from estimating Equation (2.4) by including a second interaction term between ΔCIP and other bank-level characteristics (Int_{t-5}). These variables enter the model with a five-lag period. All constitutive terms of the interactions are included in the regressions. Coefficients for $\Delta CIP_{k,t}$ and for its interactions with RSF_{t-5} and Int_{t-5} are not reported. Column I replicates the baseline results from Column V in Table 2.2. Int_{t-5} represents the following variables: log assets (Asset, col. II), deposit ratio (Dep., col. III), liquidity ratio (Liq., col. IV), and capital ratio (Cap., col. V). In columns II to V the single component Int_{t-5} replaces the respective control variable. Robust standard errors clustered at the bank and quarter level are reported between parentheses. All regressions include a set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in Appendix B.1.1. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

B.3 Auxiliary Figures and Tables

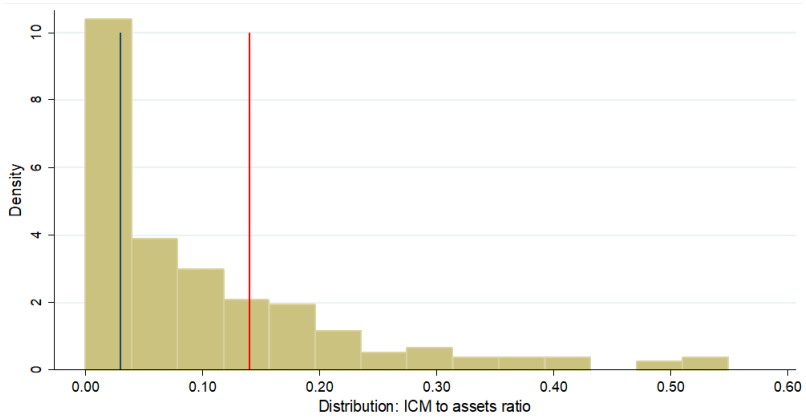


Figure B.2 Distribution of internal capital markets' funding

Notes: This figure reports an histogram with the distribution of the ICM ratio. ICM funding represent foreign internal liabilities raised outside the UK in related entities (see definition in Table B.1) The figure corresponds to the distribution of the average ICM ratio over the sample period, restricted for purposes of analysis from 2008Q1 to 2016Q1. The blue vertical line represent the median of the distribution, while the red vertical line represents the cutoff at the 75th percentile used in the article to assign banks to a group of high ICM ratio banks.

Table B.4 PRELIMINARY TEST — REGRESSING RSF ON BANK VARIABLES

	Dependent variable: RSF					
	I	II	III	IV	V	VI
$Log\,assets_{t-1}$	0.029**					0.031**
	(0.013)					(0.012)
$Dep.\,ratio_{t-1}$		-0.018				0.029
		(0.065)				(0.086)
$Liq.\,ratio_{t-1}$			0.072			0.134
			(0.088)			(0.096)
$Cap.\,ratio_{t-1}$				0.394		0.541
				(0.394)		(0.387)
$Branch$					-0.037	0.051
					(0.058)	(0.043)
Constant	-0.422**	0.096***	0.063***	0.061***	0.113**	-0.584**
	(0.212)	(0.018)	(0.023)	(0.017)	(0.055)	(0.256)
Obs	62739	62739	62739	62739	62739	62739
R^2	0.096	0.000	0.009	0.044	0.053	0.171

NOTE: This table reports the results from estimating RSF as a function of bank characteristics used in the analysis as control variables. Robust standard errors are clustered at the bank and quarter level and are reported between parentheses. In column VI we include all bank characteristics as independent variables. The variables include the log of total assets ($Log\,assets_{t-1}$), the deposit ratio ($Dep.\,ratio_{t-1}$), the liquidity ratio ($Liq.\,ratio_{t-1}$), the capital ratio ($Cap.\,ratio_{t-1}$), and a dummy equal to 1 if a bank is a foreign branch ($Branch$). Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in the article. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.5 FX FUNDING RATIOS BY BANK TYPE

	I	II	III	IV	V
	$Number$	RSF	$Total\,FX$	$Non-ICM$	ICM
Total banks	106	0.06	0.38	0.27	0.11
Foreign	93	0.06	0.40	0.29	0.11
Local	11	0.12	0.19	0.15	0.03
Branch	76	0.06	0.42	0.29	0.13
Uk-reg.	30	0.08	0.29	0.24	0.04
High ICM	27	0.05	0.45	0.21	0.24
Low ICM	79	0.07	0.36	0.29	0.06

NOTE: This table displays the average ratio of different measures of banks' FX funding by bank type. On the horizontal axis, the table reports the numbers of banks by bank-type (Number); the average RSF, the average ratio of total FX funding to total assets ($Total\,FX$), the average ratio of total FX funding from abroad excluding ICM to assets ($Non-ICM$), and the average ratio of ICM funding to total assets (i.e. ICM ratio). On the vertical axis the matrix distinguishes between foreign banks, UK-owned banks, foreign branches, UK-regulated banks, high ICM, and low ICM banks. High vs. low ICM banks are defined according to a split at the 75th percentile of the ICM ratio's distribution. Variables' definitions are reported in Table B.1 in the article.

Table B.6 ROBUSTNESS TESTS — RSF DEFINITION

Empirical change:	None	Alt. RSF_{t-5}	
	I	II	III
Joint ΔCIP x RSF_{t-5}	0.605***	0.234***	0.228***
	(0.176)	(0.0698)	(0.0538)
RSF_{t-5}	0.020	0.006	0.009
	(0.031)	(0.007)	(0.011)
Controls:			
$Total\ assets_{t-1}$	-0.013	-0.013	-0.013
	(0.010)	(0.010)	(0.010)
$Deposit\ ratio_{t-1}$	0.008	0.003	0.006
	(0.017)	(0.014)	(0.017)
$Liquidity\ ratio_{t-1}$	-0.037	-0.036	-0.040
	(0.046)	(0.043)	(0.045)
$Capital\ ratio_{t-1}$	-0.093	-0.104	-0.097
	(0.087)	(0.087)	(0.086)
$\Delta L^{\neq k}_{i,k,t}$	0.084***	0.076***	0.084***
	(0.022)	(0.023)	(0.022)
Constant	0.256	0.264	0.259
	(0.183)	(0.180)	(0.183)
Fixed effects	i,j,k	i,j	i,j,k
	j,k,t	t	j,k,t
Obs.	62,739	62,739	62,739
R^2	0.108	0.060	0.108

NOTE: This table reports the results from estimating Equation (2.4) under alternative specifications. All constitutive terms of the interactions are included in the regressions. Coefficients for $\Delta CIP_{k,t}$ and for its interactions with RSF_{t-5} are not reported. Column I replicates the baseline results from Column V in Table 2.2 without changes to the empirical setting. In Columns II and III we compute RSF_{t-5} as a continuous variable including its negative values. Column II reports a regression with bank-country and time fixed effects, whereas the regression on Column III uses the full specification with bank-country-currency and country-currency-quarter FE. Robust standard errors clustered at the bank and quarter level are reported between parentheses. All regressions include a set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in the article. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.7 ROBUSTNESS TESTS — GBP-DENOMINATED CLAIMS

Empirical change:	None	GBP flows	Base FE	Bank-time FE	Bank-country -time FE
	I	II	III	IV	V
Joint ΔCIP x RSF_{t-5}	0.601***	0.675***	0.599***	0.199**	0.305**
	(0.175)	(0.204)	(0.169)	(0.0909)	(0.119)
RSF_{t-5}	0.021	-0.008	0.021	0.010	0.009
	(0.031)	(0.016)	(0.025)	(0.021)	(0.029)
Controls:					
$Total\ assets_{t-1}$	-0.013	-0.019**	-0.016*		
	(0.010)	(0.009)	(0.009)		
$Deposit\ ratio_{t-1}$	0.006	-0.009	0.003	0.016	0.029**
	(0.018)	(0.013)	(0.016)	(0.012)	(0.012)
$Liquidity\ ratio_{t-1}$	-0.037	-0.043	-0.051*		
	(0.046)	(0.033)	(0.030)		
$Capital\ ratio_{t-1}$	-0.094	-0.135*	-0.118		
	(0.087)	(0.078)	(0.073)		
$\Delta L^{\neq k}_{i,k,t}$	0.085***	0.076***	0.095***	-1.957***	-1.873***
	(0.023)	(0.022)	(0.023)	(0.074)	(0.082)
Constant	0.260	0.380**	0.330*	0.024**	0.024**
	(0.184)	(0.161)	(0.166)	(0.010)	(0.009)
Fixed effects	i,j,k	i	i,j,k	i,j,k	i,j,k
	j,k,t	j,t	j,k,t	j,k,t	j,k,t
				i,t	i,j,t
Obs.	62,739	100,060	97,607	101,075	60,521
R^2	0.108	0.054	0.117	0.141	0.497

NOTE: This table reports the results from estimating Equation (2.4) by adding to the working sample cross-border claims denominated in GBP. All constitutive terms of the interactions are included in the regressions. Coefficients for $\Delta CIP_{k,t}$ and for its interactions with RSF_{t-5} are not reported. Column I replicates the baseline results from column V in Table 2.2 without changes to the empirical setting. In column II we estimate Eq. (2.4) with bank and country-time fixed effects (FE) including the claims denominated in GBP. Column III replicates this exercise with the benchmark FE by bank-country-currency and country-currency-time. Columns IV and V add to this later setting bank-time and bank-country-time FE, respectively. Robust standard errors clustered at the bank and quarter level are reported between parentheses. All regressions include a set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles. In columns IV and V only the coefficients for the control variables $Dep.\ ratio_{t-1}$ and $\Delta L^{\neq k}_{i,k,t}$ are reported, which vary over the bank-currency-time dimension. Other control variables are absorbed by bank-time FE. Variables' definitions are reported in Table B.1 in the article. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.8 ROBUSTNESS TESTS — CHANGES TO ECONOMETRIC SETTING

Adjustment:	1-m rates	Max CIP	Loan growth	Trunc. LHS	2.5 winsor.	Clust. bank	Clust. k,t
	I	II	III	IV	V	VI	VII
J. ΔCIP	0.634***	0.660***	2.605**	0.302**	0.496**	0.605***	0.605***
x RSF_{t-5}	(0.163)	(0.164)	(1.294)	(0.125)	(0.151	(0.178)	(0.233)
RSF_{t-5}	0.020	0.012	-0.016	0.003	0.010	0.020	0.020
	(0.031)	(0.031)	(0.303)	(0.020)	(0.027)	(0.031)	(0.038)
Controls:							
$Total\ assets_{t-1}$	-0.013	-0.013	-0.087	-0.007	-0.011	-0.013	-0.013
	(0.010)	(0.010)	(0.081)	(0.006)	(0.009)	(0.010)	(0.011)
$Dep.\ ratio_{t-1}$	0.008	0.008	0.282*	0.002	0.005	0.008	0.008
	(0.017)	(0.017)	(0.167)	(0.011)	(0.015)	(0.017)	(0.019)
$Liq.\ ratio_{t-1}$	-0.036	-0.037	-0.439	-0.020	-0.030	-0.037	-0.037
	(0.045)	(0.045)	(0.285)	(0.032)	(0.041)	(0.041)	(0.037)
$Cap.\ ratio_{t-1}$	-0.093	-0.094	-0.140	-0.093	-0.090	-0.093	-0.093
	(0.088)	(0.088)	(0.734)	(0.069)	(0.083)	(0.086)	(0.092)
$\Delta L_{i,k,t}^{\neq k}$	0.084***	0.084***	0.000	0.051***	0.071***	0.084***	0.084***
	(0.023)	(0.022)	(0.000)	(0.014)	(0.019)	(0.023)	(0.015)
Constant	0.255	0.255	2.464	0.132	0.218	0.256	0.256
	(0.183)	(0.182)	(1.487)	(0.114)	(0.157)	(0.176)	(0.193)
Obs.	62,739	62,739	60,056	62,739	62,739	62,739	62,739
R^2	0.108	0.108	0.157	0.110	0.109	0.108	0.108

NOTE: This table reports the results from estimating Equation (2.4) by changing different features of the econometric model and the data structure. All constitutive terms of the interactions are included in the regressions. Coefficients for $\Delta CIP_{k,t}$ and for its interactions with RSF_{t-5} are not reported. Column I replicates the benchmark model using 1-month interest rates to compute ΔCIP instead of 3-month interest rates. In column II we measure ΔCIP as the quarterly change in the maximum CIP deviations during a given quarter. In column III we use only cross-border loans to compute $\Delta L_{i,j,k,t}$ as the dependent variable. In column IV we truncate $\Delta L_{i,j,k,t}$ by replacing values above 1 by 1 and below 0 by 0. In column V we winsorise the variables in the model at the 2.5th and 97.5th percentiles. Finally, columns VI and VII cluster the standard errors at the bank and at the currency and time levels, respectively. Robust standard errors are clustered at the bank and quarter level in columns I to V and are reported between parentheses in all columns. All regressions include a set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles in all columns besides column V. Variables' definitions are reported in Table B.1 in the article. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.9 ROBUSTNESS TESTS — EXCLUDING RELEVANT OBSERVATIONS

	Excl. destination:			Excl. bank home country:		
Exclude:	US	EZ	US+EZ	US	EZ	US+EZ
	I	II	III	IV	V	VI
J. ΔCIP x RSF_{t-5}	0.681***	0.603***	0.726***	0.435***	0.748**	0.537**
	(0.151)	(0.191)	(0.186)	(0.155)	(0.287)	(0.242)
RSF_{t-5}	0.028	0.047	0.070	0.008	0.012	-0.003
	(0.029)	(0.048)	(0.048)	(0.031)	(0.041)	(0.040)
Controls:						
$Total\ assets_{t-1}$	-0.014	-0.012	-0.013	-0.011	-0.035**	-0.030**
	(0.011)	(0.009)	(0.013)	(0.011)	(0.014)	(0.014)
$Dep.\ ratio_{t-1}$	0.008	-0.000	-0.003	0.007	0.009	0.008
	(0.017)	(0.018)	(0.014)	(0.017)	(0.019)	(0.020)
$Liq.\ ratio_{t-1}$	-0.041	-0.055	-0.068	-0.018	-0.039	-0.016
	(0.043)	(0.056)	(0.057)	(0.043)	(0.061)	(0.061)
$Cap.\ ratio_{t-1}$	-0.095	-0.105	-0.114	-0.051	-0.134*	-0.094
	(0.095)	(0.106)	(0.128)	(0.084)	(0.076)	(0.069)
$\Delta L^{\neq k}_{i,k,t}$	0.088***	0.067**	0.069**	0.063***	0.089***	0.056**
	(0.025)	(0.025)	(0.030)	(0.021)	(0.029)	(0.026)
Constant	0.271	0.252	0.280	0.211	0.664**	0.558**
	(0.198)	(0.172)	(0.236)	(0.186)	(0.256)	(0.244)
Obs.	57,325	36,701	31,287	54,971	45,737	37,992
R^2	0.118	0.140	0.165	0.119	0.129	0.146

NOTE: This table reports the results from estimating Equation (2.4) by excluding relevant countries or banks from the analysis. All constitutive terms of the interactions are included in the regressions. In columns I to III we exclude the US (col. I), the Euro Zone (EZ, col. II), and both the US and the EZ (col. III) from our sample of destination countries in which UK-based banks hold cross-border FX claims. In columns IV to VI we exclude banks whose headquarters are located in the US (col. IV), the EZ (col. V), or either the US or the EZ (col. VI) from our sample. Robust standard errors are clustered at the bank and quarter level and are reported between parentheses. All regressions include a set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in the article. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.10 EXTENSION — ΔCIP SIGN AND CURRENCY DIFFERENCES

Definition of Dif_{t-5}:	None	1 if EUR	1 if EUR	1 if $\Delta CIP < 0$	1 if $\Delta CIP < 0$
	I	II	III	IV	V
Joint ΔCIP x RSF_{t-5} x Dif_{t-5}		-0.397	-0.348	0.152	0.179
		(0.344)	(0.343)	(0.304)	(0.301)
Joint ΔCIP x RSF_{t-5}	0.605***	0.806***	0.742***	0.510*	0.453*
	(0.176)	(0.183)	(0.157)	(0.303)	(0.261)
RSF_{t-5} x Dif_{t-5}		0.049**	0.092*	-0.0158	-0.0376
		(0.023)	(0.049)	0.0313	0.0331
RSF_{t-5}	0.020	-0.014	-0.028	0.020	0.047
	(0.031)	(0.020)	(0.041)	(0.031)	(0.036)
Controls:					
$Total\ assets_{t-1}$	-0.013	0.002	-0.014	0.001	-0.014
	(0.010)	(0.002)	(0.011)	(0.002)	(0.011)
$Dep.\ ratio_{t-1}$	0.008	-0.002	0.006	-0.002	0.007
	(0.017)	(0.012)	(0.017)	(0.013)	(0.017)
$Liq.\ ratio_{t-1}$	-0.037	-0.012	-0.034	-0.012	-0.037
	(0.046)	(0.016)	(0.046)	(0.016)	(0.046)
$Cap.\ ratio_{t-1}$	-0.093	0.037	-0.092	0.036	-0.096
	(0.087)	(0.043)	(0.087)	(0.044)	(0.087)
$\Delta L_{i,k,t}^{\neq k}$	0.084***	0.090***	0.084***	0.090***	0.084***
	(0.022)	(0.021)	(0.023)	(0.021)	(0.023)
Constant	0.256	-0.018	0.279	-0.015	0.264
	(0.183)	(0.024)	(0.192)	(0.024)	(0.186)
Fixed effects	i,j,k	k,t	i,j,k	k,t	i,j,k
	j,k,t		j,k,t		j,k,t
Obs	62,739	62,739	62,739	62,739	62,739
R^2	0.108	0.005	0.108	0.005	0.108

NOTE: This table reports the results from estimating Equation (2.4) by including a triple-interaction term between ΔCIP x RSF_{t-5} and a dummy variable Dif_{t-5} equal to 1 if the respective claims are denominated in EUR (cols. II and III), or equal to 1 if ΔCIP is negative (cols. IV and V). All constitutive terms of the interactions are included in the regressions. Robust standard errors are clustered at the bank and quarter level and are reported between parentheses. Regressions in cols. II and IV include currency-time FE, whereas the remaining cols. include the full set of fixed effects at the bank-country-currency and country-currency-time level. Variables are winsorised at the 1st and 99th percentiles. Variables' definitions are reported in Table B.1 in the article. *** indicates significance at the 1% level; ** at the 5%; * at the 10%.

Table B.11 DESCRIPTIVE STATISTICS OF COUNTRY-LEVEL REGRESSIONS

	I	II	III	IV	V
	Mean	Median	SD	Min	Max
Dependent variables:					
$\Delta L_{j,k,t}$ (within sample)	0.01	0.00	0.27	-0.95	0.96
$\Delta L_{j,k,t}$ (BIS data, RoW)	0.01	0.01	0.13	-0.53	0.43
$\Delta L_{j,k,t}$ (BIS data, CA)	0.01	0.01	0.24	-0.85	0.94
Exposure variable:					
RSF_{t-5}	0.11	0.08	0.10	0.00	0.43
Control variables:					
$Total\ assets_{t-1}$	16.94	17.56	2.04	9.43	19.26
$Dep.\ ratio_{t-1}$	0.72	0.74	0.19	0.19	1.19
$Liq.\ ratio_{t-1}$	0.39	0.39	0.12	0.12	0.67
$Cap.\ ratio_{t-1}$	0.09	0.08	0.05	0.00	0.24
$\Delta L_{i,k,t}^{\neq k}$	0.02	0.02	0.09	-0.24	0.24
CIP variables:					
GBP-CB	-0.08	-0.08	0.18	-0.76	0.41
ΔCIP	0.00	0.00	0.14	-0.74	0.46
Further variables:					
Branch share dummy	0.26	0.00	0.44	0.00	1.00
UK share dummy	0.25	0.00	0.43	0.00	1.00

NOTE: This table reports descriptive statistics for the variables used in the analysis of Section 2.5 in the main article. The variables are divided into five categories: dependent variables, exposure variable, control variables, CIP variables, and further (auxiliary) variables. The displayed descriptive statistics include the mean (col. I), median (col. II), standard deviation (col. III), minimum (col. IV), and maximum (col. V). The dependent variable $\Delta L_{j,k,t}$ is reported for the within-sample exercise displayed in Table 2.6 (computed from the aggregated bank-level data), and for the cross-country substitution exercise using BIS data displayed in Table 2.7. This later exercise considers the growth rate in total claims from the rest of the world (RoW, all reporting countries excluding the UK) and the growth rate in total claims from the US and the Euro Zone. These jurisdictions represent the home currency areas (CA) of the currencies in which cross-border claims are denominated (i.e. USD and EUR). Variables are defined in Table B.1 in the article.

C | Appendix to Chapter 3 - Dollar Shortage Shocks and Central Bank Swap Lines

C.1 Bankers' Problem

C.1.1 Baseline Model

Banker i's problem is:

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

subject to:

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

$$V_{i,t} \geq \Theta(x_{i,t}, \gamma_t)q_tS_{i,t} \tag{C.3}$$

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

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

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

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

where

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

$$\mu_t^* = E_t\left[\Omega_{t+1}(R_{t+1} - \frac{\epsilon_{t+1}}{\epsilon_t} R_{t+1}^*)\right] \tag{C.7}$$

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

$$\nu_t = \left[\Omega_{t+1} R_{t+1}\right] \tag{C.9}$$

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:

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

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

Combining (C.10) and (C.11) we obtain optimality condition (3.10) in the main text. Optimality condition (3.13) follows from the incentive compatibility constraint being binding.

C.1.2 Model With Swaps

With the introduction of swaps, banks' maximisation problem changes as described in equations (3.28)-(3.30) in the main text. In turn, the scaled problem given by (C.5) becomes:

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

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

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

which, combined with (C.10), yields optimality condition (3.32) in the main text. Optimality condition (3.33) is again derived from the incentive compatibility constraint being binding. Finally, optimality condition (3.31) 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).

C.2 Calibration and Data

C.2.1 Calibration

Table C.1 PARAMETERS CALIBRATION

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

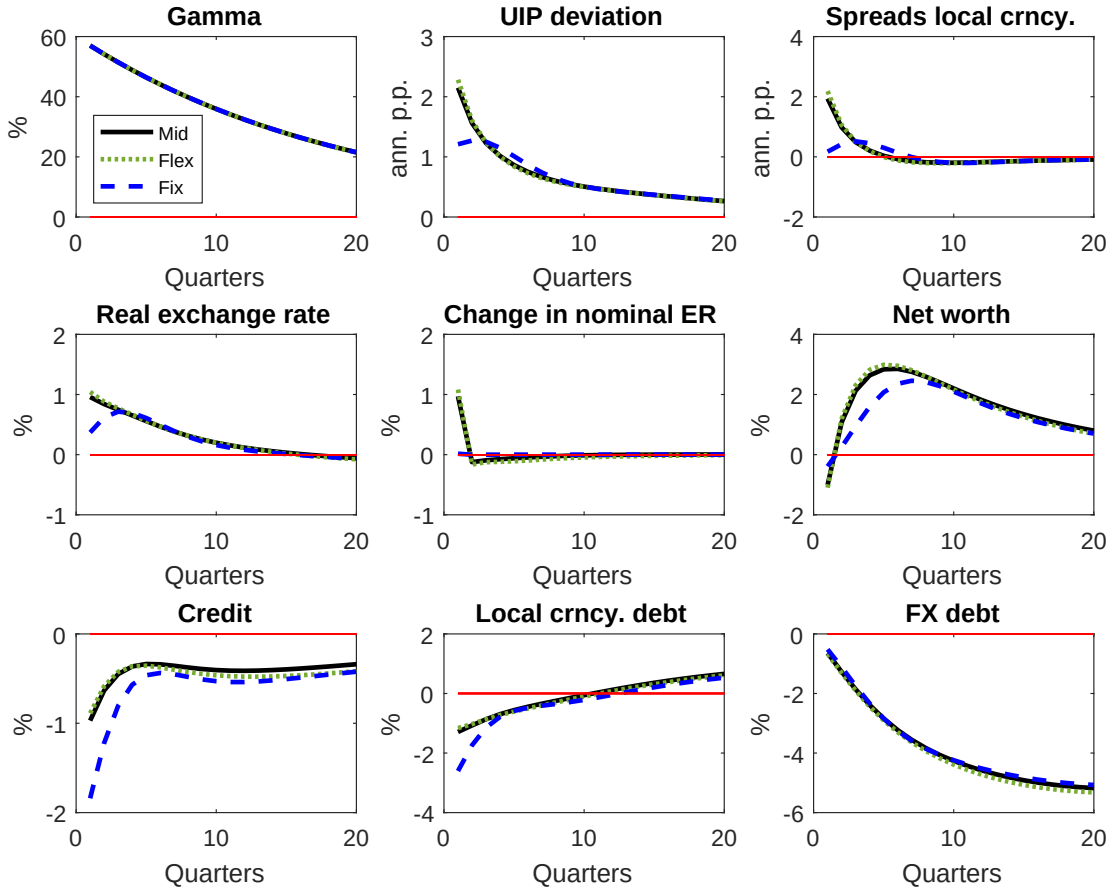
C.2.2 Data

- 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.

C.3 Model Under Producer Currency Pricing (PCP)

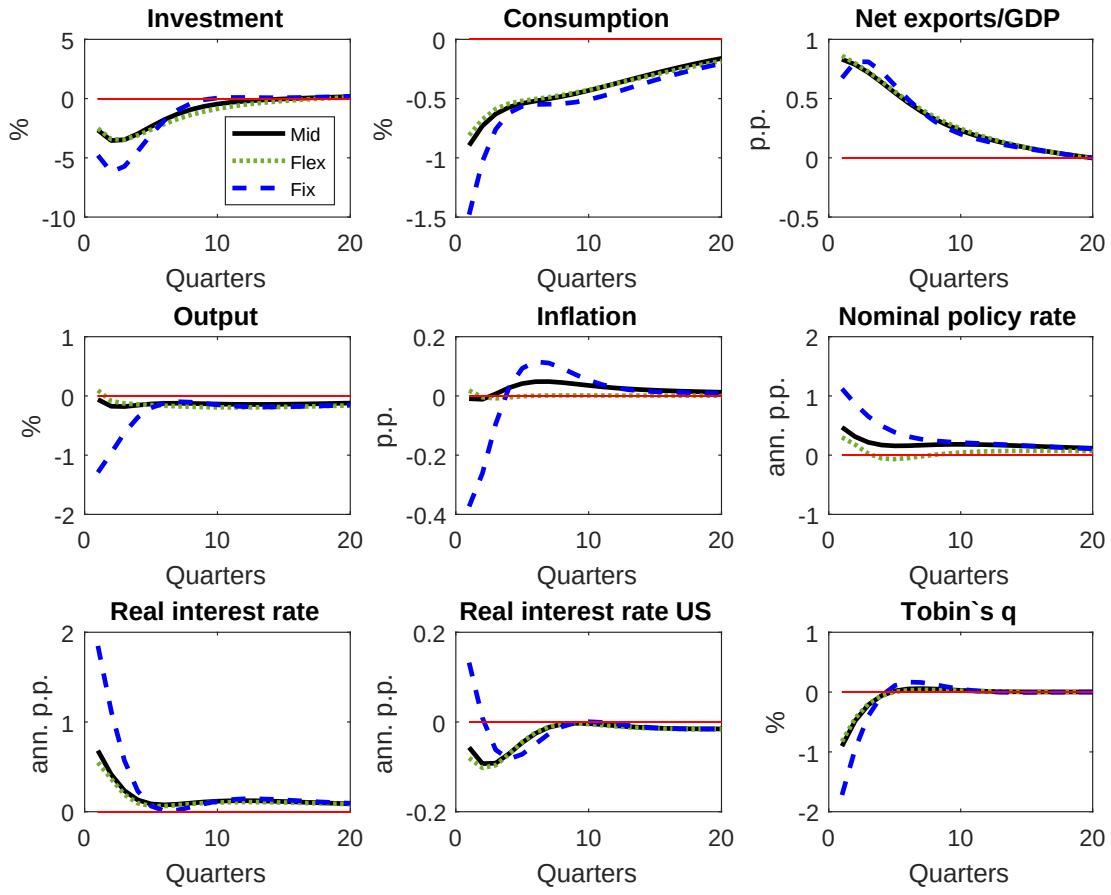
C.3.1 Dollar Shortage Shocks Under Different Exchange Rate Regimes

Figure C.1 MODEL DYNAMICS AFTER 'DOLLAR SHORTAGE' SHOCK UNDER PCP, 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 ($\gamma_e = 0.99$).

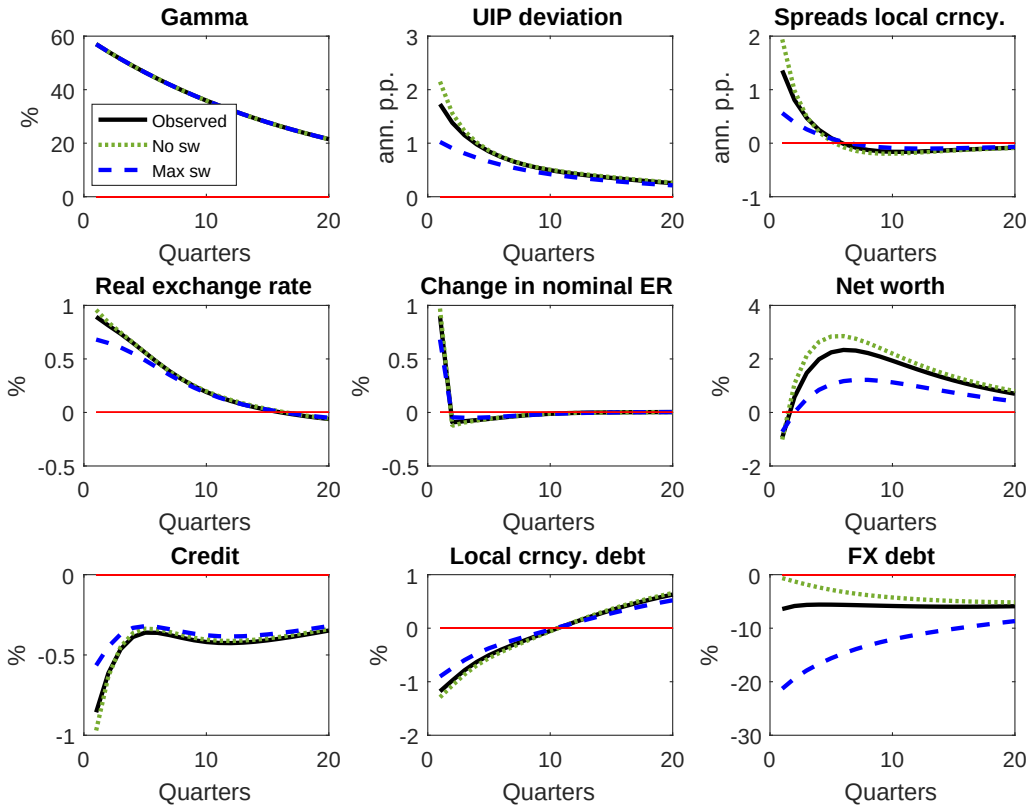
Figure C.2 MODEL DYNAMICS AFTER 'DOLLAR SHORTAGE' SHOCK UNDER PCP, MACRO VARIABLES



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 ($\gamma_e = 0.99$).

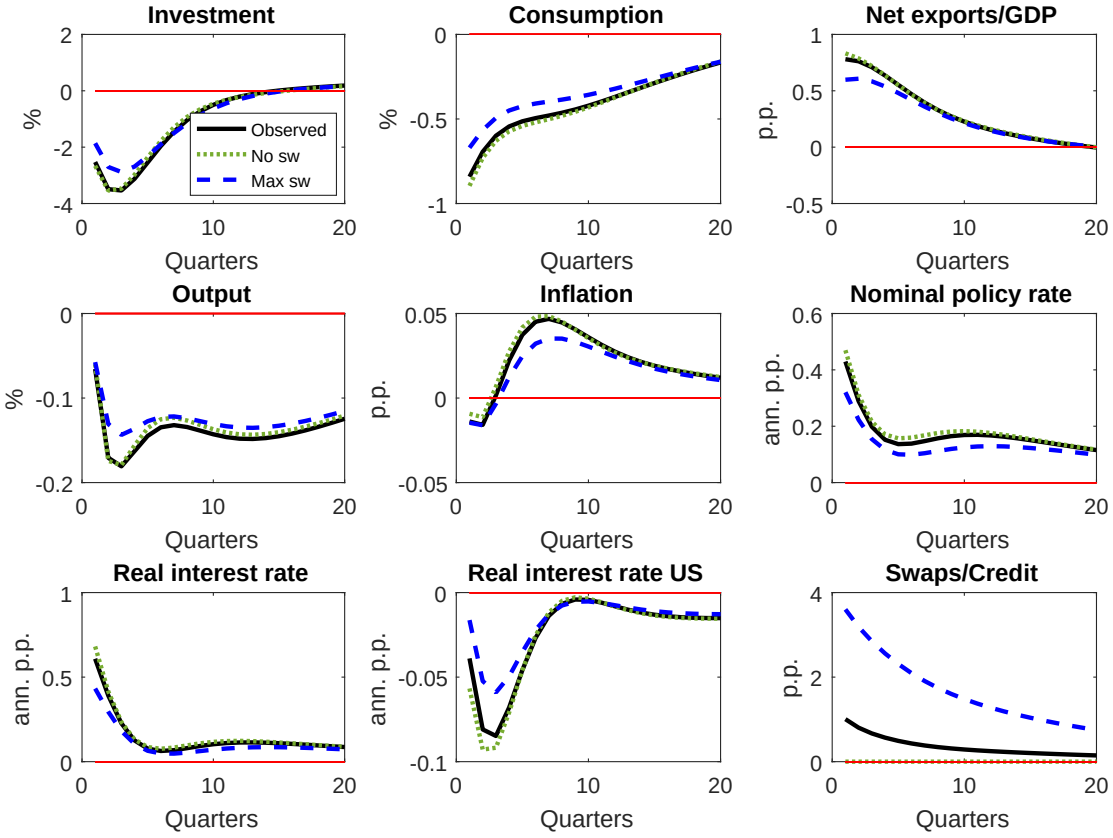
C.3.2 The Role of Swap Lines

Figure C.3 MODEL DYNAMICS AFTER 'DOLLAR SHORTAGE' SHOCK WITH SWAPS UNDER PCP, 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).

Figure C.4 MODEL DYNAMICS AFTER 'DOLLAR SHORTAGE' SHOCK WITH SWAPS UNDER PCP, 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).