Towards a New Monetary Theory of Exchange Rate Determination

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Abstract

We build a two-country general equilibrium model with banks and study exchange rate determination. Banks are modelled following the "financing through money creation" model of Jakab and Kumhof (2015), in which banks create deposits through lending, constrained only by profitability and solvency considerations, and not by the availability of "loanable funds". We embed this model in a two-country setting, where banks' willingness to lend against collateral, households' demands for different currencies, cross-border interbank flows, and banks' regulatory constraints in terms of currency exposures play an important role in determining the value of the exchange rate in general equilibrium. The model is a hybrid between modern UIP-based theories of exchange rate determination and the old monetary theory of exchange rate determination, which in important cases have opposite predictions for the sign of the exchange rate response to shocks. In environments like the ZLB, where monetary policy loses its ability to respond to the state of the economy, the dominant mechanism is that of the monetary theory, rather than a UIP-based mechanism. Besides providing a more realistic account of the workings of international banking and of international gross and net capital flows, the paper sheds new light on the international transmission of shocks through the banking system, which is relevant for the conduct of monetary and prudential policy. We find that shocks to the relative supplies of and demands for different currencies have strong effects on balance sheets and the exchange rate, and lead to sizeable deviations from uncovered interest parity due to a monetary wedge that responds to excess credit creation.

JEL Codes: E44, E51, F41, F44

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1 Introduction

It is widely recognized that exchange rates are poorly explained by macroeconomic fundamentals such as interest-rate differentials and relative supplies and demands for domestic and foreign goods. Other financial factors appear to play an important role, most importantly relative supplies and demands for domestic and foreign assets, both pure investment assets and assets demanded for their liquidity or monetary services. This paper focuses on the role of the latter, which consist of virtually the entirety of the liabilities of the domestic and foreign banking systems. In doing so our paper recognizes that the banking system does not simply intermediate but instead creates (and destroys) those liabilities, principally through the creation (and repayment) of loans. The paper therefore studies the role that the banking system plays in determining the exchange rate, both as a transmission channel and as a source of shocks in itself. The main financial shocks that thereby enter into the analysis are shocks to bank credit creation and therefore money creation in a given currency, shocks to the total demand for bank-created money in a given currency, and shocks to the relative demand for domestic versus foreign currency.

To study these ideas we bring together two previously separate strands of the literature. The first is the old literature on the monetary determinants of exchange rates (Frenkel and Mussa (1985), Boughton (1988)), which has recently been revived by Brunnermeier and Sannikov (2017), among others. This literature conceives of the exchange rate as being determined by the relative supplies and demands of two national monies. To the extent that the two monies are not perfect substitutes, their relative scarcity will affect their relative price – the exchange rate. Across this literature, the specification of money demand takes several forms, but the supply of money is typically exogenous, and more importantly it is taken to represent money supplied exogenously by the government, or narrow money. It is well known that this component of the money supply typically accounts for well under 5% of the broad money supply in modern economies. It is also well known, on both theoretical and empirical grounds[1], that there is no money multiplier relationships between narrow money and broad money, so that a focus on narrow money is likely

[1] Kydland and Prescott (1990), Brunner and Meltzer (1990), McLeay, Radia andThomas (2014a,b)), Bundesbank (2017), Goodhart (2007), Borio and Disyatat(2009), Carpenter and Demiralp (2010).

to be misleading. What is needed is instead a theory of the endogenous creation, by the banking system, of the broad money supply, and the consequences of such a theory for exchange rate determination. The other major weakness of this older literature is that it typically assumed that the central bank's policy interest rate can be treated as exogenous, rather than being determined by a policy rule that responds systematically to economic conditions.

The endogenous determination of the money supply is the point of departure for the second strand of literature, which deals with the sources and nature of money and credit in modern fractional-reserve banking systems. The endogenous creation of the money supply through credit extension by private banks, which was very well understood by the leading macroeconomists in the decades following the Great Depression, including by Friedman (1948), has recently been the subject of several central bank publications, including the Bank of England (McLeay, Radia and Thomas (2004a,b)) and the Bundesbank (2017). In the more recent academic literature this has been formalized by Goodfriend and McCallum (2007) and Jakab and Kumhof (2015). Another advantage of this literature is that it can simultaneously address the other shortcoming of the older monetary theory of exchange rate determination, by endogenizing the determination of policy interest rates.

To bring these two strands of the literature together, we build a two-country version of the 'financing-through-money-creation' (FMC) model in Jakab and Kumhof (2015) and use it study the effect that banking-sector and real-sector shocks can have on financial variables such as private and public balance sheets and spreads, on non-financial variables such as the balance of payments and national accounts aggregates, and finally on the nominal and real exchange rate. In the model, households borrow in both domestic and foreign currencies from domestic banks in order to have banks create liquidity for them. The cost of this liquidity is the spread charged by banks, while the benefit is the reduction in transactions costs for consumption goods purchases. The cost to banks of creating this liquidity is the interest rate paid on deposits plus costs of regulatory compliance, while the benefit is the interest rate earned on loans. The terms on which banks supply credit depend on the value of collateral that households are able to post, the haircuts that banks demand on collateral, and the tightness of banks' regulatory constraints on credit extension. The optimal quantity of credit and money is endogenous, as both banks and households trade off their respective costs and benefits.

In our framework, and in the real world, domestic banks can freely create foreign currency in the same way as domestic currency. This was emphasized as early as 1971, for the Eurodollar market, by Milton Friedman (1971). The difference to domestic currency creation is that, in the absence of swap lines from foreign central banks, they do not have access to a lender of last resort in foreign currency. As an insurance against liquidity shocks in foreign currency, they therefore keep interbank deposit balances in foreign currency with foreign correspondent banks. These interbank deposit balances are created by foreign banks in the same way as household deposit balances, through foreign currency loans to domestic banks. These gross positions are critical for liquidity insurance purposes, and they play a key role in our model. Critically, this extension of cross-border credit automatically matches gross international asset positions between countries. This is simply an outcome of accounting entries, or as Friedman (1971) calls it, the bookkeeper's pen. Credit-driven changes in these positions are recorded as capital 'flows' in the balance of payments, but there is no net resource flow at all when a new position is created. For example, when a domestic bank wants to make a new foreign currency deposit in the foreign country, it can only do so by obtaining a new foreign currency loan in that country. Our model therefore rationalizes the strong high-frequency co-movement of both sides of international asset positions.

One of the theoretical predictions of our framework is a direct role of relative supplies of and demands for deposits in domestic and foreign currencies as a driver of the exchange rate. To show this analytically, we derive a modified uncovered interest parity (MUIP) condition from the model's equilibrium conditions, and illustrate how a monetary wedge between the risk-free interest rate differential and the expected depreciation rate of the exchange rate can arise in response to shocks. We also take our prediction to the data, focussing on currency-specific credit supply shocks, and find supportive evidence.

The remainder of this paper is structured as follows. Section 2 provides an overview of the model. Section 3 discusses its calibration. Section 4 studies one of its theoretical predictions, namely the existence of a monetary wedge in the uncovered interest parity condition. Section 5 studies the predictions of the theoretical model, not only for responses to standard business cycle shocks but also shocks to the supply of and demand for credit and money. Section 6 takes our predictions to the data. Section 7 concludes.

2 The Model

The world economy comprises two countries, Home and Foreign. Each country is populated by households, with respective shares in the world population of n and $1-n$, and a government. The world economy features Home and Foreign goods, Home and Foreign currencies, and two domestic banking sectors.

Households in each country own the domestic stock of land[2], which both serves as an input into the production of domestic value added and as collateral for borrowing from domestic banks. Households also supply labour, the other input into production, for which they receive wages. They own both banks and firms, from whom they receive dividends and profits. Households consume a bundle of domestic and foreign goods, which they purchase by using domestic and foreign currency deposits. Firms and unions have pricing power, and set prices and wages subject to quadratic adjustment costs. Monetary policy targets CPI inflation by setting the risk-free interest rate following a Taylor-type rule. We abstract from fiscal policy considerations by assuming a balanced budget rule.

The key feature of the banking sector is that its liabilities, unlike those of any other type of economic agent, are each economy's generally accepted as a medium of exchange in payment for goods (or, in an alternative model version, in payment for assets). In the real world, the perceived safety, and at-par convertibility into cash, that leads to this unique acceptability of bank liabilities is partly due to asset diversification on the part of banks, but is mainly due to the extensive regulatory and support mechanism put in place by the government, the central bank, and various regulatory authorities. The formalization of the regulatory support mechanism in the model is

[2] We abstract from capital accumulation mainly for analytical convenience. However, it is worth noting that in fact a large share of developed countries' capital stock consists of real estate whose main component, land, is in fixed supply, as in our model.

stylized, mainly by way of minimum capital adequacy requirements (CAR) that effectively ensure a zero default risk for banks, and which limit the amount of credit creation in the economy, but also including foreign exchange mismatch regulations (FXMR), which requires overall exposures in foreign currency to be matched at all times. The formalization of the medium of exchange function of bank liabilities in the model is also stylized, by way of a Schmitt-Grohé and Uribe (2004) transactions cost technology. However, as discussed in Jakab and Kumhof (2015) and Kumhof, Tsomocos and Wang (2018), this is a shortcut for a more decentralized representation of the role of banks, where banks do serve as intermediaries, not between savers and borrowers but rather between spenders and spenders, with bank deposits circulating throughout the economy, to permit any given set of agents to become both sellers and buyers at various points in an ongoing chain of transactions.

Households bank exclusively with banks in their own country, but require liquidity in both currencies to conduct purchases of consumption goods. Banks in each country therefore issue loans in both currencies to households of that country, in order to create deposits in both currencies, with the liquidity that is jointly created by these two types of deposits lowering the transactions costs that arise in purchases of consumption goods. Households therefore need to make decisions not only about the optimal composition of their bundle of consumption goods, but also about the optimal composition of their "bundle" of liquidity. Both are treated in the model as CES aggregates, and both goods and monies are therefore imperfect substitutes. While in conventional open economy models it is therefore only relative supplies and demands of goods that, along with interest parity, determine the exchange rate, in our model it is also relative supplies and demands of bank deposits.

Because the focus of this paper is mainly on exchange rate determination rather than on international capital flows, we assume that there is no cross-border lending to households.[3] Instead, the banking sectors interact only with the respective foreign banking sector, through a cross-border interbank market in both currencies. Specifically, banks in each country issue interbank loans and accept interbank deposits in their domestic currency to banks of the other country, which gives

[3] International capital flows, in a model which features cross-border lending to both banks and households, is the subject of forthcoming work by Kumhof, Rungcharoenkitkul and Sokol (2018).

rise to a total of four gross interbank positions (two banks, two currencies) between countries. In a completely parallel fashion to households, banks require interbank deposits in foreign currency for liquidity purposes, because they only have access to lender-of-last-resort facilities in their own currency, and therefore self-insure against a run on foreign-currency household deposits. This setup implies that the net foreign asset position of a country is determined by the net interbank position of its banking sector. A schematic representation of the model is shown in Figure 1.

2.1 Conventions and Assumptions

Throughout the paper we observe the convention that a real normalized nominal variable is the nominal variable divided by the price level P_t and the level of productivity T_t, while a real normalized real variable is the real variable divided by the level of productivity. Nominal variables are denoted by upper case letters, real variables are denoted by the corresponding lower case letters, and real normalized variables are denoted by the symbol for the corresponding real variable with an added inverse hat symbol above the variable. The exogenous and constant growth rate of productivity T_t is $x = T_t/T_{t-1}$, while the endogenous and time-varying growth rate of the price level P_t is $\pi_t^p = P_t/P_{t-1}$. The nominal exchange rate E_t is the price, expressed in domestic currency, of a unit of foreign currency (so that an increase indicates a depreciation of the domestic currency), and its depreciation rate is defined as $\varepsilon_t = E_t/E_{t-1}$. The real exchange rate is defined as the ratio of the two countries' CPI price levels expressed in a common currency, $e_t = (E_t P_t^*)/P_t$. All interest rates are in gross terms, and a subscript t denotes an interest rate paid on an asset held from period t to period $t + 1$. The real interest rate on a generic domestic currency balance sheet item Z is given by $r_{zHt} = i_{zHt-1}/\pi_t^p$, while the real interest rate on a generic foreign currency balance sheet item Z is given by $r_{zF,t} = (i_{zF,t-1}\varepsilon_t)/\pi_t^p$. We present here only the key model equations for the Home economy plus the relevant world economy closing conditions. Analogous equations will hold for the foreign economy.

2.2 Banking Sector

Within each country, the banking sector has three functions. The first is wholesale lending and deposit issuance, which entails choosing the overall size of the balance sheet to maximize net worth subject to regulatory constraints. The second and third are retail lending and retail deposit issuance, which entails setting the terms of loan and deposit contracts. For analytical convenience, we split banks' optimization problem into these three components, and assign them to different sectors within the domestic banking system. Both the wholesale and the retail deposit banking sectors are involved in cross-border lending and deposit-taking.

2.2.1 Wholesale Banks

Wholesale banks issue wholesale loans in Home and Foreign currencies, $L_{H,t}$ and $L_{F,t}$, to domestic retail lending banks. They also issue interbank loans in Home currency $L^b_{H,t}$ to foreign wholesale banks, and hold interbank deposits in Foreign currency $D^b_{F,t}$ at foreign retail deposit banks. Their financing consists of wholesale deposits in both currencies, $O_{H,t}$ and $O_{F,t}$, from domestic retail deposit banks, interbank loans in Foreign currency $L^b_{F,t}$ from foreign wholesale banks, and net worth N^b_t held by domestic households. Using the results of the subsection on retail deposit banks, we can consolidate the wholesale and retail deposit sectors by setting $O_{H,t} = D_{H,t} + D^b_{H,t}$ and $O_{F,t} = D_{F,t}$, where $D_{H,t}$ and $D_{F,t}$ are retail deposits from domestic households. Using the notational convention for aggregate real normalized variables, the banking sector's aggregate balance sheet is given by

$$\check{\ell}_{H,t} + e_t\check{\ell}_{F,t} + \check{\ell}^b_{H,t} + e_t\check{d}^b_{F,t} = \check{d}_{H,t} + e_t\check{d}_{F,t} + \check{d}^b_{H,t} + e_t\check{\ell}^b_{F,t} + \check{n}^b_t \ . \tag{1}$$

Wholesale banks maximize expected net worth subject to foreign currency mismatch regulation (FXMR), capital adequacy regulation (CAR), and monetary transactions costs related to the absence of a lender of last resort in foreign currency. FXMR can take a variety of forms that can be represented by one of the following four rules

$$\begin{aligned} \check{\ell}_{F,t} + \check{d}^b_{F,t} &= \check{\ell}^b_{F,t} + \check{d}_{F,t} \ , \qquad (2) \\ \check{d}_{F,t} &= \check{\ell}_{F,t} \ , \\ \check{d}^b_{F,t} &= \check{\ell}^b_{F,t} \ , \\ \check{d}^b_{F,t} - \check{\ell}^b_{F,t} &= \varpi\left(\check{d}_{F,t} - \check{\ell}_{F,t}\right) \ . \end{aligned}$$

The first rule requires that banks match the total of their exposures vis-a-vis households and vis-a-vis banks at all times, and is our baseline assumption. The second rule requires that banks only match their exposures vis-a-vis households, with interbank exposures free to exhibit mismatches. The third rule requires that banks only match their interbank exposures, with exposures vis-a-vis households free to exhibit mismatches. The fourth rule, with $\varpi \in (0,1)$, requires that banks adjust their interbank positions to partially offset mismatches in their foreign currency exposures vis-a-vis households, for example as a liquidity buffer in case there is a sudden increase in potentially volatile foreign currency deposits that is not matched by an increase in foreign currency loans. We will experiment with variants of these rules, which can have a very material effect on the macroeconomic dynamics that follow financial shocks.

CAR limit banks' leverage, and thus their exposure to shocks to their net worth. Bank j is assumed to face a penalty $\frac{\chi}{P_t}\left[L_{H,t}(j) + E_t L_{F,t}(j) + L^b_{H,t}(j) + E_t D^b_{F,t}(j)\right]$ if net worth in the next period falls short of γ times risk-weighted assets in the next period, where the regulatory risk weight on loans to households is assumed to equal one, while $\zeta < 1$ is the regulatory risk-weight on interbank positions. The penalty is payable if the following inequality is breached:

$$
\begin{aligned}
&\left[\begin{array}{c} i_{\ell H,t} L_{H,t}(j) + E_{t+1} i_{\ell F,t} L_{F,t}(j) \\ + i^b_{\ell H,t} L^b_{H,t}(j) + E_{t+1} i^b_{dF,t} D^b_{F,t}(j) \end{array}\right] \omega^b_{t+1} \\
&- i_{oH,t} O_{H,t}(j) - E_{t+1} i_{oF,t} O_{F,t}(j) - E_{t+1} i^b_{\ell F,t} L^b_{F,t}(j) \\
&- E_{t+1} s^b_t(j) L_{F,t}(j) + P_{t+1}\left(\Pi^R_{t+1}(j) - \Lambda^\ell_{t+1}(j)\right) \\
&< \gamma \left[\begin{array}{c} i_{\ell H,t} L_{H,t}(j) + E_{t+1} i_{\ell F,t} L_{F,t}(j) \\ + \zeta\left(i^b_{\ell H,t} L^b_{H,t}(j) + E_{t+1} i^b_{dF,t} D^b_{F,t}(j)\right) \end{array}\right] \omega^b_{t+1} \, .
\end{aligned} \tag{3}
$$

The variable ω^b_{t+1} is a log-normally distributed shock to the loan return with mean 1 and variance $\left(\sigma^b\right)^2$, and we denote its pdf and cdf by $f^b(\cdot)$ and $F^b(\cdot)$. This condition gives rise to a cutoff loan return shock $\bar{\omega}^b_t$ below which regulations are breached, and the penalty has to be paid. $\Pi^R_{t+1}(j) - \Lambda^\ell_{t+1}(j)$ is the pro-rated share (by share of total bank net worth) in net profits of retail deposits banks minus net losses of retail lending banks.

A bank's foreign currency liabilities towards households give rise to a risk of foreign currency funding drying up in the absence of a lender of last resort in foreign currency. This is modelled as a monetary transactions cost that is increasing in foreign currency liabilities towards households and decreasing in interbank foreign currency liquidity. For an individual bank this cost is denoted by

$$s_t^b\left(\check{d}_{F,t}^b(j)\right)\check{\ell}_{F,t}\left(j\right)\ , \tag{4}$$

where

$$s_t^b=\frac{\varphi_b}{\vartheta_b}\left(\check{d}_{F,t}^b\right)^{-\vartheta_b}\ .$$

The objective function for net worth maximization of an individual bank j takes into account two arbitrage condition on wholesale interest rates. First, as discussed below, for retail deposit banks wholesale deposits in domestic currency and domestic government bonds are perfect substitutes, so that the equilibrium nominal interest rate for domestic currency wholesale deposits $i_{oH,t}$ equals the policy rate i_t. Second, for the domestic wholesale bank wholesale deposits in foreign currency from domestic retail deposit banks and interbank loans in foreign currency from foreign wholesale banks are perfect substitutes, so that the equilibrium nominal interest rate for foreign currency wholesale deposits $i_{oF,t}$ equals the interbank lending rate in foreign currency $i_{\ell F,t}^b$. Net worth maximization involves taking first-order conditions with respect to all balance sheet items that are not otherwise pinned down, namely all four asset side items. In this, banks internalize the risk of breaching the CAR, so expected net worth includes the penalty payable if a breach occurs, weighted by the probability of that occurring. We have

$$\max_{\left\{\begin{array}{c}L_{H,t}\left(j\right),\,L_{F,t}\left(j\right),\\ L_{H,t}^b\left(j\right),\,D_{F,t}^b\left(j\right)\end{array}\right\}}\mathbb{E}_t\left[\begin{array}{c}\left[i_{\ell H,t}L_{H,t}\left(j\right)+E_{t+1}i_{\ell F,t}L_{F,t}\left(j\right)\right.\\ \left.+i_{\ell H,t}^bL_{H,t}^b\left(j\right)+E_{t+1}i_{dF,t}^bD_{F,t}^b\left(j\right)\right]\omega_{t+1}^b\\ -i_tO_{H,t}\left(j\right)-E_{t+1}i_{\ell F,t}^bO_{F,t}\left(j\right)-E_{t+1}i_{\ell F,t}^bL_{F,t}^b\left(j\right)\\ -E_{t+1}s_t^b\left(j\right)L_{F,t}\left(j\right)+P_{t+1}\left(\Pi_{t+1}^R\left(j\right)-\Lambda_{t+1}^\ell\left(j\right)\right)\\ -P_{t+1}\int_0^{\bar{\omega}_{t+1}^b(j)}\frac{\chi}{P_t}\left[L_{H,t}\left(j\right)+E_tL_{F,t}\left(j\right)\right.\\ \left.+L_{H,t}^b\left(j\right)+E_tD_{F,t}^b\left(j\right)\right]f^b\left(\omega_{t+1}^b\right)d\omega_{t+1}^b\end{array}\right] \tag{5}$$

Optimization yields first-order conditions that we show in full, because they reveal important details concerning the structure of interest rate spreads. We drop individual indices because in equilibrium all banks will behave identically, and we show the conditions in real normalized form. Throughout, we use the notation $f_{t+1}^b\equiv f^b\left(\bar{\omega}_{t+1}^b\right)$ and $F_{t+1}^b\equiv F^b\left(\bar{\omega}_{t+1}^b\right)$. We also adopt the shorthand notation $\check{\ell}_t^\ell=\check{\ell}_{H,t}+e_t\check{\ell}_{F,t}+\check{\ell}_{H,t}^b+e_t\check{d}_{F,t}^b$. This represents total assets of the banking sector balance sheets, which is the basis to which the regulatory penalties parameter χ is applied. The expressions $\check{\Omega}_{\ell X,t}^x$ are the derivatives $\partial\bar{\omega}_{t+1}^b/\partial\check{\ell}_{X,t}^x$, with $X\in\{H,F\}$, and with x either blank for wholesale loans or equal to b for interbank loans. We note that $\check{\Omega}^{x}_{\ell X,t}$ are always positive, that they are similar in size between the two types of wholesale loans and separately between the two types of interbank loans, and finally that they are significantly smaller for interbank loans than for wholesale loans (see below).

For domestic currency wholesale loans $\check{\ell}_{H,t}$ we have

$$\mathbb{E}_t \left\{ r_{\ell H,t+1} - r_{t+1} - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}_{\ell H,t} \check{\ell}^{\ell}_t \right) \right\} = 0 \tag{6}$$

This condition shows that there is a *regulatory spread* between the wholesale lending rate in domestic currency and the risk-free rate due to regulation. Specifically, because banks internalize the risk of breaching the CAR, and because at the margin an additional loan increases the penalty payable in case of a breach, banks demand compensation.

For foreign currency wholesale loans $\check{\ell}_{F,t}$ we have

$$\mathbb{E}_t \left\{ r_{\ell F,t+1} - r^b_{\ell F,t+1} - \frac{\varepsilon_{t+1}}{\pi^p_{t+1}} s^b_t - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}_{\ell F,t} \check{\ell}^{\ell}_t \right) \right\} = 0 \tag{7}$$

There are two notable differences between this condition and the one for domestic currency wholesale loans. First, the spread is relative to the interest rate on wholesale interbank loans in foreign currency $r^b_{\ell F,t+1}$. The reason is that, as mentioned above, the wholesale deposit interest rate in foreign currency $i_{oF,t}$ is arbitraged with the interbank lending rate in foreign currency $i^b_{\ell F,t}$. Domestic banks, who do not have direct access to lender-of-last-resort facilities in foreign currency, must at the margin refinance foreign currency liabilities on the foreign currency interbank market. In that market foreign banks charge a spread over the foreign policy rate because of their own regulatory spread (this will be discussed from the point of view of domestic banks below). Second, on top of the domestic regulatory spread, there is an *interbank monetary spread*. Specifically, with our FXMR rule, any increase in foreign currency wholesale loans must be matched with either an increase in foreign currency wholesale deposits or a decrease in net foreign currency interbank positions, and foreign currency wholesale deposits are costly because they require precautionary interbank liquidity balances in foreign currency. The interbank monetary spread compensates banks for this cost.

For domestic currency interbank loans $\check{\ell}^b_{H,t}$ we have

$$\mathbb{E}_t \left\{ r^b_{\ell H,t+1} - r_{t+1} - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}^b_{\ell H,t} \check{\ell}^\ell_t \right) \right\} = 0 \tag{8}$$

This looks identical to the condition for domestic currency wholesale loans, but there is a difference that is hidden in the term $\check{\Omega}^b_{\ell H,t}$. Specifically, the Basel risk weight for interbank loans ζ is considerably lower than the one for wholesale loans, which means that the regulatory spread for interbank loans is correspondingly lower.

For foreign currency interbank deposits $\check{d}^b_{F,t}$ we have

$$\mathbb{E}_t \left\{ r^b_{dF,t+1} - r^b_{\ell F,t+1} - \frac{\varepsilon_{t+1}}{\pi^p_{t+1}} s^{b\prime}_t \check{\ell}_{F,t} - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}^b_{dF,t} \check{\ell}^\ell_t \right) \right\} = 0 \tag{9}$$

As for foreign currency wholesale loans, the spread is relative to the interest rate on wholesale interbank loans in foreign currency, in this case because of the specific FXMR that we adopt as our baseline. Under this FXMR all foreign currency positions on banks' balance sheets must be matched, so that the opportunity cost for all of them is the interest rate at which domestic banks can refinance foreign currency liabilities on the foreign currency interbank market. Foreign currency interbank deposits also attract a regulatory spread, but like for domestic currency interbank loans this is small due to the low risk weight of interbank positions. But this regulatory spread, plus the additional cost of a refinancing rate that incorporates a foreign regulatory spread, is in our calibration more than offset by the *interbank monetary discount*. The reason for this discount is that holdings of foreign currency interbank deposits mitigate foreign currency funding risk, so that $s^{b\prime}_t(\cdot) < 0$.

The model for wholesale banks is closed by a law of motion for their net worth, which can be found in the Technical Appendix.

2.2.2 Retail Deposit Banks

Retail deposit banks issue retail deposit varieties in domestic and foreign currency to domestic households. They also issue interbank deposits in domestic currency to foreign banks. Domestic currency deposits finance purchases of domestic currency wholesale deposits and government bonds, but the latter are assumed to be in zero net supply due to the specification of fiscal policy. Foreign currency retail deposits finance purchases of foreign currency wholesale deposits. The balance sheet of the aggregate retail banking system is therefore given by $\check{o}_{H,t} = \check{d}_{H,t} + \check{d}^b_{H,t}$ and $\check{o}_{F,t} = \check{d}_{F,t}$.

Retail deposit banks behave as monopolistic competitors, and depositors demand a composite of all deposit varieties in a given currency. This implies the following pricing rules for deposits

$$
\begin{aligned}
r_{dH,t} &= \mu_{dH} r_t \ , \\
r_{dF,t} &= \mu_{dF} r^b_{\ell F,t} \ , \\
r^b_{dH,t} &= \mu^b_{dH} r_t \ ,
\end{aligned}
\tag{10}
$$

where the markdown terms μ^x_{dX} are smaller than one. Retail deposit banks are fully owned by wholesale banks, and their profits are transferred to the latter in a lump-sum fashion.

2.2.3 Retail Lending Banks

The function of retail lending banks is to set the terms of loan contracts, in a formally very similar fashion to Bernanke, Gertler and Gilchrist (1999), henceforth BGG, whose set-up we follow and extend.

The collateral for loan contracts between banks and households is the value of the land $Q_t k_t$ owned by households, where Q_t is the nominal price of land and k_t is the stock of land, which is constant in equilibrium. While in most frameworks that use the BGG model the available collateral is assumed to consist of 100% of the value of collateral at all times, in our framework that fraction is subject to stochastic shocks, and not necessarily equal to 100% in steady state. Specifically, households are able to pledge shares $\kappa_{X,t}$, $X \in \{H, F\}$ of land to borrow in domestic and foreign currency from domestic retail lending banks. There are two ways to think about shocks to the shares $\kappa_{X,t}$. The first is as regulatory changes that affect loan-to-value ratios. The second is as a reduced-form representation of changes in banks' own willingness to lend against a given stock of collateral. We will adopt the second interpretation here.

Land yields a nominal return, which includes both appreciation Q_t/Q_{t-1} and rent R^k_t/Q_{t-1}, of $Ret_{k,t} = \frac{Q_t+R^k_t}{Q_{t-1}}$. Lending in Home and Foreign currency is governed by two separate loan contracts. Letting the subscript $X \in \{H, F\}$ denote the currency of the loan contract, borrowers are subject to idiosyncratic productivity shocks $\omega^k_{X,t+1}$ that are log-normally distributed, with a riskiness parameter $\sigma^k_{X,t}$ that is subject to stochastic shocks. We denote their pdf and cdf by $f^k\left(\omega^k_{X,t+1}\right)$ and $F^k\left(\omega^k_{X,t+1}\right)$. The shocks to $\kappa_{X,t}$ and $\sigma^k_{X,t}$ are the main credit supply shocks in our model.

Loan contracts stipulate retail lending rates $i_{rX,t}$ on loans $L_{X,t}$ that must be paid in full if the realization of the shock is high enough to avoid bankruptcy. Borrowers decide to declare bankruptcy if their individual productivity shock remains below a cutoff value $\bar{\omega}^k_{X,t}$, below which handing over the entire value of the project over to the bank becomes preferable to realizing the project and repaying the loan. In case of bankruptcy, because of monitoring costs, the bank can only recover a fraction $1-\xi_X$ of the project value. The cost of funding for retail lending banks is given by wholesale lending rates $i_{\ell X,t}$, which can be thought of as the lending rates for notionally riskless borrowers (which are not present in the model). Letting $E_{H,t+1}\equiv 1$ and $E_{F,t+1}=E_{t+1}$, the participation constrains for retail loans in both currencies to household j can be represented as

$$\mathbb{E}_t E_{X,t+1} i_{\ell X,t} L_{X,t}(j) = \mathbb{E}_t \left[\begin{array}{c} \left(1-F^k\left(\bar{\omega}^k_{X,t+1}(j)\right)\right) E_{X,t+1} i_{rX,t} L_{X,t}(j) \\ +\left(1-\xi_X\right)\int_0^{\bar{\omega}^k_{X,t+1}(j)} \left[\begin{array}{c} \kappa_{X,t} Q_t k_t(j) Ret_{k,t+1} \times \\ \omega^k_{X,t+1}(j) f^k\left(\omega^k_{X,t+1}(j)\right) d\omega^k_{X,t+1}(j) \end{array} \right] \end{array} \right] .$$

This states that the wholesale (riskless) return on a loan $L_{X,t}(j)$ has to be equal to the sum of two terms. The first is gross interest on fully repaid loans weighted by the probability of a sufficiently high realization of the idiosyncratic productivity shock. The second is the share of pledged collateral net of monitoring costs (note the parameter $\kappa_{X,t}$) recoverable in case of default, weighted by the probability of default. In the Technical Appendix we show that the aggregate participation constraints can be rewritten as

$$\mathbb{E}_t\left[\kappa_{X,t} Ret_{k,t+1} Q_t k_t \left(\Gamma^k_{X,t+1} - \xi_X G^k_{X,t+1}\right) - E_{X,t+1} i_{\ell X,t} L_{X,t}\right] = 0 \; , \tag{11}$$

where $\Gamma^k_{X,t+1}$ denotes a lender's gross share in pledged earnings of land, and $\xi_X G^k_{X,t+1}$ denotes a lender's monitoring costs share in pledged earnings of land. This states that ex-ante net loan losses are zero. However, ex-post loan losses can be different from zero, and are transferred in lump-sum fashion to wholesale banks, who own retail lending banks.

2.2.4 Interbank Market

Domestic and foreign banks are linked via their interbank relationships, both in terms of balance sheet positions and in terms of prices. For Home, the interest rates on Foreign currency interbank deposits and loans are identical to the rates prevailing in Foreign, $i^b_{\ell F,t} = i^{b*}_{\ell F,t}$ and $i^b_{dF,t} = i^{b*}_{dF,t}$. The corresponding interbank balance sheet positions are $\check{\ell}^b_{F,t} = \check{\ell}^{b*}_{F,t}\frac{1-n}{n}$ and $\check{d}^b_{F,t} = \check{d}^{b*}_{F,t}\frac{1-n}{n}$. Analogous relationships hold for the Home currency exposures of banks in Foreign.

2.3 Households

Households maximize lifetime utility subject to an intertemporal budget constraint and to bank participation constraints, by choosing a plan for consumption, hours worked, loans and deposits in both currencies and land holdings. Their consumption bundle is a CES aggregate that includes domestic and foreign goods. They face monetary transaction costs for purchases of the consumption bundle that are decreasing in a CES liquidity aggregate that includes domestic and foreign currencies.

The objective function for domestic household j is

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \left(1 - \frac{\nu}{x}\right) S^c_t \log\left(c_t(j) - \nu c_{t-1}\right) - \psi \frac{h_t\left(j\right)^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right\} \ , \tag{12}$$

where ν denotes habit persistence, η the elasticity of labour supply, ψ is a labour supply scale parameter, and S^c_t is a shock to consumption demand. The CES consumption bundle, with home-bias parameter b^c_H and elasticity of substitution θ_c, is given by

$$c_t = \left[\left(b^c_H\right)^{1/\theta_c} \left(c_{H,t}\right)^{\frac{\theta_c - 1}{\theta_c}} + \left(1 - b^c_H\right)^{1/\theta_c} \left(c_{F,t}\right)^{\frac{\theta_c - 1}{\theta_c}} \right]^{\frac{\theta_c}{\theta_c - 1}} \ , \tag{13}$$

with corresponding utility-based price index P_t. The Home and Foreign goods sub-aggregates are in turn given by CES bundles over a continuum of goods, with elasticity of substitution θ_p. We make the conventional assumption that $\theta_p > \theta_c$.

We assume that households demand a liquidity composite that consists of domestic and foreign currency deposits. The liquidity composite reduces the monetary transactions costs of purchasing the consumption bundle.[4] The functional form for liquidity demand is a simplified version of

[4] We also explore alternative motives for holding liquidity, such as purchases of land.

Schmitt-Grohé and Uribe (2004):

$$s_t^h = A^h S_t^{md} v_t^h \quad , \quad v_t^h = \frac{\check{c}_t}{\check{d}_t^{liq}} \; , \tag{14}$$

where S_t^{md} is a "flight to safety" shock to money demand, A^h is a parameter that determines the size of overall liquidity demand, and v_t^h is the consumption velocity of money. The CES liquidity composite over Home and Foreign currency deposits, with elasticity of substitution θ_d and "financial home bias" parameter b_H^d, is given by

$$\check{d}_t^{liq} = \left[\left(b_H^d S_t^{mm} \right)^{1/\theta_d} \left(\check{d}_{H,t} \right)^{\frac{\theta_d - 1}{\theta_d}} + \left(1 - b_H^d S_t^{mm} \right)^{1/\theta_d} \left(e_t \check{d}_{F,t} \right)^{\frac{\theta_d - 1}{\theta_d}} \right]^{\frac{\theta_d}{\theta_d - 1}} \tag{15}$$

where S_t^{mm} denotes a "financial home bias" money demand shock.

Households' flow budget constraint is given by[5]

$$\begin{aligned} & \check{d}_{H,t}(j) + e_t \check{d}_{F,t}(j) + \check{q}_t k_t(j) - \check{\ell}_{H,t}(j) - e_t \check{\ell}_{F,t}(j) \qquad (16) \\ = \; & \frac{r_{dH,t}}{x} \check{d}_{H,t-1}(j) + \frac{r_{dF,t}}{x} e_t \check{d}_{F,t-1}(j) \\ & + ret_{k,t} \check{q}_{t-1} k_{t-1}(j) \left(1 - \kappa_{H,t-1} \Gamma_{H,t}^k(j) - \kappa_{F,t-1} \Gamma_{F,t}^k(j) \right) \\ & - \left(1 + s_t^h(j) \right) \check{c}_t(j) + \check{w}_t^{hh} h_t(j) + \check{\Upsilon}_t(j) \end{aligned}$$

This states that households' net assets (deposits plus land minus loans) at time t must equal the gross return on net assets held in the previous period (on deposits and on the share of land returns that do not go to banks to repay loans) minus consumption (including transaction costs $s_t^h(j)\check{c}_t(j)$) plus labour income and lump-sum net income $\check{\Upsilon}_t(j)$. Households also face the participation constraints (11) for taking out loans in domestic and foreign currency. The multipliers on these participation constraints are denoted by $\tilde{\lambda}_{X,t+1}$.

The first-order conditions drop individual indices because in equilibrium all households will make identical decisions. The optimality conditions for domestic and foreign consumption goods are standard. For aggregate consumption we have

$$\frac{S_t^c \left(1 - \frac{\nu}{x} \right)}{\check{C}_t} = \check{\lambda}_t \left(1 + s_t^h + s_t^{h'} v_t^h \right) \; , \tag{17}$$

[5] We simplify by abstracting from loan adjustment costs, which are only included for numerical reasons. See the Technical Appendix.

where $\check{C}_t = \check{c}_t - \frac{\nu}{x}\check{c}_{t-1}$ is the consumption habit and $\check{\lambda}_t$ is the Lagrange multiplier on the budget constraint. The presence of the monetary transactions cost introduces a wedge between the marginal utility of consumption and the Lagrange multiplier. The first-order condition for hours worked is standard:

$$\psi (h_t)^{\frac{1}{\eta}} = \check{\lambda}_t \check{w}_t^{hh} \ . \tag{18}$$

The first-order conditions for Home and Foreign currency deposits are

$$1 - s_t^{h'} \left(v_t^h\right)^2 d_t^{\prime X} = \frac{\beta}{x}\mathbb{E}_t \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} r_{dX,t+1} \ , \tag{19}$$

where $d_t^{\prime H}$ and $d_t^{\prime F}$ are the derivatives of $\check{d}_t^{liq}$ with respect to domestic and foreign currency deposits. The monetary transactions cost introduces wedges in the Euler equations for deposits that are inversely related to (the square of) the amount of liquidity in circulation. The first-order conditions for Home and Foreign currency loans are

$$1 = \frac{\beta}{x}\mathbb{E}_t \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} \tilde{\lambda}_{X,t+1} r_{\ell X,t+1} \ , \tag{20}$$

where $\tilde{\lambda}_{X,t+1}$ is the Lagrange multiplier on the participation constraint. The first-order conditions for the bankruptcy cutoff condition $\bar{\omega}_{X,t+1}^k$ are identical to BGG:

$$\mathbb{E}_t \tilde{\lambda}_{X,t+1} = \mathbb{E}_t \frac{\Gamma_{X,t+1}^{k,\omega}}{\Gamma_{X,t+1}^{k,\omega} - \xi_H G_{X,t+1}^{k,\omega}} \ , \tag{21}$$

where the superscript ω denotes a derivative with respect to the cutoff productivity level. Finally, the first-order condition for holdings of land is

$$1 = \beta \mathbb{E}_t \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} r\check{e}t_{k,t+1} \left[\left(1 - \Sigma_X \kappa_{X,t} \Gamma_{X,t+1}^k\right) + \Sigma_X \tilde{\lambda}_{X,t+1} \kappa_{X,t} \left(\Gamma_{X,t+1}^k - \xi_X G_{X,t+1}^k\right) \right] \ . \tag{22}$$

2.4 Firms, Unions and Goods Market Clearing

Firms combine labour and land to produce varieties of the domestic good. Their price setting takes place in an environment of monopolistic competition subject to quadratic inflation adjustment costs. The production function for firm j is given by

$$y_t (j) = T_t \left(S_t^a h_t (j)\right)^{1-\alpha} \left(K_t (j)\right)^{\alpha} \ , \tag{23}$$

where S_t^a is a labour-augmenting technology shock, and where we have adopted the timing convention $K_t = k_{t-1}$. This gives rise to standard expressions for real marginal cost and for factor demands. Finally, because land is in fixed supply, we have $k_t = \bar{k}$, where $\bar{k}$ is an exogenous constant. For price setting, in our baseline we adopt the assumption of producer-currency pricing (PCP). Pricing rules under local-currency pricing (LCP) are presented in the Technical Appendix. Optimization with respect to $P_{H,t}(j)$ and $P_{H,t}^*(j)$ yields a pair of standard New Keynesian Phillips curves.

Unions buy labor from households at a nominal consumer wage rate W_t^{hh} set in a competitive labor market. Firms demand a composite of labor varieties with elasticity of substitution θ_w. Unions sell labor to firms at a union-specific nominal producer wage rate $W_t^{pr}(j)$, which is set subject to monopolistic competition. Unions set the nominal producer wage to maximize discounted nominal profits subject to a quadratic wage inflation adjustment cost, taking the consumer wage as given. Optimization with respect to $W_t^{pr}(j)$ yields a standard wage Phillips curve.

The model features no investment and government spending, and all adjustment costs are rebated in a lump-sum fashion to households. The goods market clearing condition is therefore given by

$$\check{y}_t = \check{c}_{H,t} + \check{c}_{H,t}^* \frac{1-n}{n} \ , \tag{24}$$

while real (normalized) GDP[6] is defined as

$$g\check{d}p_t = \check{c}_t + \check{x}_t - \check{m}_t \ , \tag{25}$$

where real exports are given by $\check{x}_t = e_t p_{H,t}^* c_{H,t}^* \frac{1-n}{n}$ and real imports by $\check{m}_t = p_{F,t}\check{c}_{F,t}$.

2.5 Monetary Policy

Monetary policy is assumed to follow a simple inflation-forecast-based interest rate rule

$$i_t = S_t^i \left(i_{t-1}\right)^{m_i} \left(\bar{r}\bar{\pi}^p\right)^{1-m_i} \left(\frac{\pi_{4,t+3}^p}{\bar{\pi}^p}\right)^{(1-m_i)m_\pi} \ , \tag{26}$$

[6] To simplify the exposition, here we simply deflate nominal GDP using the CPI deflator. However, for the reporting variable “GDP” in our model we construct a Fisher index.

with $\pi^p_{4,t} = \left(\pi^p_t \pi^p_{t-1} \pi^p_{t-2} \pi^p_{t-3}\right)^{\frac{1}{4}}$, and the expression for the equilibrium real interest rate $\bar{r} = (x/\beta\mu_{dH})\left(1 - \bar{s}^{h'}\left(\bar{v}^h\right)^2 \bar{d}^H\right)$ can be obtained by combining the first-order condition for domestic-currency deposits with the pricing condition for retail deposits in domestic currency. As for fiscal policy, the initial stock of government debt is assumed to equal zero, and both government spending and taxation are zero at all times, so that government debt remains at zero at all times.

2.6 Balance of Payments

There are two links between Home and Foreign. First, households in both countries trade among each other in Home and Foreign goods. Second, banks in both countries maintain interbank positions with each other in Home and Foreign currencies. This implies the following expression for the net foreign assets position:

$$\begin{aligned} & \check{\ell}^b_{H,t} + e_t \check{d}^b_{F,t} - \check{d}^b_{H,t} - e_t \check{\ell}^b_{F,t} \\ = \ & \frac{1}{x}\left(r^b_{\ell H,t}\check{\ell}^b_{H,t-1} + r^b_{dF,t} e_{t-1}\check{d}^b_{F,t-1} - r^b_{dH,t}\check{d}^b_{H,t-1} - r^b_{\ell F,t} e_{t-1}\check{\ell}^b_{F,t-1}\right) + \check{x}_t - \check{m}_t \ . \end{aligned} \tag{27}$$

The above states that the net foreign assets position in period t equals the difference between two gross interbank credit positions (Home currency loans and Foreign currency deposits) and two gross interbank debit positions (Home currency deposits and Foreign currency loans). The change in the net foreign asset position equals the sum of the net changes of these four gross positions, which in turn equals the sum of net interest payments on the four gross positions plus the trade balance.

But crucially, our model keeps track of all gross asset positions, as all interbank balance sheet items are explicitly modelled and can respond to shocks in different ways.

3 Calibration

Our calibration strategy is to use a combination of US and international data to calibrate the model. The reason is that the US is the benchmark economy for much macroeconomic research and has a relatively high level of data availability. However, the US is atypical in one important respect - its currency lies at the centre of international trade in goods and assets. For this reason, it relies much less than most countries on foreign currencies to transact in goods and assets. Therefore, for certain parameters, especially those relating to the use of foreign currencies, but also where US data are unavailable, UK or euro area (EA) values are used. Parameters relating to the regulation of banks are largely agreed at the international level, and we use these regulations as the basis for our calibration wherever available. We will discuss the calibration in terms of the parameters of Home. In our calibration we start from a fully symmetric setup, and then set n to 5% to be consistent with the share of the UK in the world economy.

3.1 Financial Sector Parameters

The first subset of parameters relates to prudential regulation and the riskiness of banks and their borrowers. The capital adequacy ratio γ is set at 8.5% which is the sum of the 4.5% Basel III minimum CET1 (Common Equity Tier 1) ratio, the 2.5% capital conservation buffer (see Basel Committee on Banking Supervision (2017)), and the non-CET component of the Pillar 1 buffer. We omit the countercyclical and GSIB buffers, and the additional supervisory requirements, as these do not apply to all banks at all times. Note that in our setup banks will end up holding some capital above the regulatory minimum to self-insure against the risk of violating the CAR. We therefore set the actual capital adequacy ratio to 11% in steady state, by adjusting banks' dividend payout parameter δ^b. The cumulative share of banks that violate the Basel minimum is F^b_{t+1} , and to our knowledge, no good measure of this exists in the data. We set it to 2.5% in steady state, close to the approximate historical frequency of systemic banking crises in Jorda, Schularick and Taylor (2011), by adjusting the bank riskiness parameter σ^b. Bankruptcy rates of domestic and foreign bank borrowers, $F_{H,t+1}$ and $F_{F,t+1}$, respectively, are set at 1.5% in steady state by adjusting the steady state borrower riskiness parameters $\bar{\sigma}_H$ and $\bar{\sigma}_F$. This corresponds to the figure found by

Brooks and Ueda (2011) for non-financial listed US companies, and also approximately matches the historical average of per-capita default rates of the first two quartiles of borrowers reported in Albanesi et al. (2017).

The second subset of financial sector calibration targets relates to steady-state interest-rate spreads in the banking system. We first discuss banks' asset-side rates, and then turn to liability-side rates. We set the parameter ζ, the Basel risk weight on interbank claims, to zero. The risk weight was given a value of 20 percent in the Basel I rules, but subsequent versions of the Basel rules made this parameter model-based or risk-sensitive, and hence non-unique (see Basel Committee on Banking Supervision (2017)). This implies a spread between the interbank lending rate in domestic currency and the short-term policy rate of 22 basis points, which is close to the 16 basis points average spread, over the period 2000-2016, between the 1-month LIBOR and the effective Federal Funds rate. To exactly match that spread would have required setting ζ to a slightly negative value. The wholesale lending spreads over the marginal cost of funds for loans in domestic and foreign currency, respectively, are set 60 and 70 basis points by adjusting the CAR parameter χ and the willingness-to-lend parameter for foreign currency loans $\bar{\kappa}_F$. The 10 basis points difference reflects the fact that loans in Foreign currency attract an additional small interbank monetary spread, which is due to the necessity to hold some foreign interbank liquidity in the absence of a lender of last resort in foreign currency. For loans in Home currency, this spread is calibrated on the basis of the average value of the TED spread, which equals the difference between the interest rates on 3-month interbank loans and on 3-month T-bills, between 1986, the first year for which data are available on FRED, and 2016. The external finance premia, in other words the differences between the retail and wholesale lending rates, are set to 150 and 140 basis points for loans in domestic and foreign currency, respectively, by adjusting the loss-given-default parameters ξ_H and ξ_F. The 10 basis points difference between the rates reflects the fact that foreign borrowers that apply for loans to domestic banks tend to be multinationals, and are on average larger and more creditworthy than domestic borrowers. The calibration is based on the average spread between US residential mortgages and US dollar 3-month LIBOR rates over the 1996-2015 period. Steady state retail lending rates therefore equal 5 per annum for all non-bank borrowers.

The steady state spread between the interbank deposit rate in domestic currency and the central bank's policy rate is calibrated at -10 basis points by adjusting the spread parameter μ^b_{dH}. This calibration is based on interpreting the interbank deposit rate as LIBID, and based on the fact that the historic spread between US LIBID and the Fed Funds rate has been around that magnitude over 1990-2008, i.e. prior to the effective zero lower bound period. The steady state spreads between the retail rates on deposits in both currencies are calibrated at minus 110 basis points by adjusting the spread parameters μ_{dH} and μ_{dF}. The calibration of this spread is based on the average spread between the UK policy rate and the effective interest rate on household current accounts between September 1998 (the first date for which monthly data are available) and October 2016, and is close to the calibration in Barrdear and Kumhof (2016).

The third subset of parameters describe the size of the financial system along various dimensions. The recent ratios of home-currency interbank deposits to annual GDP in the UK equal 7.4%˙They are likely to be lower in larger economic blocs like the US and the euro area, so we set this value equal to 5% and set a symmetric value for foreign-currency interbank deposits, in each case by adjusting the scale parameters of the interbank money demand function φ_b. In order to obtain a symmetric steady state, we also set the interbank loan positions to 5% of GDP, by adjusting the second parameter of the respective interbank deposit demand functions, ϑ_b. The total size of loans to non-banks is calibrated at 100% of GDP by adjusting the money demand parameter A_h. This corresponds approximately to the ratio of loans of the US commercial banking sector to GDP, and excludes the shadow banking sector. The elasticity of substitution between domestic and foreign currency deposits θ_d is calibrated at 1.5. There is to our knowledge no established literature on this parameter, and we will conduct sensitivity analysis to explore the sensitivity of our results to θ_d. However, with this value of θ_d the implied interest semi-elasticity of the demand for domestic currency deposits (the vast majority of domestic deposits) equals around 9, a reasonable value in light of the historic literature on interest semi-elasticities for broader monetary aggregates. We do not directly calibrate the leverage of the household sector, which equals the ratio of loans to the difference between the value of land and loans. Instead we calibrate the ratio of the value of land to GDP, which can be shown, based on Fed and NIPA data, to equal around 250% of GDP. To calibrate this value we adjust the stead-state willingness-to-lend parameter $\bar{\kappa}_H$, while we adjust the endowment of land $\bar{k}$ in order to normalize the steady state real land price $\bar{q}$ to 1. The resulting private leverage ratio is 67%˙ It is difficult to compare this to real-world counterparts, because of model simplifications where non-financial household wealth consists exclusively of land, and household debt consists only of liabilities to the commercial banking sector. The share of foreign-currency deposits in total household deposits is set to equal 6% by adjusting the deposits home bias parameter b^d_H. The value of 6% is in line with UK household balance sheet data in the ONS Blue Book for the end of 2015, the latest available datapoint.

3.2 Real Sector Parameters

For parameters that affect the real sector we mostly use standard values. Productivity growth x equals 2% in annual terms, while the equilibrium real interest rate $\bar{r}$ and the CPI inflation target $\bar{\pi}^p$ equal 3% and 2% in annualized terms, respectively, the former by adjusting the rate of time preference β. We normalize the steady state labour supply to 1, by adjusting the preference weight ψ. We set the share of foreign goods in the domestic consumption basket to 14% in steady state, by adjusting the goods market home bias parameter b^c_H. The value of 14% matches the ratio of imports to total final expenditure in the US. The elasticity of substitution θ_c between domestic and foreign goods is set to 1.5, a common value in the literature. We set the elasticity of labour supply η to 1, again a common value in the business cycle literature, and the habit parameter ν to the fairly standard value of 0.7. For the economy's technology, we set the land share of income to 20% by adjusting the share parameter α. The basis for this calibration is that it can be shown (Kumhof and Tidemann (in progress)) that land accounts for slightly less than half of the income attributed to capital in the national accounts, capital in turn accounting for 41% in the most recent data. This means that the labour share in our model effectively adds the income shares of labour and physical capital income. We set both price and wage gross markups, μ_p and μ_w, to 1.1, and the price- and wage-adjustment cost parameters ϕ_p and ϕ_w to 200, which implies price and wage durations of around 5 quarters in a Calvo setup with full indexation to past inflation. Finally, for the monetary policy rule, we set the smoothing and inflation feedback parameters to $m_i = 0.7$ and $m_\pi = 2$.

4 Demand for Liquidity and the Monetary UIP Wedge

One key theoretical prediction of our model is a direct role of relative deposit supplies in Home and Foreign currency as drivers of the exchange rate. To show this analytically, we derive a modified uncovered interest parity (UIP) condition from the model's equilibrium conditions. The starting point are the household first-order conditions for domestic and foreign currency deposits (19). Dividing one of these condition by the other and log-approximating we obtain an analytical expression for the wedge between deposit rates in different currencies (expressed in common currency):

$$\ln \frac{r_{dH,t+1}}{r_{dF,t+1}} \approx A^h S_t^{md} \left(v_t^h\right)^2 d_t^{\prime H} \left(\left(\frac{1 - b_H^d S_t^{mm}}{b_H^d S_t^{mm}} \frac{\check{d}_{H,t}}{e_t \check{d}_{F,t}} \right)^{\frac{1}{\theta_d}} - 1 \right) = sp_t^{mon} \ .$$

Furthermore, by using the retail deposit pricing conditions (10), rewriting the relationship in nominal terms, and using the foreign counterpart to the first-order condition for the pricing of interbank loans (8), we can write a modified UIP condition in terms of the respective risk-free nominal rates. To do so we use the approximation $\ln i_{\ell F,t}^{b*} \approx \ln i_t^* + sp_t^{prud*}$, where $sp_t^{prud*} = \chi^* \left[F_{t+1}^{b*} + f_{t+1}^{b*} \check{\Omega}_{\ell F,t}^{b*} \check{\ell}_t^{\ell *} \right] \pi_{t+1}^{p*} / i_t^*$. We obtain the Home modified UIP (MUIP) condition

$$\ln i_t - \ln i_t^* - \ln \varepsilon_{t+1} \approx \kappa + sp_t^{prud^*} + sp_t^{mon} \ . \tag{28}$$

Expression (28) states that apart from a constant term κ, which is due to potential differences in retail deposit spreads in the two currencies, the behavior of the risk-free interest rate differential can deviate from that implied by uncovered interest parity for two reasons. The first is a foreign prudential spread $sp_t^{prud^*}$, which arises because the marginal cost of funding in foreign currency is an interbank rate that includes a prudential spread component. The second is a domestic monetary spread sp_t^{mon}, which arises due to imperfect substitutability between deposits in domestic and foreign currency. For the shocks that we consider, the term $sp_t^{prud^*}$ is both small and not very variable, so that here, as in our empirical section, we mainly focus on the monetary spread sp_t^{mon}. We also note, and this is important for the results, that when combined with the MUIP condition for Foreign, the above can be used to show that the monetary wedges will be equalized across countries, except for the small variations in regulatory wedges.

It is clear from (28) that a UIP wedge can only arise if the home bias-adjusted relative supply of Home and Foreign currency deposits is different from 1. The strength of this effect is governed by the (square of the) velocity of money v_t^h, the sensitivity of the liquidity aggregator to changes in domestic deposits $d_t'^H$, the transactions cost parameter A^h and the elasticity of substitution between deposits in different currencies in the liquidity aggregator θ_d.

We will now discuss the economic logic of this relationship. A key concept here, which is well known from the monetary economics literature, is the convenience yield of money, meaning the marginal value of the non-pecuniary liquidity services that money provides to its users. Users of money equate the opportunity cost of holding money, e.g. the financial return on a pure store-of-value asset such as government securities, to the sum of the financial return on money and its convenience yield. As money becomes more abundant, the liquidity services of the marginal unit of money become less valuable, in other words its convenience yield declines. Assuming an unchanged opportunity cost, its financial return must increase. In other words, the financial return on money is increasing in the quantity of money. Figure 2 illustrates this.

Consider now the effects of an increase in the relative supply of domestic currency in our model. From (28) this implies that $sp_t^{mon} > 0$, in other words domestic currency needs to pay a premium relative to foreign currency. The reason is that the greater relative abundance of domestic currency reduces its convenience yield and increases its required financial return. In other words, in a credit boom in domestic currency, that currency will have to pay a premium relative to foreign currency. We will encounter this argument repeatedly in our model simulations, and in the empirical results.

Consider next the effects, for a given increase in the relative supply of domestic currency, of different values for the elasticity of substitution. On the one hand, as $\theta_d \to \infty$, i.e. as the two types of deposits become perfect substitutes, the term in brackets will always equal 0, and the monetary UIP wedge is eliminated. On the other hand, as domestic and foreign currency assets become increasingly imperfect substitutes, the effect of the UIP wedge becomes increasingly important, because it implies that the convenience yield on money, and therefore its required financial return, becomes highly sensitive to the quantity of money created by the banking system.

5 Simulation Results

We now study the model economy's properties by way of impulse responses. Our main shock, which we will study in depth, is a negative shock to the supply of Home currency credit, through a decrease in the willingness of banks to lend in that currency, implemented via persistent decreases in the variables $\kappa_{H,t}$ and $\kappa^*_{H,t}$. We then also study two other important financial shocks, namely shocks to the demand for total liquidity in Home (meaning liquidity in both currencies), S_t^{md}, and shocks to the demand for Foreign liquidity in Home, S_t^{mm}. We also briefly comment on standard shocks that are familiar from the literature, namely technology shocks (S_t^a), shocks to consumption demand (S_t^c), and monetary policy shocks (S_t^i).

5.1 Credit Supply Shocks

5.1.1 Baseline Simulation

Figure 3 illustrates this shock. The solid line is our baseline simulation, while the dotted line in some of the charts illustrates an alternative where the standard UIP condition, without monetary wedge, holds because $\theta_d \longrightarrow \infty$.

The sudden and persistent reduction in the willingness of banks to lend in Home currency lead to a contraction in both loans and money in Home currency equal to around 5% of GDP on impact. Because this instant bank deleveraging leads to a significant improvement of regulatory capital ratios, the wholesale lending spread of banks drops by over 20 basis points. Borrowers also deleverage, but because this shock is highly contractionary, their riskiness nevertheless increases, with the retail lending spread increasing by around 40 basis points on impact. The lending spreads for foreign currency loans are of similar magnitude. But the changes in the size of Foreign currency loans and money are negligible, because the shock directly only affects Home currency activity. Because the shock is to domestic currency balance sheet items, there are no large changes in foreign currency liquidity requirements, which implies that the changes to interbank positions are not very large.

The real effects of this shock are contractionary, with GDP and inflation dropping by 0.4% and 0.55% on impact, and the real policy rate following suit. The real exchange rate depreciates on impact, and the current account improves. However, a comparison with the UIP model shows that the exchange rate depreciation is far smaller in our model. In other words, the monetary factors lead to an appreciation relative to the pure UIP case. This incremental effect is of course exactly as predicted by the old literature on the monetary determination of the exchange rate, which held that *for a given policy rate* a contraction in the money supply will lead to an appreciation of the exchange rate. The counterpart of this can be seen in the UIP monetary wedge, which under the UIP case does not change at all (the blip in our chart occurs because we do not literally set θ_d to ∞), whereas it drops by around 30 basis points in our model.

Under UIP, there is only a small change in the foreign interest rate, and no change in the monetary UIP wedge. The monetary contraction is disinflationary, which implies that the nominal and real policy rate has to drop. To compensate holders of domestic currency for the lower return, the currency needs to be expected to appreciate. This in turn requires a large and immediate exchange rate depreciation on impact. By contrast, under MUIP, while the behavior of the foreign interest rate is identical to the UIP case, the monetary wedge is now not constant, rather it drops by around 30 basis points on impact. This means that the Home currency has become scarce due to the large loan and deposit contraction. As a result, its convenience yield increases and its relative financial return can drop. In other words, the holders of the remaining Home currency assets are content to live with a significantly lower relative financial return, which means that they do not need to be compensated to the same extent for the lower policy rate by an expected appreciation (in fact, in the first period there's a small expected nominal depreciation). This is despite the fact that the policy rate, due to larger contractionary effects under MUIP, drops more strongly and therefore ceteris paribus would require a larger initial depreciation. In fact in this case, the nominal exchange rate hardly moves on impact, and then starts to appreciate. Furthermore, the real exchange rate exhibits a hump-shaped profile, with no large initial jump.

5.1.2 Different Degrees of Substitutability in Money Demand

Figure 4 continues with the same shock, but now compares the economy's response under three different assumptions about the substitutability between domestic and foreign money. Our baseline MUIP assumption, shown as the black solid line, is $\theta_d = 1.5$, the UIP alternative, shown as the red dotted line is $\theta_d = 100$, and finally the very low substitutability XMUIP alternative, shown as the blue dashed line, is $\theta_d = 0.5$.

The main difference concerns the monetary UIP wedge, which as already mentioned barely changes under UIP, drops by around 30 basis points under MUIP, and by around 75 basis points under XMUIP. Under the latter assumption, the scarcity of domestic money now has such severe effects that its tendency towards appreciation more than offsets the tendency towards depreciation of lower policy rates. As a result, the GDP contraction is significantly stronger, and the current account and NFA hardly move. In other words, reductions in substitutability between different monies dampen fluctuations in the current account. Further work will be required to establish the generality of this result.

Lower substitutability, and therefore a larger MUIP wedge, leads to a smaller initial depreciation, and larger subsequent expected depreciation, despite the fact that the policy rate, due to larger contractionary effects under lower substitutability, drops more strongly and therefore ceteris paribus requires a larger initial depreciation.

5.1.3 Lower Responsiveness of Monetary Policy

We have seen so far that the monetary effects of a contraction in lending, through the MUIP wedge, have opposite exchange rate effects to standard UIP interest parity effects. It therefore stands to reason that when monetary policy loses the ability to respond to a collapse in lending through a drop in the policy rate, the MUIP effects will prevail not only in relative terms but also in absolute terms. In other words, a monetary contraction should now lead to an absolute exchange rate appreciation. This is exactly as envisaged under the old monetary theory of exchange rate determination, where the assumption of fixed policy rates was not made because of a ZLB problem, but because the systematic component of monetary policy reaction functions had not been incorporated into monetary models yet. On the other hand, this also means that the monetary theory should under present conditions have much stronger explanatory power regarding the exchange rate than during earlier times. One consequence is that this theory should now also be of much greater interest to policymakers.

Figure 5 studies this question. The black solid line is our baseline and the red dotted line is an alternative with strong interest rate smoothing and a very small response to inflation, $m_i = 0.95$ and $m_\pi = 1.05$, with the blue dashed lines showing an intermediate case. In this case the response of the real policy rate is of course almost entirely driven by the drop in inflation. The behavior of the UIP monetary wedge is very similar to the baseline case, but this is now the dominant effect on the exchange rate, which appreciates very strongly on impact. Notice that this appreciation would not happen in the UIP case, despite the large change in the real interest rate due to inflation. The reason is that inflation would affect both domestic and foreign currency real interest rates in very similar ways, and there would be no need for the exchange rate to move very much, given that both domestic and foreign policy rates remain nearly constant and the MUIP wedge equals zero.

5.2 Money Demand Shocks

5.2.1 Home Increase in Demand for Both Currencies

Figure 6 studies the case of an increase in demand for liquidity in Home, where the increase in demand does not distinguish between domestic and foreign currencies. But because the overwhelming majority of domestic money consists of domestic currency money, the main effect of the shock is of course on domestic currency positions.

An increase in liquidity demand represents a "flight to safety" shock, where households hold on to their liquidity, and have banks create more liquidity for them, but do not spend this liquidity at the same rate as before. In other words, money velocity declines, and this has contractionary effects on economic activity. In our specific example, we observe an increase in loans and deposits equal to around 1.5 percent of GDP due to higher demand, accompanied by a 0.3% contraction in GDP. For such shocks, the correlation between credit and economic activity is therefore the opposite to what we observed under credit supply shocks.

But more importantly for our purposes, the MUIP wedge is virtually unaffected, so that deviations from the case of pure UIP are only slight. This was however to be expected, because in this case the change in money demand affected domestic and foreign currency monies in the same way.

5.2.2 Home Increase in Demand for Foreign Currency

Figure 7 studies the case of an increase in demand for Foreign currency liquidity in Home. This shock is not accompanied by a corresponding change in banks' willingness to extend credit in either currency, and as a result loan supplies do not change markedly. Instead there is a strong shift from domestic currency to foreign currency deposits. Because this would, ceteris paribus, lead to a currency mismatch for banks that violates their FXMR, they respond by reducing their foreign currency interbank loans by a similar amount as the increase in foreign currency household deposits. There is comparatively little change in interbank deposits in either currency, because precautionary liquidity demand has only changed by relatively small amounts. At the same time, because this shock does not lead to a large impact change in the net foreign asset position, which consists of the net sum of the four interbank items, the balance sheet item that responds to the reduction in foreign currency loans is domestic currency loans to foreign banks, which also fall.

As for the MUIP wedge, it increases by around 100 basis points on impact. This happens despite the fact that domestic currency deposits drop strongly relative to foreign currency deposits, and the reason is that what matters is the size of this drop relative to the drop in the home bias parameter, which is even stronger. In other words, domestic currency is still abundant relative to households' demand, which means that their convenience yield drops and their required relative return increases. Because this shock has only modest effects on inflation (besides a one-off base effect due to the sharp depreciation on impact) and therefore on the response of policy rates, this relative return can only increase through a decrease in the return on foreign currency assets, in other words through an expected appreciation. This however requires an initial exchange rate depreciation, in our example of just under 2%. That the exchange rate should depreciate when the relative demand for foreign currency assets increases is of course a highly intuitive result, but this result would not obtain in a pure UIP model.

5.3 Monetary Policy Shocks

Figure 8 studies the case of a contractionary interest rate shock[7]. We observe that this shock has only very small effects on the quantities of loans and deposits. It also has very minor effects on the MUIP wedge, and consequently our impulse responses would be virtually identical with a pure UIP model. This has two important implications.

First, if our model is correct, it implies that we can study standard business cycle shocks under the UIP assumption without much loss of generality, while we would obtain very misleading results for shocks that affect the relative supply or demand of different currencies. We will return to this below, for standard real shocks.

Second, it implies that the effect of the policy rate on credit supply and money demand are very weak, and that only autonomous sources of variation in these variables can explain large changes in financial sector balance sheets and spreads. This has important policy implications, because if correct it means that the policy rate does not mainly work, as often envisaged in central bank thinking, through changes in the willingness of banks to supply credit, or of borrowers to demand credit. Rather, it works very much through standard real rather than financial channels, namely by affecting the intertemporal substitution of consumers and the discount rate of investors. Again, if correct, this implies that other policy tools should be used to affect financial variables.

5.4 Real Shocks

Figures 9 and 10 study contractionary technology shocks and consumption demand shocks. The results are standard for the business cycle literature, and the deviations from the pure UIP case are minimal, similarly to monetary policy shocks above. Again, it is shocks that affect the relative supply or demand of different currencies that have by far the greatest effects on financial sector balance sheets, and that lead to the greatest deviations from uncovered interest parity.

[7] A contractionary shock to S_t^i would entail, ceteris paribus, an increase in the nominal interest rate. But due to the specification of the interest rate rule, there's an endogenous response to the drop in inflation, which is, however, more muted than in the absence of the shock.

6 Empirical Analysis

In this section we take some of the testable implications of our framework to the data. At the core of our model are three notions concerning money. First, money is largely created by banks in the course of credit extension. Second, money provides transactions services and therefore has a use value or convenience yield. Third, the transactions services provided by different currencies are imperfect substitutes, such that the relative price of these services depends on the balance of their relative demands and supplies. Together, this implies that shocks that affect banks' willingness or ability to extend credit will affect the supply of the currency created through that credit. To the extent that changes in the supply of credit occur asymmetrically across countries, this will affect the relative supply of different currencies, and thereby the relative return from holding them.

To test this implication we need three pieces of information. The first is a source of exogenous variation in **credit supply**, meaning in the relative willingness of the banks in two currency areas to extend credit. The second is a measure of the **relative returns** from holding different currencies. The third, ideally, is a model-consistent measure of the **relative money supply** that should mediate the impact of the former on the latter. We discuss these three issues next.

We begin with credit supply. The volume of bank credit is affected not only by supply but also by demand. Demand is influenced, among other things, by borrowers' prospects. Supply is influenced by the strength of both lender and borrower balance sheets, and by any applicable regulations. Crucially, the volume of bank credit and money will also be influenced by money demand, as a rise in money demand will tend to lower banks' funding costs and facilitate credit extension and hence an expansion of the money supply. This is why the relative quantity of money supply would not by itself be solely a measure of the relative abundance of the transactions services available in two currencies - the money supply and the relative price of a country's money could move because of demand as well as supply.

In addition to this identification problem, we also have a measurement problem. Standard measures of the money supply focus on the domestic-currency liabilities of banks to the domestic non-bank private sector. In contrast, in our model we also need information on the foreign-currency liabilities of home banks. Furthermore, because of the international arbitrage relationship between the Home and Foreign monetary UIP wedges, we also need the same information for foreign banks.

With this in mind, we focus instead on sources of exogenous variation in credit supply, and a direct mapping from these to relative currency returns, comparing £/$ relative nominal returns and exchange rates. Our measure of relative returns is the annualized 'UIP wedge'

$$\mathcal{W}_t^h = \frac{12}{h}\frac{E_{t+h} - E_t}{E_t} - \left(r_t^{h,UK} - r_t^{h,US}\right) \ , \tag{29}$$

the difference between the ex post change in sterling against the dollar and the ex ante interest-rate differential at a corresponding tenor, measured by taking the difference between sterling and dollar LIBOR at tenor h. This is conceptually close to the model-based monetary spread sp_t^{mon} introduced in the previous section.[8] The UK-US UIP wedge is plotted in Figure 11.

As we explain in more detail below, we use credit supply shocks as the best available measure of money supply shocks in the data. We make this choice because there are no widely accepted, direct measures of money supply shocks, in the sense of the term that is used in this study. Monetary supply shocks in the sense of, for example, Friedman (1968) correspond more closely to monetary *policy* shocks in modern parlance. Our model predicts that their effects are very different to the money supply shocks in the sense used here. We therefore focus on credit supply shocks, which affect the money supply through the money-creating effect of credit extension. Credit supply shocks can originate from changes in regulation or from changes in behavior in the banking sector. In the former case, we would have too few observations for any given country to yield well-determined estimates. In the latter case, it would be logical to use bank credit conditions surveys. However, outside the US, to our knowledge the length of the available time series it too short and/or the frequency is too low. Market-based measures —specifically bond spreads— are in contrast available at high frequency and for a long backrun. We therefore employ bond-based measures of bank credit conditions. These will be correlated with bank credit extension to the extent that bonds and loans are substitutes for both borrowers and investors.

To construct a measure of credit supply shocks we proceed by collecting data for the US Excess

8 We abstract from the prudential spread $sp_t^{prud^*}$ here, mainly because as in the model, this term is likely to be small for the shocks we are seeking to identify.

Bond Premium (EBP, see Gilchrist and Zakrajsek (2012)). This is the component of US corporate bond yields in excess of their 'fair' value, i.e. the compensation required in excess of their expected default losses. As Gilchrist and Zakrajsek (2012) show, fluctuations in the EBP are tightly linked to changes in the supply of credit. Anderson et al. (2018) apply the Gilchrist-Zakrajsek methodology to the UK, and derive a UK EBP measure constructed using Sterling-denominated corporate bonds issued by UK firms. Figure 12 plots the time series of the US and UK EBP, respectively. Because we are interested in the relative supply of sterling to US dollars, we project UK spreads on to their US analogues, and take the residuals (also shown in Figure 12) $\mathcal{S}_t$ as our measure of relative credit supply, and hence money supply, in the UK.

To flexibly estimate the dynamic response of the UIP wedge we estimate the following local projection model, following Jorda et al. (2005)):

$$sp^h_{t+j} = \beta_0 + \beta_1^{h,j}\mathcal{S}_t + \epsilon_t \ . \tag{30}$$

Here sp^h_{t+j} is the UIP spread at tenor h, measured starting j months after the shock —i.e., the excess return on £ assets vis a vis the \$ between periods $t+j$ and $t+j+h$.

Table 1 shows the resulting cumulative value of $\beta_1^{h,j}$ for $h = 1, 3, 6, 12$, $j = 1, 2, 3$. The table shows that a tightening of financial conditions (represented by a rise in $\mathcal{S}$ and measured using the UK-specific EBP) leads to a statistically significant fall in the monetary UIP spread, in other words to a reduction in the currency adjusted returns on sterling assets, at shorter tenors h of 1 and 3 months. It is worth emphasizing that shorter tenors correspond to more liquid, or money-like, assets, which means that both the sign of the result and its restriction to shorter tenors are consistent with our theory.

It is important to note that this negative return does not include the period in which the shock occurs. Furthermore, if the mechanism that generated these results were such that a rise in the relative risk premium on sterling assets generated a relative rise in the UK bond premia, we should expect the results to be of the opposite sign. Specifically, a higher bond spread would then lead to a rise in the UIP wedge, when in fact we observe a fall.

Turning to the economic significance of our results, the standard deviation of the UIP wedge is approximately 3 at the 1-month tenor, rising to 10 at the 12-month tenor, compared to 16 for the

UK-specific EBP. This means that a 1 standard deviation rise in the UK-specific EBP can reduce the 1-month UIP wedge by around 0.1 standard deviations. These are appreciable effects.

As a cross-check on our results, we repeat the estimation after substituting financial for monetary shocks, which according to our model should have no appreciable effect on the UIP wedge. As a measure of monetary policy shocks we use the 'high frequency' monetary surprises of Cesa-Bianchi et al. (2016), which exploit high frequency (i.e., 30-minute) changes in futures contracts around key monetary events to isolate monetary policy surprises (as, for example, in Gurkaynak et al. (2005)). Focusing on a tight window around these events helps to isolate monetary policy news from other types of shocks. Consistent with the predictions of our model, monetary shocks have no statistically significant impact, and the quantitative impact is smaller on average in absolute value (see Table 1, panel labelled 'HFI').

7 Conclusions

The monetary theory of exchange rate determination was very popular in the 1970s and 1980s. We argue that the theory underlying this literature had many strengths, but also two important shortcomings. The first is the assumption of fixed interest rates that do not, as in modern models built around a Taylor-type rule, systematically respond to the state of the economy. The second is the assumption that money is exogenous and created by the government, rather than, as in the real world and in the new class of financing through money creation models, being endogenous and created by commercial banks, through loans. Both of these shortcomings can be addressed in a modern DSGE open economy model, and we find that when this is done, we end up with a theory that is a hybrid between the monetary theory and more recent UIP-based approaches to exchange rate determination. Importantly, in an environment like the ZLB where policy rates lose their ability to systematically respond to the state of the economy, the transmission channel of the monetary approach dominates, which means that the relative demands and supplies of credit and money in different currencies become the critical determinant of exchange rates and of deviations from uncovered interest parity. On the other hand, for standard business cycle shocks there is little to distinguish our model from conventional open economy DSGE models.

The size of the deviations from uncovered interest parity, and the importance of shocks to relative demand and supplies of credit and money in different currencies, depend critically on the extent of substitutability between domestic and foreign bank liabilities. It is therefore promising that our first empirical results show a surprisingly strong relationship, with the sign predicted by our theory and with empirically meaningful magnitudes, between proxies of relative credit supply and deviations from uncovered interest parity, although much more work remains to be done to corroborate this result. We note however that such results are not contradicted by empirically successful tests of uncovered interest parity that use narrow, comparable asset classes in two different currencies. The reason is that our theory is based on the notion that the private sectors of the two economies need to absorb the entire spectrum of financial system liabilities offered by their respective banking systems. While perfect substitutability and therefore UIP is clearly a reasonable prior for narrow, comparable asset classes, this is not so for the asset classes that form the core of our model. We argue that imperfect substitutability must remain a reasonable prior for this case. The degree of substitutability that we have used to build our baseline simulations is broadly consistent with existing estimates of the interest semi-elasticity of money demand, and leads to very significant deviations from standard UIP-based theories of the exchange rate. To conclude, we want to highlight the two most interesting predictions of our theory. First, the sign of the response of the exchange rate to changes in the supply of credit and money is ambiguous. While a contraction in the supply of credit and money would lead to an unambiguous depreciation of the exchange rate in standard models built around the UIP relationship, in our model this depreciation is unambiguously weaker and hump-shaped, and furthermore it can turn to an appreciation if the degree of substitutability between different currencies is low, and if monetary policy loses its ability to respond systematically to the state of the economy. Second, the exchange rate responds to an increase in the demand for foreign currency through a depreciation, while in UIP-type models the exchange rate would not be affected by such shocks.

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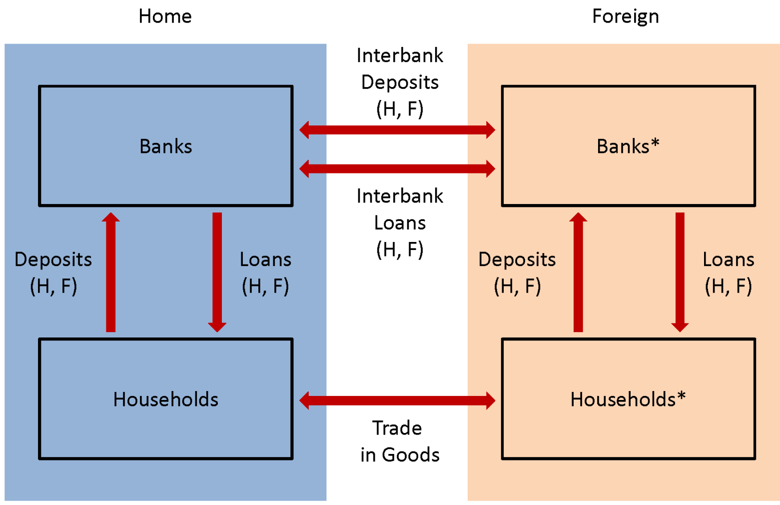

Figure 1: Overview of the Model Economy

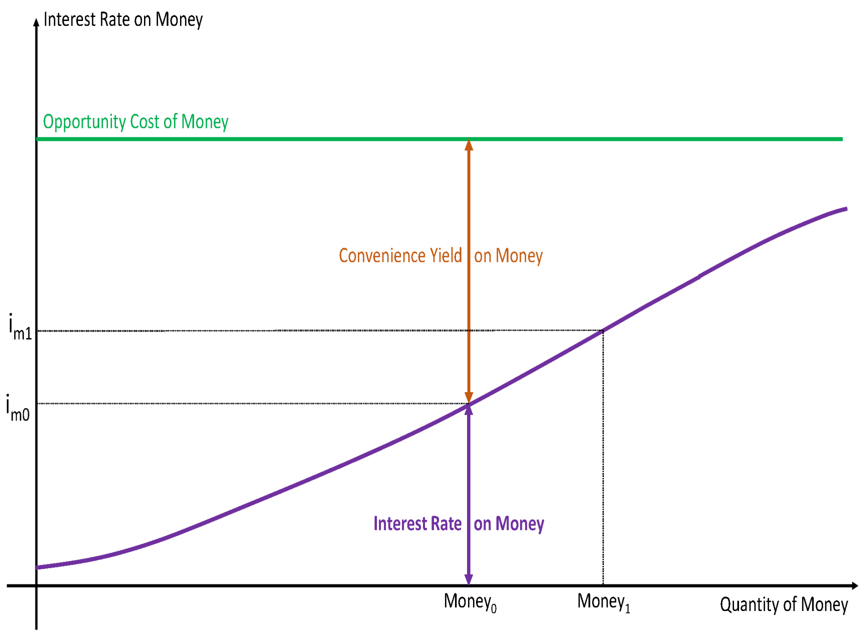

Figure 2: Interest Rate and Convenience Yield on Money

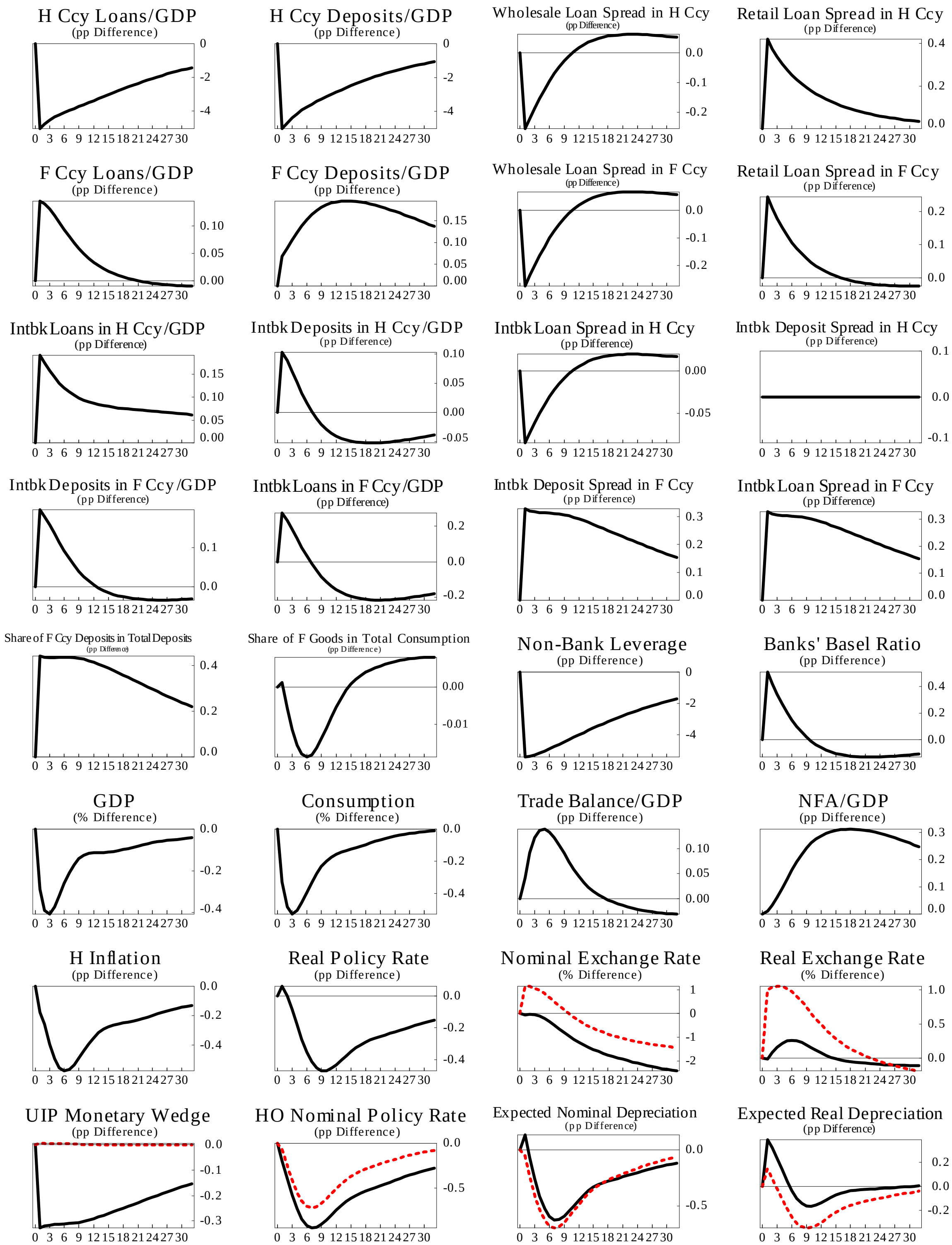

Figure 3: Negative Credit Supply Shock - Effects on Home

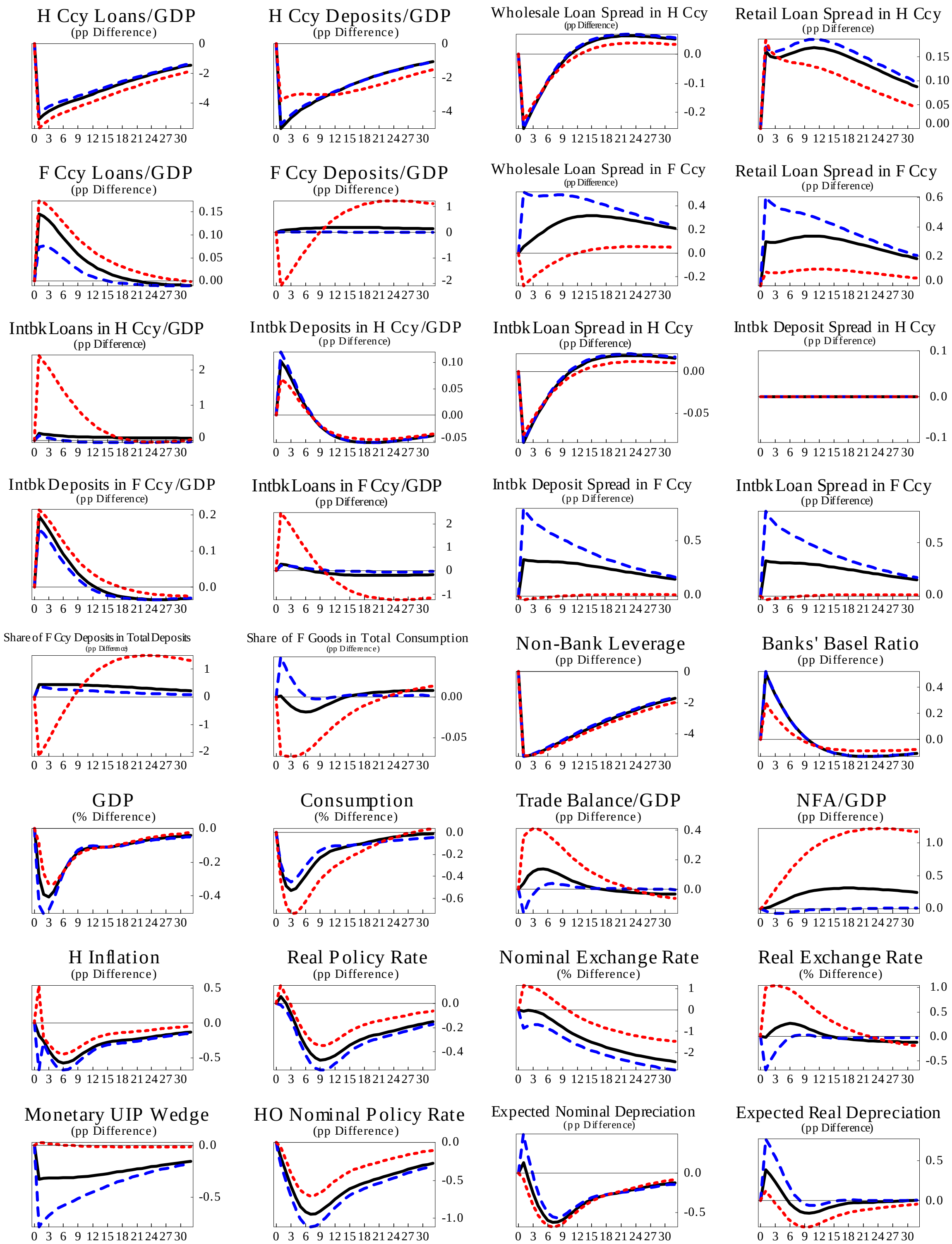

Figure 4: Negative Credit Supply Shock - Different θ_d

θ_d: __ = 1.5 (MUIP), - - - = 0.5 (XMUIP), ... = 100 (UIP)

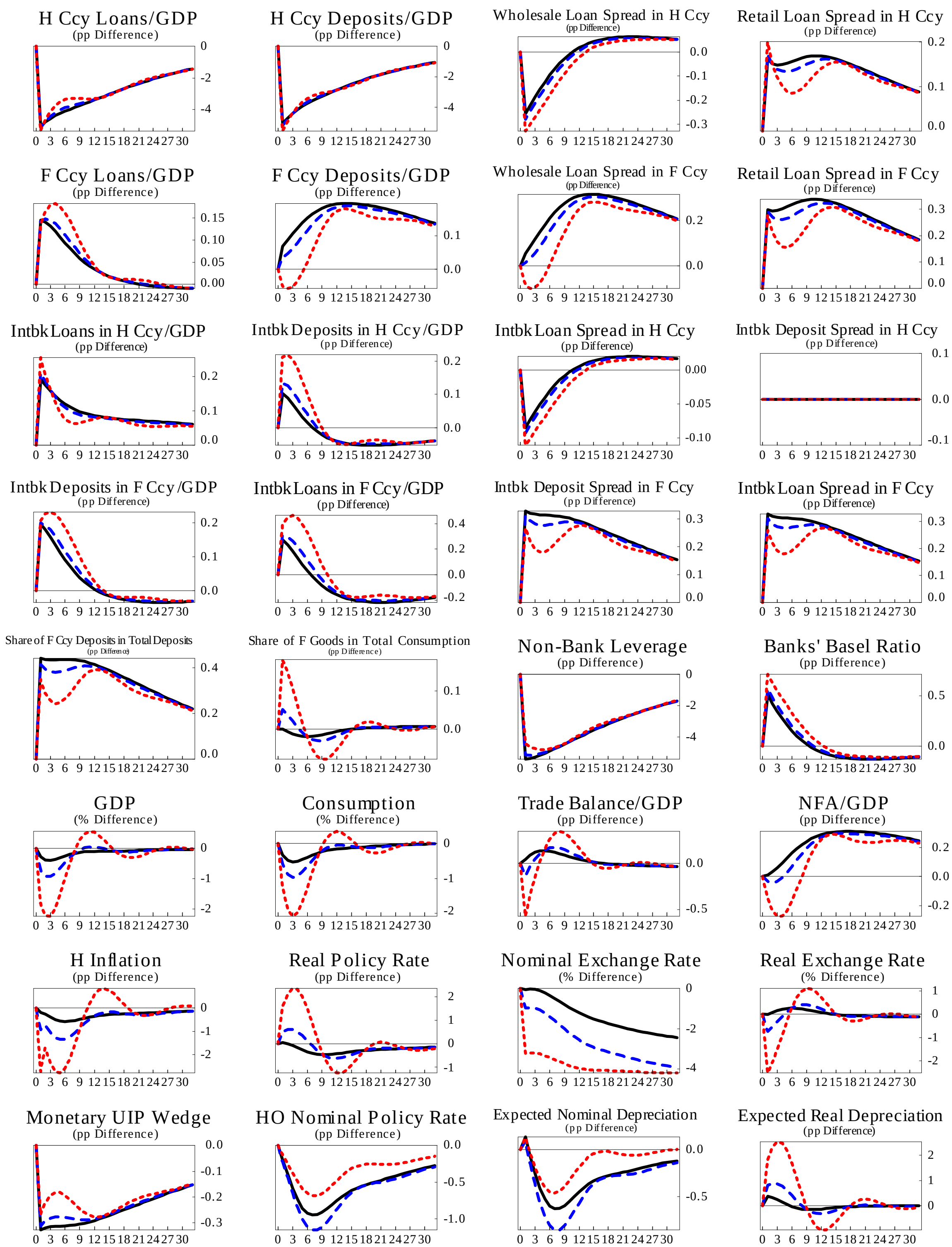

Figure 5: Negative Credit Supply Shock - Different m_i/m_π

m_i/m_π: __ = 0.7/2.0 (Baseline), - - - = 0.8/1.5, ... = 0.95/1.05

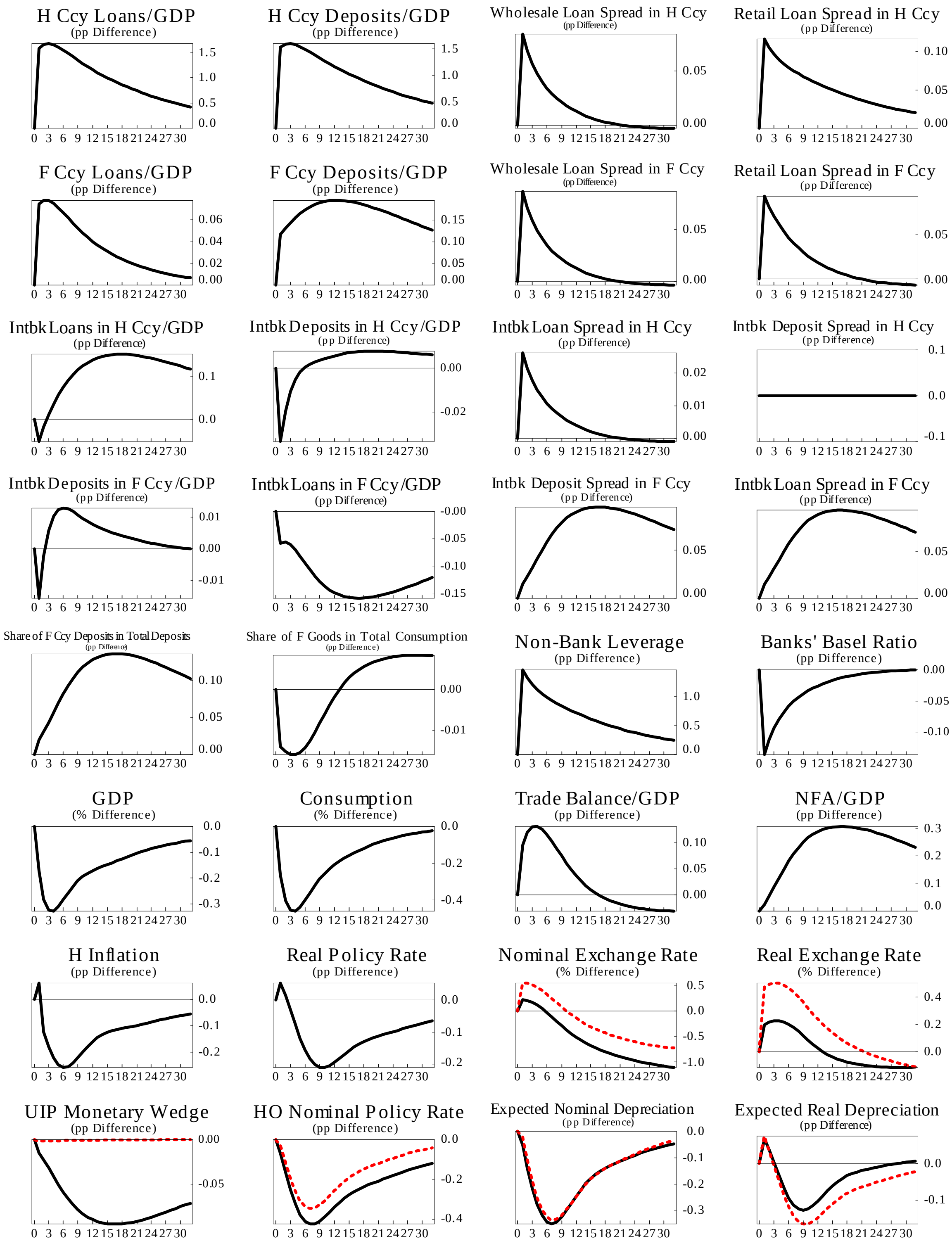

Figure 6: Increase in Home Money Demand

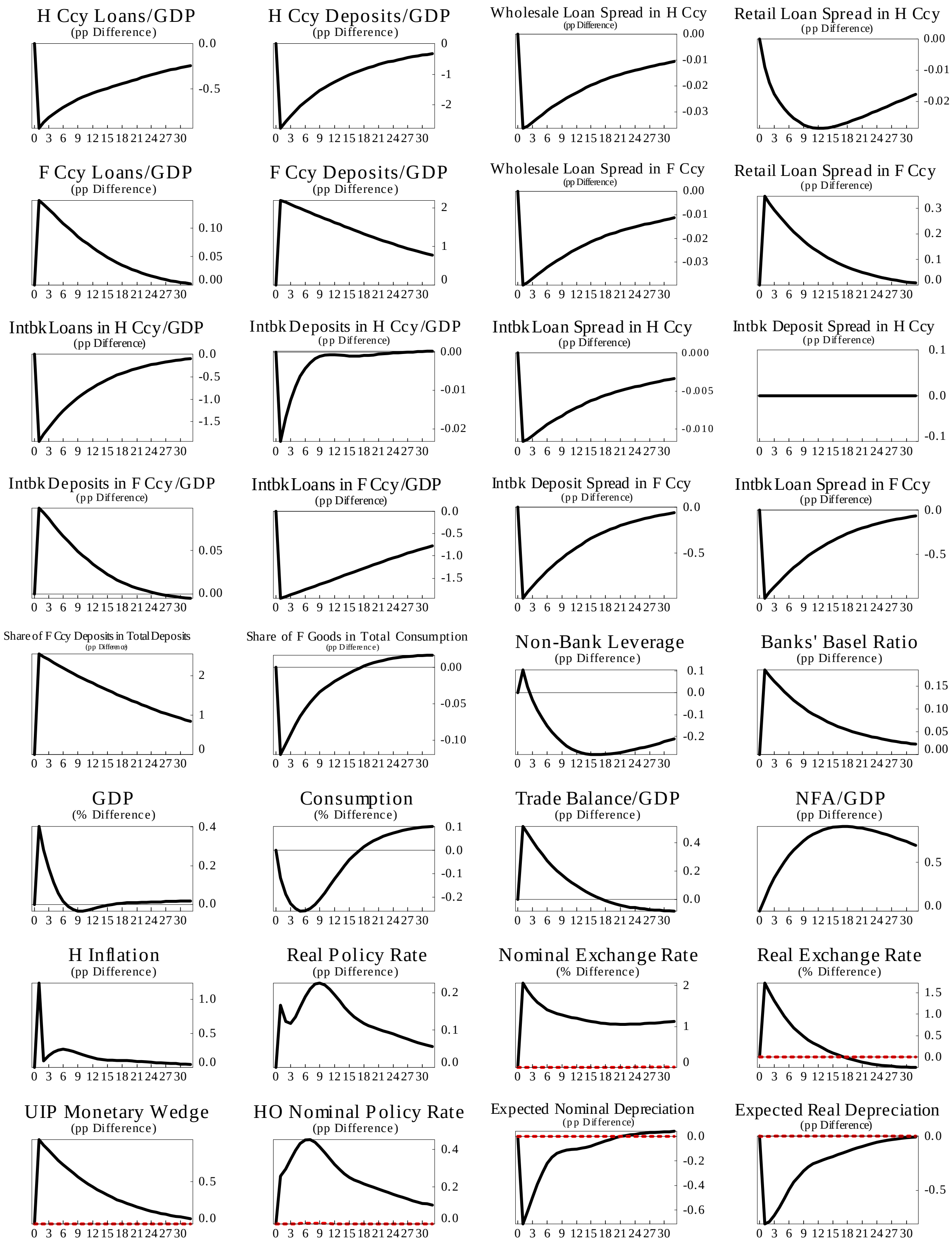

Figure 7: Increase in Home Demand for Foreign Currency

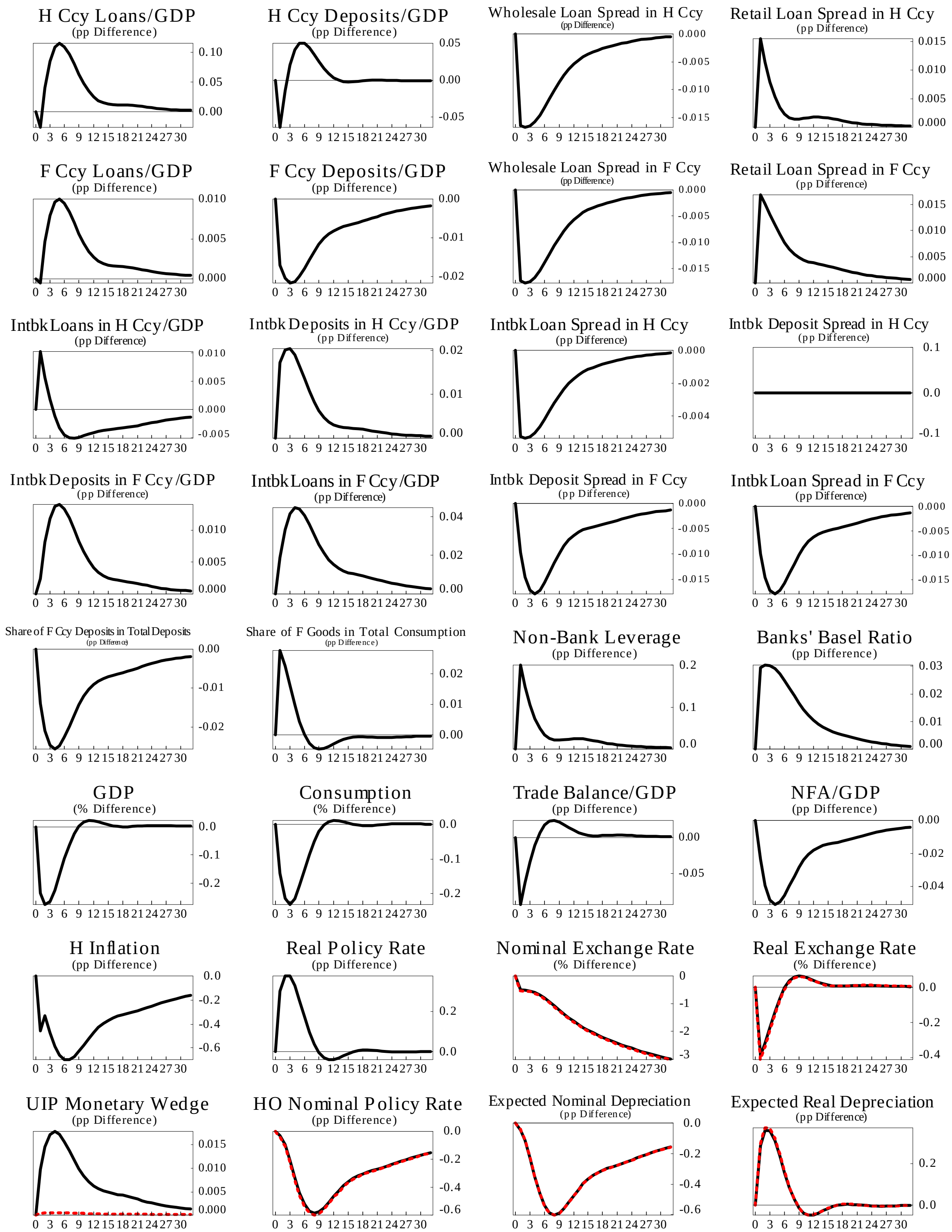

Figure 8: Contractionary Monetary Policy Shock

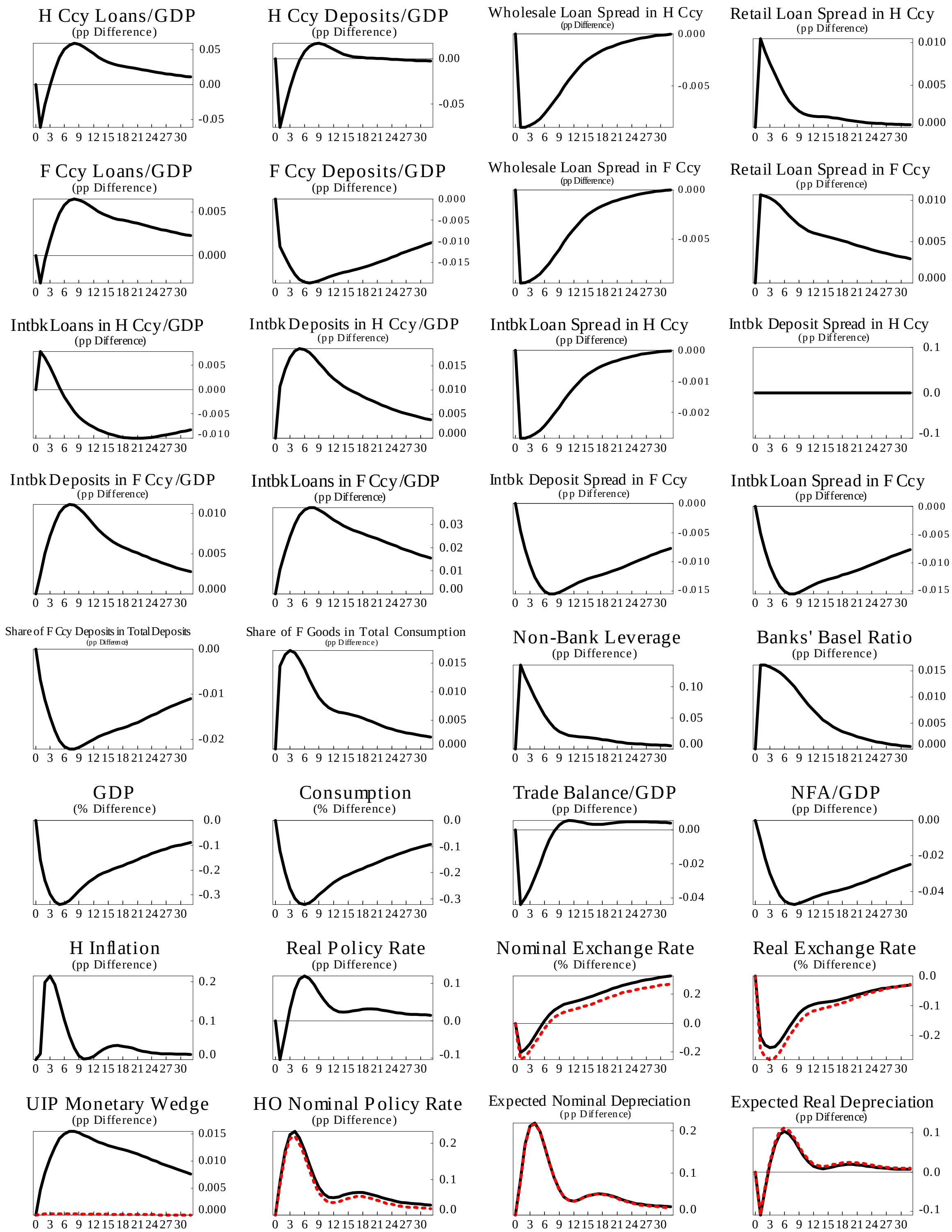

Figure 9: Contractionary Technology Shock

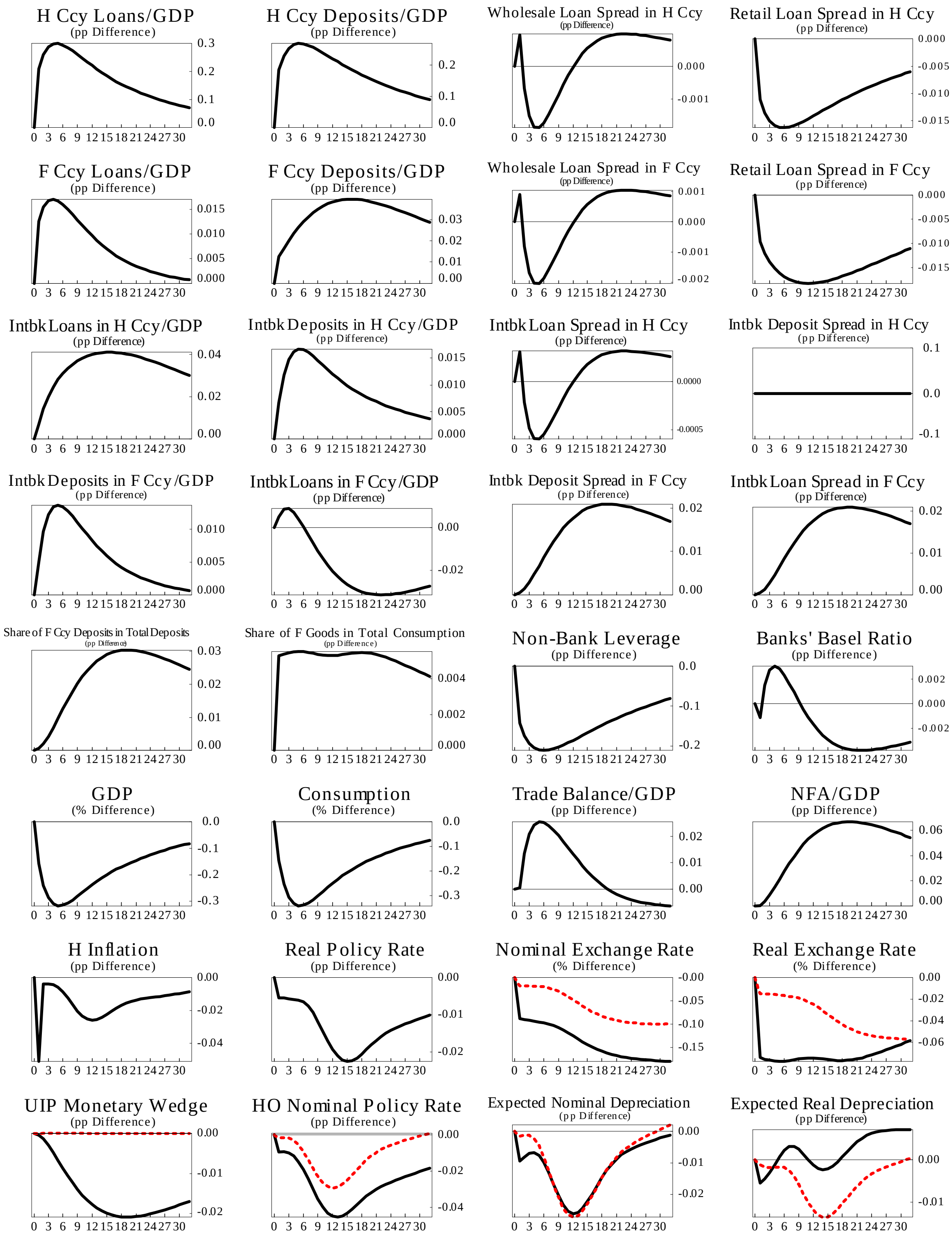

Figure 10: Contractionary Demand Shock

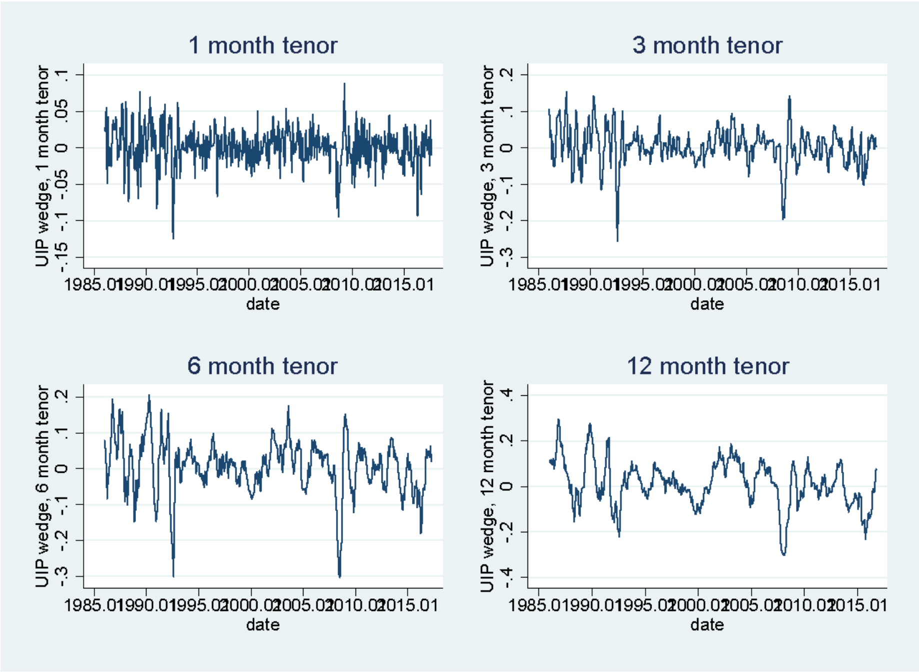

Figure 11: UIP Wedges

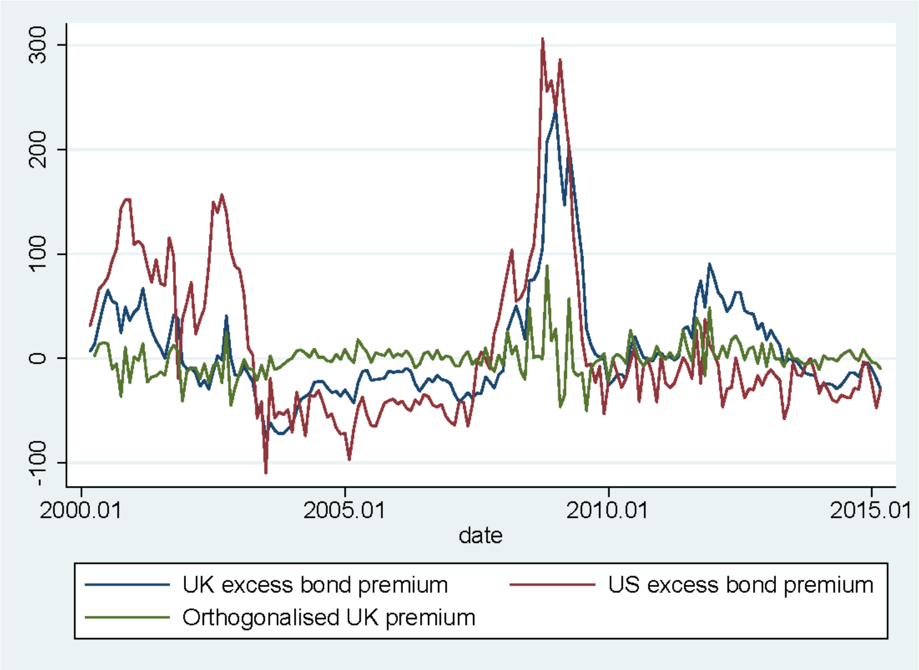

Figure 12: Excess Bond Premia

Table 1: Local projection of UIP wedge on financial and monetary shocks

			Cumulative IRF					
Shock	Tenor	Horizon	Mean	Std	Z	p val	CI lo	CI hi
EBP	1	1	-0.024**	0.012	-2.09	0.036	-0.047	-0.002
		2	-0.039**	0.017	-2.32	0.02	-0.072	-0.006
		3	-0.044**	0.021	-2.07	0.039	-0.086	-0.002
	3	1	-0.044**	0.021	-2.05	0.04	-0.086	-0.002
		2	-0.067*	0.040	-1.66	0.096	-0.145	0.012
		3	-0.049	0.057	-0.86	0.392	-0.160	0.063
	6	1	-0.014	0.033	-0.44	0.663	-0.079	0.050
		2	-0.014	0.064	-0.23	0.822	-0.139	0.110
		3	0.011	0.092	0.12	0.905	-0.169	0.191
	12	1	-0.038	0.042	-0.91	0.361	-0.120	0.044
		2	-0.048	0.082	-0.59	0.554	-0.209	0.112
		3	-0.026	0.120	-0.21	0.831	-0.261	0.210
HFI	1	1	0.053	0.044	1.22	0.224	-0.033	0.139
		2	0.062	0.063	0.97	0.331	-0.063	0.186
		3	0.117	0.079	1.49	0.137	-0.037	0.272
	3	1	0.117	0.079	1.49	0.136	-0.037	0.272
		2	0.190	0.148	1.28	0.199	-0.100	0.480
		3	0.163	0.210	0.78	0.436	-0.248	0.574
	6	1	-0.070	0.122	-0.58	0.563	-0.309	0.168
		2	-0.289	0.235	-1.23	0.219	-0.751	0.172
		3	-0.489	0.341	-1.43	0.152	-1.158	0.180
	12	1	-0.196	0.162	-1.21	0.227	-0.513	0.121
		2	-0.396	0.318	-1.24	0.213	-1.019	0.227
		3	-0.474	0.470	-1.01	0.313	-1.395	0.447