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Abstract

We study exchange rate determination in a 2-country model where domestic banks create each economy's supply of domestic and foreign currency. The model combines the UIP-based and monetary theories of exchange rate determination, but the latter with a focus on private rather than public money creation. The model features an endogenous monetary spread or excess return in the UIP condition. This spread experiences sizeable changes when shocks affect the relative supplies (of bank loans) or demands (for bank deposits) of the two currencies. Under such shocks, monetary effects dominate traditional UIP effects in the determination of exchange rates and allocations, and this becomes stronger as domestic and foreign currencies become more imperfect substitutes. With these shocks, the model successfully addresses the UIP puzzle, and it is also consistent with the Meese-Rogoff and PPP puzzles.

Key words: Bank lending, money creation, money demand, endogenous money, uncovered interest parity, exchange rate determination, international capital flows, gross capital flows.

JEL classification: E44, E51, F41, F44.

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1. Introduction

It is widely recognized that exchange rates are poorly explained by the macroeconomic fundamentals found in UIP-based theories of exchange rate determination, such as interest-rate differentials and relative supplies and demands of domestic and foreign output. Other, mainly financial, factors appear to play an important role, most importantly relative supplies and demands of financial assets and liabilities denominated in different currencies. The largest components of such financial positions are the liabilities, which we will generically refer to as bank deposits, and the assets, various types of bank loans and securities holdings, of national financial sectors. This paper focuses on the contribution of these assets and liabilities to exchange rate determination, in a model where the use of bank deposits reduces trading frictions in the real economy, and where bank loans are the means of creating bank deposits. This monetary focus does not discard traditional UIP-based theories but augments and improves upon them, and by doing so it simultaneously leads to an enhanced version of the monetary theory of exchange rate determination that was popular in the 1970s and 1980s. However, exchange rate determination is not driven by narrow monetary aggregates that are created by monetary authorities, as in the old monetary theory, but rather by broad monetary aggregates that are created by banks, and whose size is determined by the interaction of the profit-maximizing activities of banks and their customers.

Our conceptual framework therefore stresses two key features of financial sector assets and liabilities. First, virtually all financial sector liabilities (except equity) serve an important role in facilitating payments, both in payments for real goods and services and in payments for purely financial transactions, either directly or as collateral. As a result, bank deposits are demanded both for their financial or investment yield and for their liquidity or monetary convenience yield, where the latter depends on the quantity of deposits outstanding. This is an explicit ingredient of our model. Second, deposits in either currency are predominantly created (and destroyed) through the creation (and repayment) of loans in that currency, and also, but to a much lesser extent (see Jakab and Kumhof (2019)), through the purchase (and sale) of securities. This means that not only the demand for deposits by non-banks, in other words their willingness to hold deposits in different currencies, but also the supply of deposits by banks, in other words their willingness to create deposits in different currencies by creating the necessary loans, becomes an important source of shocks, and this also is an explicit ingredient of our model. We will henceforth treat the terms currencies and bank deposits interchangeably, because in our model economy, as in the real world, bank deposits are the principal form of money used in domestic and international trade. The paper therefore studies the role of the banking system in the determination of the exchange rate both as a transmission channel and as a source of shocks. The main financial shocks that thereby enter into the analysis are shocks to bank credit creation and therefore currency creation, and shocks to the demand for different currencies.

To study these ideas we join three previously separate strands of the literature. The first is the older literature on the monetary theory of exchange rate determination (Frenkel (1976), Mussa (1976), Frenkel and Mussa (1985), Boughton (1988)). This literature conceives of the exchange rate between two economies as being determined by the relative supplies and demands of the respective national currencies. To the extent that the two currencies are not perfect substitutes, their relative scarcity will affect their relative price – the exchange rate. The ingredients of this theory are an exogenous supply of money, a money demand that depends on output and the risk-free interest rate, risk-free interest rates that are treated as exogenous, a UIP condition between risk-free interest rates, a long-run PPP condition and rational expectations. In our view this literature had many merits, but they were at the time outweighed by theoretical and empirical shortcomings, and as a result this theory was largely abandoned. One shortcoming is that this theory typically assumes 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. This has long been addressed by the modern literature through the introduction of Taylor-type interest rate reaction functions, and we follow that literature in this paper. Another major shortcoming of this theory is that it has never been empirically successful, as documented by Meese and Rogoff (1983) and a long subsequent literature. But we would add another critical shortcoming, namely that the relevant money supply was assumed to be exogenous, and to consist of the narrow monetary aggregates created by the respective economies' central banks. It is well known that this component of the money supply typically accounts for well under 5% of the broad money supply in advanced economies. It is also well known, on both theoretical and empirical grounds[1], that there is no systematic money multiplier mechanism that links the supply of broad money to narrow money, so that a focus on narrow money is very likely to be misleading. What is needed is instead a theory of the creation of the broad money supply through the interactions of the profit maximization decisions of the banking system and its customers, and the consequences of such a theory for exchange rate determination. We offer such a theory in this paper.

The second related strand of literature is the modern literature on UIP-based theories of exchange rate determination. The ingredients of this theory are risk-free interest rates that are set according to monetary policy reaction functions, a UIP condition between risk-free interest rates, a long-run PPP condition and rational expectations, with no role for money supply and money demand. The introduction of monetary policy reaction functions is of course a gain, but we will argue that the discarding of the money market is a loss. But in addition, like monetary theories, UIP-based theories have not been empirically successful. What we will argue in this paper is that the combination of the modern UIP-based theory with a modernized monetary theory could represent a step forward for theories of exchange rate determination. This theory will have some similarities with the portfolio balance theory of exchange rate determination (Branson and Henderson (1985), Blanchard, Giavazzi and Sa (2005)), which was popular at around the same time as the monetary theory, had similar ingredients plus a role for relative securities supplies in the UIP condition, and which also suffered from a lack of empirical success. However, these similarities are superficial because the securities supplies in the UIP condition were typically of risk-free government securities, so that their demand was not based on a money demand motive while their supply was not determined by a banking sector that can rapidly change the size of its gross balance sheet positions but rather by a government that gradually accumulates a stock of debt through net flows of deficits. And, of course, like the monetary theory, the portfolio balance theory treated risk-free interest rates as exogenous rather than as set by a policy rule.

The third related strand of literature studies the sources and nature of money and credit in modern banking systems, specifically the endogenous creation of the money supply through the interaction of the profit-maximizing decisions of banks and their customers. This mechanism and its significance was very well understood by the leading macroeconomists in the decades following the Great Depression, including by Friedman (1948), and has recently been the subject of several central bank publications, including the Bank of England (McLeay, Radia and Thomas (2014a,b)), numerous papers by the Bank for International Settlements (see e.g. Borio and Disyatat (2011, 2015)), the Bundesbank (2017) and the Reserve Bank of Australia (Doherty et al. (2018)). Decker and Goodhart (2018) is another key contribution to this literature that supports our modeling approach. In the recent academic literature the same notion has been formalized by Goodfriend and McCallum

[1] Kydland and Prescott (1990), Brunner and Meltzer (1990), Goodhart (2007), Borio and Disyatat (2009) and Carpenter and Demiralp (2010).

(2007), Benes and Kumhof (2012), Jakab and Kumhof (2015, 2019), Faure and Gersbach (2017) and Kumhof and Wang (2019). Jakab and Kumhof (2019) refer to this as the financing through money creation model, or for brevity the financing model, of banking.

To bring these literatures together, we build a two-country two-good two-currency DSGE model. We use that model to study the effects of financial and real shocks on financial variables such as balance sheets and spreads, on non-financial variables such as current accounts and GDP, and finally on nominal and real exchange rates. In the model, domestic households borrow from domestic banks in both domestic and foreign currencies, and these loans create deposits in domestic and foreign currencies for the same domestic households. The cost of this liquidity creation to households is the loan-deposit interest rate spread charged by banks, while the benefit is the reduction in transactions costs for purchases of consumption goods. The cost of this liquidity creation to banks is the interest rate paid on deposits plus the 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 that collateral, and the tightness of banks' regulatory constraints on credit extension. The equilibrium quantity of credit and money is endogenous, as both banks and households trade off their respective costs and benefits, a point that is central to Decker and Goodhart (2018).

In modern financial markets domestic banks can create foreign currency in nearly the same way as domestic currency. This was emphasized as early as 1971, for the Eurodollar market, by Milton Friedman (1971), who also emphasized that the source of all currency creation is the "bookkeepers pen". The difference to domestic currency creation is that domestic banks do not have direct access to a lender of last resort in foreign currency. As an insurance against liquidity shocks in foreign currency, they therefore keep foreign currency interbank deposit balances with foreign correspondent banks, who in turn do have access to a lender of last resort in foreign currency. Interbank deposits are created by foreign banks in the same way as household deposits, through foreign currency loans. Gross interbank positions play a key role in our model because they allow for clearing of cross-border payments. They represent the only cross-border financial positions, as households are assumed to only maintain accounts with their domestic institutions. This is true even for payments in international goods trade, where export receipts are deposited with and import payments are withdrawn from domestic bank accounts, and settled by domestic banks with foreign correspondent banks. This has two important implications. First, the acquisition of foreign currency by domestic households does not necessitate any cross-border capital flows. When this currency is originally created by domestic banks, it does not even involve interbank cross-border flows, because it happens exclusively on domestic bank balance sheets, while when it is not originally created by domestic banks because it is received from foreigners as payment for goods, this will give rise to cross-border interbank positions, with the currency of denomination of such positions determined among other things by foreign exchange mismatch regulations. Second, cross-border financial flows that are not connected with any goods market transactions or interest payments correctly record the fact that such flows do not involve any change in net positions and therefore in resource flows, but that they rather represent the creation of two matching gross positions that net to zero. An example in our model is the creation of foreign currency interbank deposits by foreign banks for domestic banks, through foreign currency interbank loans. More complex cross-border flows that involve both households and banks are studied in a separate forthcoming paper (Kumhof et al. (2019)) that primarily focuses on capital flows, rather than on exchange rate determination as in the present paper.

An important prediction of our model is a direct role for relative supplies of and demands for bank-created currencies as drivers of the exchange rate. To show this analytically, we derive a monetary uncovered interest parity (MUIP) condition from the model's equilibrium conditions, and illustrate how an MUIP spread between the risk-free interest rates adjusted for expected exchange rate depreciation arises in response to shocks. The result is a theory in which exchange rates are determined by the interaction of interest differentials, relative demands for and supplies of goods, and relative demands for and supplies of currencies. The relative importance of these factors depends on the nature of the shocks, but all factors are present at all times. We study this mechanism in the data, focussing on currency-specific credit supply shocks. We find supportive evidence for the role of such shocks in determining MUIP spreads and by implication exchange rates. We also show that this theory is capable of addressing several puzzles in open economy macroeconomics. We focus mainly on the UIP puzzle, and find that shocks to relative currency demand and relative currency supply give rise to a negative coefficient on interest differentials in Fama (1984) regressions. To interpret these shocks, we note that shocks to currency demand are due to shifts in investor sentiment, while shocks to currency supply are due to shifts in banks' lending behavior.

We conclude this introduction with an important observation concerning the UIP condition. Tests of UIP typically use nominal interest rates on narrow, comparable asset classes in two different currencies, such as risk-free government securities of equal tenor, together with the corresponding changes in the nominal exchange rate. We know that these tests tend to fail empirically. However, our interpretation of this failure relies on a different hypothesis from that of UIP tests. The hypothesis of the latter is that the exchange rate is expected to adjust to make agents indifferent between holding not the two currencies per se, but the narrow, comparable assets in those currencies. However, at the macroeconomic level a more reasonable hypothesis is that the exchange is expected to adjust so that the private sectors of the two economies are willing to absorb the entire spectrum of assets offered by the global financial system in these two currencies. These assets range from highly liquid assets with low interest rates to less liquid assets with higher interest rates. Perfect substitutability between such broad asset classes is not an obvious prior. Putting this differently, if the exchange rate does adjust in the sense that we suggest, then there is no reason to expect that UIP will hold for any specific pair of comparable assets. But more interestingly, as we will show in this paper, under such conditions the deviations from UIP between risk-free government securities will exhibit *systematic* deviations from UIP that depend on the relative supply of and demand for the entire spectrum of assets that is available in the two currencies.

The remainder of this paper is structured as follows. Section 2 provides a review of the related recent literatures on banking and on exchange rate determination in open economies. Section 3 presents the model. Section 4 discusses its calibration. Section 5 takes our predictions for credit supply shocks to the data. Section 6 studies the response of the model to currency supply shocks, currency demand shocks and standard business cycle shocks. Section 7 studies the extent to which our model can address a number of exchange rate related puzzles that have been discussed in the literature. Section 8 concludes.

2. Related Literature

2.1. The Open Economy Banking Literature

Kollmann et al. (2011) and Kollmann (2013) incorporate a single global bank into a two-country business cycle model. In their model the global bank collects deposits from households in both countries, makes loans to entrepreneurs in both countries, and is subject to a capital requirement. Kalemli-Ozcan et al. (2013) develop a general equilibrium model of international business cycles where banks intermediate funds between households and firms. Their model nests the case of financial autarky, in which all banks only operate domestically, and the case of full financial integration, in which all banks are global and all consumers and firms in both countries have financial transactions through the same set of banks. Bruno and Shin (2015) develop a partial equilibrium model of the international banking system where firms get funding in foreign currency from global banks (via local banks), and banks operate under a value at risk constraint. Aoki et al. (2018) and Akinci and Queralto (2018) develop New Keynesian open economy models where financial intermediaries fund domestic capital investment by obtaining deposits from home households and borrowing from foreigners. A key feature of these models is that home deposits are denominated in home currency while foreign borrowings are denominated in foreign currency. Cesa-Bianchi et al. (2018) build a small open economy model where a representative global bank funds its activity with a mix of equity and deposits raised in the rest of the world, and then lends to domestic agents both in domestic and foreign currency.

There are several differences between this literature and our paper. Perhaps most importantly, we model banks as creators of deposits of digital currency, created through Friedman's (1971) bookkeeper's pen as in Jakab and Kumhof (2019) and Kumhof and Wang (2019), rather than as intermediaries of deposits of physical savings as in this literature. The willingness of households to hold deposits is therefore not determined by their preferences over net physical flows of resources, but rather by their preferences over gross financial stocks of asset and liability ledger entries, where the asset ledger entries serve as a means of payment for physical resources but are not themselves accumulated as physical resources. This implies that banks have the ability to create currency deposits instantaneously through the creation of matching asset and liability ledger entries, as opposed to the much slower creation of savings deposits through deposits of physical resources in other models. The dynamic effects especially of credit supply shocks, but also of all other shocks, are therefore fundamentally different from other models. Households' preferences over asset and liability stocks give rise to a monetary spread in the UIP condition, and as such our paper is related to the literature that studies such spreads, such as the above-mentioned Akinci and Queralto (2018), as well as Itskhoki and Mukhin (2017), Eichenbaum et al. (2018) and Valchev (2019), which are discussed in the next subsection. Another difference is that we explicitly model domestic and foreign banks and their interactions by way of correspondent banking arrangements, rather than relying on a model of global banks. This allows us to keep track of gross capital flows between countries, a topic that is increasingly recognized as being important.

2.2. The Recent Theoretical Literature on Exchange Rate Determination

The introduction reviewed the original monetary and portfolio balance theories of exchange rate determination. In this subsection we review the recent literature on the related question of whether financial shocks can be important drivers of exchange rates, and whether they can contribute to addressing some of the well-known puzzles of open economy macroeconomics. There have recently been several important contributions to this literature.

Rossi (2013) provides a comprehensive and relatively recent review of the empirical literature on exchange rate predictability. She finds that while Taylor rule fundamentals (inflation gaps and output gaps) and net foreign assets have shown some success at forecasting exchange rates, traditional fundamentals, including differentials of interest rates, inflation rates, output, productivity, bond stocks and money stocks, have continued to perform much more poorly, as first pointed out by Meese and Rogoff (1983). The results concerning money stocks do not however speak directly to our paper. First, while we emphasize the importance of money stocks, Rossi's measure of the money stock is M1, rather than the broad measure of financial sector liabilities that would correctly proxy for money in our model. Second, following the monetary theory of exchange rates, her measure is of domestic and foreign money stocks, rather than, as in our model, of the domestic and foreign currency components of the domestically and foreign held money stocks.

Itskhoki and Mukhin (2017) observe that conventional 2-country DSGE models have long suffered from a number of exchange-rate-related puzzles, including not only the already mentioned Meese-Rogoff disconnect puzzle but also the PPP puzzle, the terms-of-trade puzzle, the Backus-Smith puzzle and the UIP puzzle. They then demonstrate that when, and only when, such models are augmented by an exogenous shock to international asset demand, all of these puzzles can be addressed. In their optimality conditions this shock appears as an exogenous wedge in the UIP condition. This is a powerful result, and it is directly related to our paper because this exogenous relative asset demand shock corresponds to the endogenous relative convenience yield spread in our model. This therefore responds to the call in the conclusion of Itskhoki and Mukhin (2017) that a microfoundation for the financial shock is essential especially for normative analysis, because it may endogenously interact with government or central bank policy, as is indeed the case in our model.[2] We have found that our model has a similar ability to account for the UIP puzzle through international asset demand shocks, but that international asset supply shocks also have that ability. Furthermore, like in Itskhoki and Mukhin (2017), the model addresses the UIP puzzle without significantly altering the transmission mechanism for standard open economy business cycle shocks because, conditional on a shock, the model relies on a transmission mechanism with mostly conventional ingredients.

An important advantage of our model is that it incorporates a completely specified banking sector, with banks whose lending and deposit activity directly interacts with the real economy, and with households whose preferences are over the gross asset and liability positions offered by that sector rather than only about their net foreign currency exposures. In fact, in our model net foreign asset and net foreign currency positions are accounting residuals that can be computed from various gross positions, with households only deciding on their gross asset and liability positions vis-à-vis banks. Our model features rich two-way interactions between the real and banking sectors, and several novel structural shocks in the banking sector. Financial cycles driven by currency supply as well as currency demand become an important driver of UIP deviations and exchange rate changes, and our empirical evidence confirms that credit supply does indeed play a role in driving UIP deviations and therefore, by implication, exchange rate movements. The deeper point is that in models where both relative goods and relative asset and liability demands and supplies affect equilibrium allocations, the exchange rate is determined through the interaction of both goods and currency markets, but with the former more important for standard business cycle shocks and the latter more important for financial shocks. This is true even under complete goods market autarky,

[2] Itskhoki and Mukhin (2017) also present a financial sector extension in the spirit of Gabaix and Maggiori (2015), which we will discuss below.

where Itskhoki and Mukhin (2017) find that, with an exogenous UIP wedge, the nominal exchange rate is of no consequence to the rest of the economy. In our model, with an endogenous UIP wedge, this is not the case as long as households continue to hold both currencies, because in this case the exchange rate affects the real economy through its effects on the banking sector. In our model complete autarky requires both goods market and currency market autarky.

Engel (2016) studies the paradox of the coexistence of the UIP puzzle, whereby high interest currencies tend to have positive current excess returns, and a real exchange rate puzzle, whereby high interest currencies tend to have a stronger real exchange rate than can be accounted for by the path of their interest differentials alone. The paradox is that the former implies a positive covariance between the currency's interest differential and its current excess return, while the latter implies a negative covariance between the interest differential and the undiscounted sum of future excess returns. Existing models that successfully address the UIP puzzle, through mechanisms and shocks that simultaneously increase the interest differential and the excess return, can therefore not account for the real exchange rate puzzle. The same is true for our model, where in response to currency demand shocks and currency supply shocks, which are successful at addressing the UIP puzzle, the MUIP spread, which corresponds to the excess return on domestic currency, does not change sign at some point during the transition. Sequences of shocks that give rise to financial cycles would address this problem.

Gabaix and Maggiori (2015) is another key contribution to the recent literature. To our knowledge this is the first theoretical model to explain exchange rate determination based on both financial flows and goods flows. In this model financiers are the only agents that can have balance sheets with mismatched currency exposures, while households can only hold their domestic currency. Financiers face credit constraints because they are known to be able to divert a portion of the funds on their balance sheet. As a result they have limited capacity to expand their balance sheet, and demand higher returns for larger exposures. This allows the model to successfully address the UIP puzzle as well as exchange-rate driven feedback effects between financial shocks and real outcomes.[3] In Gabaix and Maggiori (2015) imperfect currency substitutability is related to risk, specifically to the limited capacity of financiers to bear exchange rate risk that is due to offsetting balance sheet positions in two currencies, while in our paper imperfect currency substitutability is related to liquidity, specifically to non-banks experiencing diminishing marginal usefulness of the two currencies as transactions media. The banks in our model play a fundamentally different role to the financiers of Gabaix and Maggiori (2015), due to two assumptions. First, banks in our model, as in practice, face regulatory limits on mismatched currency exposures, although our simplified representation of these regulations is stricter than what is found in most countries.[4] Second, their balance sheets, again as in practice, exhibit positive gross asset and liability positions for each currency, unlike the financiers of Gabaix and Maggiori (2015), who are always short one currency and long another. In terms of our model the financiers of Gabaix and Maggiori (2015) are therefore part of the household sector, and that household sector is able to take gross asset and liability positions in both currencies.

[3] Similarly, Amador et al. (2017), Cavallino (2019) and Fanelli and Straub (2018) study the role of exchange rate intervention policies in models where the presence of financial constraints and/or asset market segmentation can introduce violations of international arbitrage. In these models changes in the portfolio of the central bank can induce UIP deviations. By contrast, in our paper we focus on UIP deviations generated by endogenous changes in the balance sheet of the financial sector.

[4] See Hofstetter et al. (2018).

In Valchev (2019) imperfect currency substitutability is, as in our model, related to liquidity. The paper studies a two-country two-currency DSGE model with convenience yields of different currencies and finds that this offers a promising explanation for the UIP puzzle. Similar to our model, liquidity is needed to economize on the cost of consumption, while the key difference is that the assets yielding liquidity services are cash and government bonds, with no role for bank liabilities, as banks are absent from the model. Our reason for making banks a key part of a model of relative liquidity services is that bank liabilities are used in the vast majority of goods and financial market transactions in any modern economy, while cash only accounts for a very minor share. As for government securities, they are primarily used for financial markets transactions, they are mostly not directly held by households but rather by financial institutions, and they are a very slow-moving variable because they are accumulated through flows of net fiscal deficits over time. Bank deposits on the other hand can be, and are, much faster-moving because they are created almost exclusively through loans, that is through instantaneous changes in gross stock positions on bank balance sheets. The latter difference between the two models becomes evident in the elasticity of substitution between different currencies that must be calibrated in the two models in order to obtain sizeable exchange rate volatility. In Valchev (2019) that elasticity is extremely low, so that even the empirically observed and comparatively small quarter-on-quarter changes in government debt can have large effects on relative convenience yields, while in our model that elasticity is several times larger, because empirically observed quarter-on-quarter changes in bank deposits are frequently very large.

Eichenbaum et al. (2018) document two new facts concerning real and nominal exchange rates, for a cross section of economies with flexible exchange rates and inflation targeting regimes. First, the real exchange rate is negatively correlated with future changes in the nominal exchange rate, the more so the longer the horizon. Second, the real exchange rate is virtually uncorrelated with future inflation rates at all horizons. These correlation patterns reverse for economies with a fixed exchange rate regime, where the real exchange rate is correlated with future inflation rates, but not with the nominal exchange rate. The authors then develop a DSGE model that can quantitatively account for these facts, featuring Calvo-style nominal wage and price rigidities and habit formation in consumption. The model is not only consistent with the high correlation between real and nominal exchange rates, but it also matches the persistence of the real exchange rate and the short-run failure of UIP. To obtain deviations from the UIP condition, instead of introducing a shock directly into the UIP condition, the authors assume that households derive utility from domestic bond holdings and that this utility flow varies over time. The standard deviation of their UIP shock is calibrated to match the coefficient of the Fama (1984) regression. Eichenbaum et al. (2018) is related to our paper in that they provide a microfoundation for the UIP spread. However, like in Valchev (2019), their spread is ultimately based on the stock of government bonds, rather than on the liabilities of the banking sector as in our paper.

Finally, in a recent empirical paper, Schmitt-Grohé and Uribe (2018) compare the effects of transitory and permanent monetary policy shocks on exchange rates and currency excess returns, and find that they have opposite effects, with permanent monetary tightening leading to a short-run depreciation of the exchange rate and UIP deviations against domestic assets. We use our model to study transitory and permanent monetary policy shocks, and find the same qualitative results as in Schmitt-Grohé and Uribe (2018).

3. The Model

3.1. Overview

The world economy consists of two countries, Home and Foreign, with respective shares in the world population of n and $1-n$. Each country is populated by households, manufacturers, unions, banks and a government. Except for their share in the world population the two countries are symmetric in economic structure and in the calibration of key parameters.

Households in each country own the domestic stock of land, which serves as both an input into the production of domestic output and as collateral for borrowing from domestic banks.[5] Output is produced using labor in addition to land. Household income consists of land rents, wages and lump-sum profit distributions from manufacturers, unions and banks. Households consume a composite of imperfectly substitutable domestic and foreign goods, and they purchase these goods by using a composite of imperfectly substitutable domestic and foreign currency deposits. Manufacturers and unions have pricing power, and set prices and wages subject to nominal rigidities. Monetary policy targets inflation by setting the risk-free interest rate according to an inflation-forecast-based interest rate rule. The model abstracts from all fiscal considerations.

The key feature of the banking sector is that its non-equity liabilities, which we will generically refer to as deposits, serve as the economy's sole medium of exchange in purchases and sales of goods. Deposits are perceived to be safe due to minimum capital adequacy requirements (MCAR) that ensure a zero risk of default (capital dropping below 0% of assets) for banks. Banks optimally limit their leverage to minimize the risk of regulatory penalties for MCAR violations (capital dropping below 8.5% of assets), thereby limiting the amount of credit and money creation. Regulations also include foreign exchange mismatch regulations (FXMR), which require banks to match overall balance sheet exposures in foreign currency at all times. The specification of the medium of exchange function of bank liabilities in the model is based on the Schmitt-Grohé and Uribe (2004) transactions cost technology. As shown in Kumhof and Wang (2019), this is a shortcut for a more decentralized representation where banks serve as intermediaries between different spenders of circulating bank deposits. Our model merges these multiple spenders into a single representative household in the spirit of Lucas (1990) and Schmitt-Grohé and Uribe (2004).

Households bank exclusively with banks in their own country but require liquidity in both domestic and foreign currencies to purchase domestic and foreign consumption goods. Domestic banks therefore issue loans in both currencies to create deposits in both currencies, and the liquidity that is jointly created by these two types of deposits lowers transactions costs for consumption goods purchases. 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 bank deposits. Both are treated in the model as CES aggregates with a finite elasticity of substitution. Therefore, while in typical open economy models the exchange rate is determined by relative supplies and demands of goods together with the interest parity condition, in our model it is determined by relative supplies and demands of both goods and bank deposits, with an interest parity condition that now contains a monetary wedge.

Because the focus of this paper is mainly on exchange rate determination rather than on international capital flows, we assume that households do not engage in cross-border borrowing and lend-

[5] We abstract from capital accumulation mainly for simplicity. However, we note that a large share of developed countries' capital stock consists of real estate whose main component, land, is in fixed supply, as in our model.

ing.[6] Instead, only the banking sectors have financial exposures to the foreign economy, through cross-border interbank markets in the two currencies. Specifically, banks in each country issue interbank loans and accept interbank deposits in their domestic currency to banks of the other country. This gives rise to a total of four gross interbank positions (two banks, two currencies) between countries. In a 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. This setup implies that the net foreign asset position of a country equals the net interbank position of its banking sector. A schematic representation of the model is shown in Figure 1.

3.2. Conventions and Assumptions

Wherever possible our model description focuses only on the domestic economy, which is referred to as Home where this is necessary for clarity, with symmetry implying identical equations for the foreign economy, which is referred to as Foreign where necessary. Where interactions between Home and Foreign are described, superscript asterisks * indicate Foreign variables. We observe the convention that a real normalized variable is the nominal variable divided by the CPI price level P_t and the level of world productivity T_t, where all nominal loans and deposits are divided by the CPI price level pertaining to their currency of denomination. The exogenous and constant growth rate of world productivity 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, $e_t = (E_t P_t^*)/P_t$. Nominal variables are denoted by upper case letters, real variables are denoted by the corresponding lower case letters[7], real normalized variables are denoted by the symbol for the corresponding real variable with an added inverse hat symbol above the variable, and steady state variables replace the inverse hat with a bar. Home and Foreign goods production/consumption and Home and Foreign currency asset/liability balance sheet positions are indicated by the subscripts H and F, and superscripts b indicate interbank positions. For the example of domestic and foreign currency deposits held by Home households we therefore have $\check{d}_{H,t} = d_{H,t}/T_t = D_{H,t}/(T_t P_t)$ and $e_t \check{d}_{F,t} = e_t d_{F,t}/T_t = (E_t D_{F,t})/(T_t P_t)$. 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 in Home 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 describe original optimization problems in nominal and agent-specific form, while optimality conditions are shown in real, normalized and aggregated form.

3.3. Banking Sector

The banking sector has three functions. The first is wholesale lending and wholesale deposit issuance, where banks choose the overall size of the balance sheet to maximize net worth. This maximization is subject to foreign currency mismatch regulation (FXMR), which requires banks

[6] International capital flows, in a model which features cross-border financial exposures by households, is the subject of forthcoming work by Kumhof et al. (2019). We note that in the principal developed economies more than 50% of all cross-border liabilities of banks are interbank positions.

[7] For loans, the nominal and real symbols are L and ℓ.

to eliminate foreign currency mismatches on their balance sheet, foreign currency monetary transactions costs (MONFX), which requires banks to maintain correspondent accounts with foreign banks in order to compensate for the absence of a lender of last resort in foreign currency, and minimum capital adequacy regulation (MCAR), which imposes penalties on banks whose capital drops below a specified minimum percentage of total assets. The second and third functions of the banking sector are retail lending and retail deposit issuance, where banks set 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 banking system. Banks in Home and Foreign each extend loans and create deposits in the currencies of both Home and Foreign, and where possible we will use a single subscript $X \in \{H, F\}$ to indicate symmetric conditions for both currencies. Superscripts x are used to indicate interbank positions, $x = b$, while positions vis-à-vis households have no superscripts, $x = \emptyset$.

3.3.1. Wholesale Banks

Wholesale banks have unit mass and are indexed by j, where individual banks differ by the size of their net worth. Wholesale banks issue wholesale loans in Home and Foreign currencies, $L_{H,t}(j)$ and $L_{F,t}(j)$, to domestic retail lending banks. Home wholesale banks also issue interbank loans in Home currency $L^b_{H,t}(j)$ to foreign wholesale banks, and hold interbank deposits in Foreign currency $D^b_{F,t}(j)$ at foreign retail deposit banks. Their financing consists of wholesale deposits in both currencies, $O_{H,t}(j)$ and $O_{F,t}(j)$, from domestic retail deposit banks, interbank loans in Foreign currency $L^b_{F,t}(j)$ from foreign wholesale banks, and net worth $N^b_t(j)$, which is held by domestic households. Then an individual wholesale bank's balance sheet is given by

$$L_{H,t}(j) + E_t L_{F,t}(j) + L^b_{H,t}(j) + E_t D^b_{F,t}(j) = O_{H,t}(j) + E_t O_{F,t}(j) + E_t L^b_{F,t}(j) + N^b_t(j) \ . \quad (1)$$

We can derive an expression for the banking sector's aggregate balance sheet by using the results of subsections 3.3.2 and 3.3.3 on retail deposit and retail lending banks to consolidate the wholesale and retail sectors. Specifically, we set $O_{H,t}(j) = D_{H,t}(j) + D^b_{H,t}(j)$ and $O_{F,t}(j) = D_{F,t}(j)$, where $D_{H,t}(j)$ and $D_{F,t}(j)$ are retail deposits from domestic households in Home and Foreign currencies, and note that the symbols for wholesale and retail loans are identical. After aggregating over all banks, we obtain

$$L_{H,t} + E_t L_{F,t} + L^b_{H,t} + E_t D^b_{F,t} = D_{H,t} + E_t D_{F,t} + D^b_{H,t} + E_t L^b_{F,t} + N^b_t \ . \quad (2)$$

FXMR requires that wholesale banks' foreign currency net liabilities vis-à-vis non-banks must be matched fully by foreign currency net assets vis-à-vis foreign banks,

$$D^b_{F,t}(j) - L^b_{F,t}(j) = O_{F,t}(j) - L_{F,t}(j) \ . \quad (3)$$

MONFX reflects the fact that for wholesale banks foreign currency exposures to non-banks are costlier than domestic currency exposures. The reason is the absence of a lender of last resort in foreign currency, which requires that banks maintain readily accessible foreign currency liquidity in foreign banks. This is modelled as a monetary transactions cost that is increasing in foreign currency loans to households $L_{F,t}(j)$ and decreasing in interbank foreign currency liquidity $D^b_{F,t}(j)$. We choose the functional form for the total cost of $s^b_t(j) L_{F,t}(j)$, where

$$s^b_t(j) = \frac{\varphi_b}{\vartheta_b} \left(\check{d}^b_{F,t}(j) \right)^{-\vartheta_b} \ . \quad (4)$$

MCAR limits wholesale banks' ability to create credit and money. Bank j faces a future penalty if net worth in the following period should fall short of γ times risk-weighted assets, where the size of the penalty equals of $\chi \frac{P_{t+1}}{P_t} \left[L_{H,t}(j) + E_t L_{F,t}(j) + L^b_{H,t}(j) + E_t D^b_{F,t}(j) \right]$, and where the regulatory risk weight on loans to households equals one while the regulatory risk-weight on interbank positions equals $\zeta < 1$. The penalty is payable if

$$\begin{aligned} & \left[i_{\ell H,t} L_{H,t}(j) + E_{t+1} i_{\ell F,t} L_{F,t}(j) + i^b_{\ell H,t} L^b_{H,t}(j) + E_{t+1} i^b_{dF,t} D^b_{F,t}(j) \right] \omega^b_{t+1} \\ & - i_{oH,t} O_{H,t}(j) - E_{t+1} i_{oF,t} O_{F,t}(j) - E_{t+1} i^b_{\ell F,t} L^b_{F,t}(j) \\ & - E_{t+1} s^b_t(j) L_{F,t}(j) + P_{t+1} \left(\Pi^R_{t+1}(j) - \Lambda^\ell_{t+1}(j) \right) \\ & < \gamma \left[i_{\ell H,t} L_{H,t}(j) + E_{t+1} i_{\ell F,t} L_{F,t}(j) + \zeta \left(i^b_{\ell H,t} L^b_{H,t}(j) + E_{t+1} i^b_{dF,t} D^b_{F,t}(j) \right) \right] \omega^b_{t+1} \ . \end{aligned} \tag{5}$$

Here the terms $\Pi^R_{t+1}(j) - \Lambda^\ell_{t+1}(j)$ represent 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. The variable ω^b_{t+1} is a log-normally distributed idiosyncratic shock to the loan return with mean 1 and variance $\left(\sigma^b\right)^2$. It can reflect a number of individual bank characteristics, such as differing success at raising non-interest income and minimizing non-interest expenses, where the sum of the two equals zero over all banks. We denote the pdf and cdf of the idiosyncratic shock by $f^b\left(\omega^b_{t+1}\right)$ and $F^b\left(\omega^b_{t+1}\right)$. The lagged condition (5) implicitly defines a cutoff loan return shock $\bar{\omega}^b_t$ below which regulations are breached and the penalty has to be paid, and we define $f^b_t \equiv f^b\left(\bar{\omega}^b_t\right)$, $F^b_t \equiv F^b\left(\bar{\omega}^b_t\right)$ for future reference. The closed-form expression for $\bar{\omega}^b_t$ is omitted to conserve space.

The objective function for net worth maximization of an individual wholesale bank j takes into account two arbitrage conditions on wholesale interest rates. First, for an individual retail deposit bank, investments in wholesale deposits in domestic currency and in domestic government bonds are perfect substitutes, so that the equilibrium nominal interest rate on domestic currency wholesale deposits $i_{oH,t}$ must equal the policy rate i_t. Second, for an individual domestic wholesale bank, funding through wholesale deposits in foreign currency from domestic retail deposit banks and through interbank loans in foreign currency from foreign wholesale banks are perfect substitutes, so that the equilibrium nominal interest rate on foreign currency wholesale deposits $i_{oF,t}$ must equal the interbank lending rate in foreign currency $i^b_{\ell F,t}$.

Net worth maximization involves taking first-order conditions with respect to all four asset side items. Banks internalize the risk of breaching the MCAR, so that expected net worth includes the penalty payable if a breach occurs, weighted by the probability of a breach. We have the maximization problem for pre-dividend next-period net worth

$$\max_{\left\{ \begin{array}{c} L_{H,t}(j),\ L_{F,t}(j), \\ L^b_{H,t}(j),\ D^b_{F,t}(j) \end{array} \right\}} \mathbb{E}_t \left[\begin{array}{c} \left[i_{\ell H,t} L_{H,t}(j) + E_{t+1} i_{\ell F,t} L_{F,t}(j) + i^b_{\ell H,t} L^b_{H,t}(j) + E_{t+1} i^b_{dF,t} D^b_{F,t}(j) \right] \omega^b_{t+1} \\ - i_t O_{H,t}(j) - E_{t+1} i^b_{\ell F,t} O_{F,t}(j) - E_{t+1} i^b_{\ell F,t} L^b_{F,t}(j) \\ - E_{t+1} s^b_t(j) L_{F,t}(j) + P_{t+1} \Pi^R_{t+1}(j) - P_{t+1} \Lambda^\ell_{t+1}(j) \\ - P_{t+1} \int_0^{\bar{\omega}^b_{t+1}(j)} \frac{\chi}{P_t} \left(L_{H,t}(j) + E_t L_{F,t}(j) + L^b_{H,t}(j) + E_t D^b_{F,t}(j) \right) f^b\left(\omega^b_{t+1}\right) d\omega^b_{t+1} \end{array} \right], \tag{6}$$

where the wholesale deposit terms must be replaced using a combination of the balance sheet identity (1) and the FXMR rule (3). We arrive at post-dividend net worth by deducting dividends that equal a fixed fraction of net worth, and which are paid out to households in a lump-sum fashion, a specification that can be obtained by applying the "extended family" approach of Gertler and Karadi (2011). The law of motion for net worth is not shown to conserve space.

Optimization yields first-order conditions that we show in full, because they reveal important details concerning the structure of interest rate spreads. We can drop individual indices and show the conditions in real normalized form because in equilibrium the ratios to net worth of loans, deposits, retail deposit profits and retail lending losses are identical across banks. We adopt the shorthand notation $\check{\ell}^{\ell}_t = \check{\ell}_{H,t} + e_t\check{\ell}_{F,t} + \check{\ell}^b_{H,t} + e_t\check{d}^b_{F,t}$ for aggregate total real assets, which is the basis to which the regulatory penalty parameter χ is applied. The expressions involving the symbol $\check{\Omega}$ are the partial derivatives of $\bar{\omega}^b_{t+1}$ with respect to the four components of total assets. We note that these terms are always positive, that they are very 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, due to a much lower regulatory risk weight ζ on interbank positions.

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

$$\mathbb{E}_t \left\{ r_{\ell H,t+1} - r_{t+1} - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}_{\ell H,t} \check{\ell}^{\ell}_t \right) \right\} = 0 \; . \tag{7}$$

This condition shows that there is a *regulatory spread* $\chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}_{\ell H,t} \check{\ell}^{\ell}_t \right)$ between the domestic currency wholesale lending rate and the policy rate. Specifically, the wholesale lending rate compensates wholesale banks for the fact that that at the margin an additional loan increases the penalty payable in case of a breach of MCAR. The size of this spread depends on a combination of the size of the MCAR, γ (this enters $\check{\Omega}_{\ell H,t}$), the penalty payable in case of a breach of MCAR, χ (this also enters $\check{\Omega}_{\ell H,t}$), and the likelihood of a breach given the riskiness of individual banks, F^b_{t+1} and f^b_{t+1}.

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

$$\mathbb{E}_t \left\{ (r_{\ell F,t+1} - r_{t+1}) - \left(r^b_{\ell F,t+1} - r_{t+1} \right) - \frac{\varepsilon_{t+1}}{\pi^p_{t+1}} s^b_t - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}_{\ell F,t} \check{\ell}^{\ell}_t \right) \right\} = 0 \; . \tag{8}$$

While the regulatory spread $\chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}_{\ell F,t} \check{\ell}^{\ell}_t \right)$ is virtually identical in size to that of domestic currency wholesale loans, this condition contains two additional spreads. First, the overall spread is not relative to the policy rate but relative to the interest rate on foreign currency wholesale interbank loans $r^b_{\ell F,t+1}$, with the difference between these two rates representing an additional *interbank borrowing spread* $\left(r^b_{\ell F,t+1} - r_{t+1} \right)$. The reason is that $r^b_{\ell F,t+1}$ is the marginal cost of financing additional foreign currency wholesale loans, and $r^b_{\ell F,t+1}$ is set by foreign banks to include a regulatory spread (this will be discussed from the point of view of domestic banks below, see (9)). Second, an additional *interbank monetary spread* $\left(\varepsilon_{t+1}/\pi^p_{t+1} \right) s^b_t$ arises because an increase in foreign currency exposures to households must be matched with a costly increase in foreign currency interbank liquidity.

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

$$\mathbb{E}_t \left\{ r^b_{\ell H,t+1} - r_{t+1} - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}^b_{\ell H,t} \check{\ell}^{\ell}_t \right) \right\} = 0 \; . \tag{9}$$

The difference to the condition for domestic currency wholesale loans is that the regulatory spread for interbank loans $\chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}^b_{\ell H,t} \check{\ell}^{\ell}_t \right)$ is significantly smaller, due to a much lower risk weight ζ (this enters $\check{\Omega}^b_{\ell H,t}$). As discussed in connection with (8), for banks in Foreign the interest rate $r^b_{\ell H,t+1}$ represents the marginal cost of financing Home currency wholesale loans, and also Home currency interbank deposits (this will be discussed from the point of view of domestic banks below, see (10)).

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

$$\mathbb{E}_t \left\{ \left(r^b_{dF,t+1} - r_{t+1} \right) - \left(r^b_{\ell F,t+1} - r_{t+1} \right) - \frac{\varepsilon_{t+1}}{\pi^p_{t+1}} s^{b\prime}_t \check{\ell}_{F,t} - \chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}^b_{dF,t} \check{\ell}^\ell_t \right) \right\} = 0 \; . \tag{10}$$

The *interbank borrowing spread* $\left(r^b_{\ell F,t+1} - r_{t+1} \right)$ is the same as for foreign currency wholesale loans, and is present for the same reason. The *regulatory spread* $\chi \left(F^b_{t+1} + f^b_{t+1} \check{\Omega}^b_{dF,t} \check{\ell}^\ell_t \right)$ is virtually identical in size to that of domestic currency interbank loans. In equilibrium the sum of these spreads is however more than offset by the *interbank monetary discount* $\left(\varepsilon_{t+1}/\pi^p_{t+1} \right) s^{b\prime}_t \check{\ell}_{F,t}$. The reason for this discount is that holdings of foreign currency interbank deposits reduce the cost of foreign currency exposures to non-banks, with $s^{b'}_t (\cdot) < 0$.

3.3.2. Retail Deposit Banks

There are two retail deposit banking sectors, one for domestic currency deposits and the other for foreign currency deposits. Retail deposit banks in each sector have unit mass and are indexed by j, where individual banks differ by the deposit variety they offer. Domestic currency retail deposit banks issue retail deposit varieties in domestic currency to domestic households, and interbank deposit varieties in domestic currency to foreign wholesale banks. Foreign currency retail deposit banks issue retail deposit varieties in foreign currency to domestic households. Domestic currency retail and interbank deposits finance purchases of domestic currency wholesale deposits and government bonds, where the latter are 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 an individual domestic currency retail deposit bank is therefore given by $O_{H,t}(j) + B_t(j) = D_{H,t}(j) + D^b_{H,t}(j)$, with $B_t(j) = 0$ in a symmetric equilibrium, and that of an individual foreign currency retail deposit bank is $O_{F,t}(j) = D_{F,t}(j)$. As explained above, arbitrage implies that $i_{oH,t} = i_t$ and $i_{oF,t} = i^b_{\ell F,t}$. Depositors demand a CES composite of all deposit varieties in a given currency, and retail deposit banks behave as monopolistic competitors in the three segments of the domestic currency deposit market. This implies the pricing rules for deposits

$$\begin{aligned} i_{dH,t} &= \mu_{dH} i_t \; , \\ i_{dF,t} &= \mu_{dF} i^b_{\ell F,t} \; , \\ i^b_{dH,t} &= \mu^b_{dH} i_t \; , \end{aligned} \tag{11}$$

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

3.3.3. Retail Lending Banks

There are two retail lending banking sectors, one for domestic currency loans and the other for foreign currency loans. Borrowers of retail lending banks have unit mass and are indexed by j, where individual borrowers differ by the size of their internal funds. Retail lending banks themselves are homogenous, and each of them lends equal amounts to any given borrower j. The function of retail lending banks is to set the terms of domestic and foreign currency loan contracts. The set-up of these problems is formally very similar to Bernanke et al. (1999), henceforth BGG, whose set-up we follow and extend.

The collateral for a loan contract between retail lending banks and borrower household j is the value of land $Q_t k_t(j)$, where Q_t is the nominal price of land and $k_t(j)$ is the stock of land owned by household j, where the aggregate stock of land k_t is constant in aggregate. 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 does not need to equal 100% in steady state. Specifically, domestic retail lending banks allow borrower j to pledge a time-varying share $\kappa_{X,t}$ of land to collateralize loans $L_{X,t}(j)$. 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' willingness to lend against a given stock of collateral. We will adopt the second interpretation here and refer to shocks to $\kappa_{X,t}$, which follows a first-order autocorrelated process, as willingness-to-lend shocks. Shocks to $\kappa_{X,t}$ are one of the two types of credit supply shocks in our model.

Land yields a nominal return that includes both appreciation Q_t/Q_{t-1} and rent R_t^k/Q_{t-1}, with nominal return $Ret_{k,t} = \left(Q_t + R_t^k\right)/Q_{t-1}$ and real return $ret_{k,t} = Ret_{k,t}/\left(x\pi_t^p\right)$. Borrowers in currency X at time t are subject to idiosyncratic productivity shocks $\omega_{X,t+1}^k$ that are log-normally distributed with mean 1 and stochastic variance $(\sigma_{X,t}^k)^2$. We denote the pdf and cdf of these shocks by $f^k(\omega_{X,t+1}^k)$ and $F^k(\omega_{X,t+1}^k)$ and the cutoff productivity shocks below which bankruptcy occurs ex-post by $\bar{\omega}_{X,t}^k$, and we define $f_{X,t}^k = f^k(\bar{\omega}_{X,t}^k)$ and $F_{X,t}^k = F^k(\bar{\omega}_{X,t}^k)$ for future reference. We will refer to shocks to $\sigma_{X,t}^k$, which follows a first-order autocorrelated process, as borrower riskiness shocks. Shocks to $\sigma_{X,t}^k$ are the second type of credit supply shocks in our model.

Loan contracts stipulate non-contingent retail lending rates $i_{rX,t}$ on loans $L_{X,t}(j)$ that must be paid in full if the realization of the shock $\omega_{X,t}^k$ is sufficiently high to avoid bankruptcy. Borrowers decide to declare bankruptcy if their individual productivity shock remains below a cutoff value $\bar{\omega}_{X,t}^k$, below which handing over the entire value of the project to the bank becomes preferable to realizing the project and repaying the loan. We omit the closed form expression for $\bar{\omega}_{X,t}^k$ to conserve space. In case of bankruptcy, because of monitoring costs, the bank can only recover a fraction $1-\xi_X$ of the project value, where ξ_X is the loss-given-default percentage. 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 that would apply to riskless borrowers (not present in the model). Letting $E_{H,t+1} \equiv 1$ and $E_{F,t+1} = E_{t+1}$, banks' participation constraints for retail loans in both currencies are

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

This states that the wholesale return on a loan $L_{X,t}(j)$ must equal 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 value of pledged collateral (note the parameter $\kappa_{X,t}$)[8] net of monitoring costs (note the parameter ξ_X) recoverable in case of default.

[8] Note that while the borrower j for the two loan types is the same, the land stocks pledged for the two loan types ($\kappa_{H,t} Q_t k_t(j)$ and $\kappa_{F,t} Q_t k_t(j)$) are separate.

These constraints can be rewritten as

$$\mathbb{E}_t \left[\kappa_{X,t} Ret_{k,t+1} Q_t k_t(j) \left(\Gamma^k_{X,t+1}(j) - \xi_X G^k_{X,t+1}(j) \right) - E_{X,t+1} i_{\ell X,t} L_{X,t}(j) \right] = 0 \;, \qquad (12)$$

where $\Gamma^k_{X,t+1}(j)$ denotes lenders' gross share in pledged earnings of land, and $\xi_X G^k_{X,t+1}(j)$ denotes lenders' monitoring costs share in pledged earnings of land. This states that ex-ante net lending losses must equal zero. Ex-post net lending losses can be different from zero because lending rates are non-contingent. Retail lending banks are fully owned by wholesale banks, and their net aggregate loan losses $\check{\Lambda}^\ell_t$ are transferred to the latter in a lump-sum fashion. The participation constraints (12) enter into households' optimization problems, and affect their decision rules for land and loans.

3.3.4. Interbank Market

Domestic and foreign banks are linked via interbank relationships. For Home, the nominal interest rates on foreign currency interbank loans and deposits are identical to those 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 $\check{\ell}^b_{F,t} = \check{\ell}^{b*}_{F,t} \left((1-n) / n \right)$ and $\check{d}^b_{F,t} = \check{d}^{b*}_{F,t} \left((1-n) / n \right)$. Analogous relationships hold for Home currency interest rates and Home currency balance sheet positions of banks in Foreign.

3.4. Households

3.4.1. Optimization Problem

Households have unit mass and are indexed by j. Households maximize lifetime utility, subject to sequences of intertemporal budget constraints and bank participation constraints, by choosing plans for consumption $c_t(j)$, hours worked $h_t(j)$, loans in both currencies $L_{X,t}(j)$, deposits in both currencies $D_{X,t}(j)$, and land holdings $k_t(j)$. Their consumption bundle is a CES physical aggregate that includes both domestic and foreign goods $c_{H,t}(j)$ and $c_{F,t}(j)$. They face monetary transaction costs for purchases of the consumption bundle that are decreasing in a CES monetary aggregate that includes the purchasing power of both domestic and foreign currency deposits $D_{H,t}(j)$ and $E_t D_{F,t}(j)$. The objective function for domestic household j is

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \left(1 - \frac{\nu}{x}\right) S^c_t \log\left(c_t(j) - \nu c_{t-1}\right) - \psi \frac{h_t(j)^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right\} \;, \qquad (13)$$

where ν parameterizes external habit persistence, η is the elasticity of labour supply, ψ is a labour supply scale parameter, and S^c_t is a first-order autoregressive process for shocks to consumption demand. The CES consumption bundle, with consumption home-bias parameter b^c and elasticity of substitution θ_c, is given by

$$c_t(j) = \left[(b^c)^{1/\theta_c} \left(c_{H,t}(j)\right)^{\frac{\theta_c - 1}{\theta_c}} + (1-b^c)^{1/\theta_c} \left(c_{F,t}(j)\right)^{\frac{\theta_c - 1}{\theta_c}} \right]^{\frac{\theta_c}{\theta_c - 1}} \;, \qquad (14)$$

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 elasticities of substitution θ_p. We make the conventional assumption that $\theta_p > \theta_c$.

Households demand a monetary aggregate that consists of domestic and foreign currency deposits, and that reduces the monetary transactions costs of purchasing the bundle of consumption goods. The functional form for the transactions cost technology is a simplified version of the one used in Schmitt-Grohé and Uribe (2004),[9]

$$s_t^h(j) = A^h S_t^{md} v_t^h(j) \quad , \quad v_t^h = \frac{P_t c_t(j)}{D_t^{liq}(j)} \; , \tag{15}$$

where A^h is a parameter that determines the steady state size of overall money demand, $v_t^h(j)$ is the endogenous velocity of circulation of money, and S_t^{md} is a first-order autoregressive process for shocks to the aggregate demand for money. We will think of the latter as a "flight to safety" shock, because an increase in S_t^{md} can be thought of as an increase in the demand for the safety of money, in either currency, at a given level of real activity. In equilibrium this will reduce both real activity and the velocity of circulation. The nominal CES monetary aggregate over Home and Foreign currency deposits, with financial home bias parameter b^d and elasticity of substitution θ_d, is given by

$$D_t^{liq}(j) = \left[\left(b^d S_t^{mm} \right)^{1/\theta_d} \left(D_{H,t}(j) \right)^{\frac{\theta_d - 1}{\theta_d}} + \left(1 - b^d S_t^{mm} \right)^{1/\theta_d} \left(E_t D_{F,t}(j) \right)^{\frac{\theta_d - 1}{\theta_d}} \right]^{\frac{\theta_d}{\theta_d - 1}} \; , \tag{16}$$

where S_t^{mm} is a first-order autoregressive process for shocks to the demand for foreign versus domestic currency. We will think of the latter as a "flight to the dollar" shock, because a decrease in S_t^{mm} can be thought of representing an increase in the demand for foreign versus domestic currency, at a given level of real activity. In equilibrium the main effect of this shock will be a depreciation of the domestic currency, with the size of the depreciation depending on the substitutability θ_d between domestic and foreign currency. For future reference, the derivatives of real liquidity $\check{d}_t^{liq}(j)$ with respect to its two arguments are denoted by $d_t^{\prime H}(j)$ and $d_t^{\prime F}(j)$.

The representative household's nominal flow budget constraint can be shown to be

$$\begin{aligned} & D_{H,t}(j) + E_t D_{F,t}(j) + Q_t k_t(j) - L_{H,t}(j) - E_t L_{F,t}(j) \\ = \; & i_{dH,t-1} D_{H,t-1}(j) + i_{dF,t-1} E_t D_{F,t-1}(j) \\ & + Ret_{k,t} Q_{t-1} k_{t-1}(j) \left(1 - \kappa_{H,t-1} \Gamma_{H,t}^k(j) - \kappa_{F,t-1} \Gamma_{F,t}^k(j) \right) \\ & - \left(1 + s_t^h(j) \right) P_t c_t(j) + W_t^{hh} h_t(j) + P_t \Upsilon_t(j) \end{aligned} \tag{17}$$

This states that households' net assets (deposits minus loans plus land) at time t must equal the gross return on net assets held in the previous period (on deposits and on the shares of land returns that do not go to banks to repay loans) minus consumption (including transaction costs $s_t^h P_t c_t(j)$) plus labour income $W_t^{hh} h_t(j)$ (where W_t^{hh} is the wage paid to households by unions) and lump-sum net income $P_t \Upsilon_t(j)$. The latter equals the sum of profits and dividends of manufacturers, unions and banks, price and wage adjustment costs, costs of monitoring manufacturers, penalty costs paid by banks, and monetary transactions costs related to retail and interbank deposits.[10] The real normalized Lagrange multiplier on the budget constraint is $\check{\lambda}_t$. Households also face the two participation constraints (12) for taking out loans in domestic and foreign currencies. The real normalized multipliers on these constraints are denoted by $\check{\lambda}_t \tilde{\lambda}_{X,t+1}$.

[9] The simplification is that there is no satiation point for money, because this feature is not important for our analysis.

[10] All adjustment and transactions costs are therefore assumed to represent payments to households rather than resource costs, which means that they do not appear in aggregate resource constraints.

3.4.2. Optimality Conditions

We assume that each household j holds identical initial stocks of all physical and financial assets and liabilities, and receives identical lump-sum dividends from banks, manufacturers and unions. Because they also face identical prices, this implies that households make identical decisions, and remain symmetric at all times. The index j can therefore be dropped when stating the optimality conditions, which are presented in real normalized form. The first-order conditions for domestic and foreign consumption goods, hours worked, and the bankruptcy cutoff conditions, are standard for models in this class, and are omitted to conserve space.

The first-order condition for consumption is

$$\frac{S_t^c \left(1 - \frac{\nu}{x}\right)}{\check{c}_t - \frac{\nu}{x}\check{c}_{t-1}} = \check{\lambda}_t \left(1 + s_t^h + s_t^{h'} v_t^h\right) \ . \tag{18}$$

This states that the marginal utility of consumption equals the marginal utility of wealth multiplied by the effective purchase price of consumption goods p_t^h, a key variable for the transmission mechanism of our model:

$$p_t^h = 1 + s_t^h + s_t^{h'} v_t^h \ . \tag{19}$$

We note that p_t^h exceeds one due to time-varying monetary transactions costs, and that it is decreasing in the quantity of deposits provided by the banking sector.

The first-order condition for land is

$$\begin{aligned} 1 \ = \ & \beta \mathbb{E}_t \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} \check{ret}_{k,t+1} \Big[\left(1 - \kappa_{H,t}\Gamma_{H,t+1}^k - \kappa_{F,t}\Gamma_{F,t+1}^k\right) \\ & + \tilde{\lambda}_{H,t+1}\kappa_{H,t}\left(\Gamma_{H,t+1}^k - \xi_H G_{H,t+1}^k\right) + \tilde{\lambda}_{F,t+1}\kappa_{F,t}\left(\Gamma_{F,t+1}^k - \xi_F G_{F,t+1}^k\right)\Big] \ , \end{aligned} \tag{20}$$

which reflects that some shares of land returns go to banks to repay loans, and that the availability of land as collateral relaxes banks' participation constraints.

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

$$1 - s_t^{h'} \left(v_t^h\right)^2 d_t^{\prime X} = \frac{\beta}{x} \mathbb{E}_t \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} r_{dX,t+1} \ . \tag{21}$$

This states that the product of the intertemporal marginal rate of substitution and the deposit interest rate is less than one, due to marginal monetary transactions costs $s_t^{h'} \left(v_t^h\right)^2 d_t^{\prime X}$ that are inversely related to the amount of currency X in circulation.

Finally, the first-order conditions for Home and Foreign currency loans are

$$1 = \frac{\beta}{x} \mathbb{E}_t \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} \tilde{\lambda}_{X,t+1} r_{\ell X,t+1} \ . \tag{22}$$

3.4.3. The MUIP Condition

Analytical Expressions The key theoretical prediction of our model is that relative supplies and demands of Home and Foreign currency deposits are key drivers of the exchange rate, in addition to relative supplies and demands of Home and Foreign goods. To show this analytically, we derive a monetary uncovered interest parity (MUIP) condition, using the two first-order conditions for domestic and foreign currency deposits (21). We can log-approximate these two conditions to obtain the following expression for the excess return of domestic over foreign currency assets:[11]

$$xsr_t = \mathbb{E}_t \ln\left(i_t - \ln i_t^* - \ln \varepsilon_{t+1}\right) = \mathbb{E}_t \left(\ln r_{t+1} - \ln r_{t+1}^* - \ln \varepsilon_{t+1}^{\text{real}}\right) = \mathbb{E}_t \left(\kappa + s_t^* + m_t\right) . \quad (23)$$

The components of this excess return are the constant $\kappa = \ln\left(\mu_{dF}/\mu_{dH}\right)$, the foreign regulatory spread s_t^*

$$s_t^* = \frac{\chi^*}{r_{t+1}^*}\left(F_{t+1}^{b^*} + f_{t+1}^{b^*}\Omega_{\ell F,t}^{b^*}\left(\check{\ell}_{F,t}^* + e_t^*\check{\ell}_{H,t}^* + \check{\ell}_{F,t}^{b^*} + e_t^*\check{d}_{H,t}^{b^*}\right)\right) , \quad (24)$$

and the MUIP spread

$$m_t = \mathbb{E}_t \frac{A^h S_t^{md}\left(v_t^h\right)^2 (x/\beta)\left(\check{\lambda}_t/\check{\lambda}_{t+1}\right) d_t^{\prime H}}{\mu_{dF} r_{\ell F,t+1}^{b^*}}\left(\left(\frac{1-b^d S_t^{mm}}{b^d S_t^{mm}}\frac{\check{d}_{H,t}}{e_t\check{d}_{F,t}}\right)^{\frac{1}{\theta_d}} - 1\right) . \quad (25)$$

The MUIP condition (23) states that the exchange rate adjusted policy interest rate differential can deviate from uncovered interest parity for two reasons. The first is variations in the foreign regulatory spread $\kappa + s_t^*$, which enter this condition because the marginal cost of funding in foreign currency is not the foreign policy rate but an interbank rate with a time-varying regulatory spread. The second is variations in the domestic monetary spread m_t, which enter due to imperfect substitutability between deposits in domestic and foreign currencies. In steady state $\kappa + \bar{s}^* = 0$ and $\bar{m} = 0$. For all the shocks that we consider, the foreign regulatory spread exhibits very little variability[12], so that in our exposition we mainly focus on the domestic monetary spread. We also note that, because the two policy rates and exchange rate depreciation are common across countries, the two countries' MUIP spreads must be arbitraged internationally, and arbitraged exactly when $\kappa + s_t^* = 0\ \forall t$. Under the latter assumption we therefore have

$$m_t + m_t^* = 0 . \quad (26)$$

We can also derive an expression for the real exchange rate as a function of future real interest rate differentials and MUIP spreads. Again simplifying by setting $\kappa + s_t^* = 0\ \forall t$, and anticipating a calibration of the steady state real exchange rate at 1, we obtain[13]

$$\ln\left(e_t\right) = \Sigma_{j=0}^{\infty}\left(\ln\left(r_{t+j+1}^*\right) - \ln\left(r_{t+j+1}\right) + m_{t+j}\right) . \quad (27)$$

In other words, increases in the domestic real policy rate, which reflect a greater attractiveness of the domestic currency in terms of its financial return, appreciate the real exchange rate by standard UIP arguments, while decreases in the MUIP spread, which reflect a greater attractiveness of the domestic currency in terms of its non-financial or convenience yield (see the next subsection), appreciate the real exchange rate by MUIP arguments.

Interpretation of the MUIP Spread A key concept in the interpretation of the MUIP spread is the convenience yield of a currency, which represents the marginal value of the non-pecuniary monetary services that this currency provides to its users. In the case of two currencies the relative

[11] We use the notation $\varepsilon_{t+1}^{\text{real}} = e_{t+1}/e_t$.

[12] The main reason is that we study domestic shocks in a Home economy that is small relative to the rest of the world. Such shocks only have minimal effects on foreign spreads.

[13] A similar expression can be derived for the nominal exchange rate, but the long-run value of the nominal exchange rate is of course path dependent.

convenience yield matters, and its counterpart in our model is the MUIP spread (25). This spread is nonzero if the home bias-adjusted relative quantity of domestic and foreign currency deposits is different from one. Specifically, as one form of money becomes more abundant, the liquidity services of its marginal unit become less valuable and its relative convenience yield declines. This means that, ceteris paribus, its financial return, which includes expected exchange rate appreciation, must increase. In other words, the market-clearing relative financial return on a currency is increasing in the relative quantity of that currency. Figure 2 illustrates this. We note that in (25) the MUIP spread is the relative convenience yield of *Foreign* currency. We can see this both by observing that this spread is added to the financial return on foreign currency deposits, and also by noting that the spread is, ceteris paribus, decreasing in the quantity of foreign currency deposits.

Consider now the effects of an increase in the supply of domestic currency due to an increase in domestic currency lending, and reflected in (25) in higher $\check{d}_{H,t}$. From (23) this implies that ceteris paribus $m_t > 0$, because domestic currency becomes more abundant so that the relative convenience yield of domestic currency declines. This implies that domestic currency needs to pay a financial premium relative to foreign currency. But this premium will not exclusively take the form of a higher domestic nominal policy interest rate, which is set with inertia by the policymaker. Rather, the response will also involve exchange rate appreciation. Appreciation over time implies an upward jump, or a depreciation, of the exchange rate on impact. Therefore, an increase in the supply of domestic currency leads to an exchange rate depreciation.

Consider next the effects, for a given increase in the supply of domestic currency, of different elasticities of substitution. On the one hand, as $\theta_d \to \infty$, or as the two types of deposits become perfect substitutes, the term in brackets in (25) approaches zero regardless of the relative supplies of the two currencies, and the MUIP spread is eliminated. On the other hand, as domestic and foreign currency assets become increasingly imperfect substitutes, changes in the MUIP spread become larger, because the relative convenience yield, and therefore the required relative financial return on domestic currency assets, becomes more sensitive to the relative amounts of currency created by the two banking systems.

Finally, consider the effects of an increase in the demand for domestic currency, reflected in (25) in higher S_t^{mm}. From (23) this implies, ceteris paribus, that $m_t < 0$, because the relative convenience yield of domestic currency increases. This implies that domestic currency can pay a financial discount relative to foreign currency. This occurs mainly through expected exchange rate depreciation, which in turn implies an appreciation of the exchange rate on impact. Therefore, an increase in the demand for domestic currency leads to an exchange rate appreciation.

UIP Effects versus MUIP Effects on the Exchange Rate UIP effects on the exchange rate are transmitted through interest rate changes, either due to exogenous monetary policy shocks or due to systematic responses to Taylor rule fundamentals such as inflation gaps and output gaps, and such effects occur in all modern open economy models. Changes in the nominal interest rates of the two economies in turn lead to changes in the exchange rate to ensure that the UIP condition holds. UIP effects are also present in our model.

MUIP effects on the exchange rate are transmitted through changes in the MUIP spread and are specific to our model. In this case economic shocks trigger UIP effects as in standard models, but they also trigger changes in the MUIP spread that lead to exchange rate changes independently of and in addition to UIP effects. Because in general such exchange rate changes affect the real economy, they also trigger second-round UIP effects, through the systematic component of monetary policy.

The relative importance of UIP and MUIP effects depends on both the strength of the respective transmission channels and the nature of economic shocks. When MUIP spreads are not very responsive to changes in relative currency supplies, such as when the elasticity of substitution between currencies is very high, this decreases the relative importance of MUIP effects. The same is true when economic shocks are primarily to relative supplies and demands of goods. But when the elasticity of substitution between currencies is lower, and when economic shocks are primarily to relative supplies and demands of currencies, this increases the relative importance of MUIP effects. We will study these phenomena in our simulations.

3.5. Manufacturers, Unions and Goods Market Clearing

Manufacturers have unit mass and are indexed by j, where individual manufacturers differ by the goods variety that they produce and sell. Manufacturers optimally combine labour $h_t(j)$ and land $K_t(j)$ to produce and price varieties of the domestic good $y_t(j)$, with buyers demanding a composite of output varieties with elasticity of substitution θ_p. Manufacturers set the price of their output variety $P_t(j)$ subject to monopolistic competition and Rotemberg (1982) quadratic price adjustment costs. The production function of manufacturer j is given by

$$y_t(j) = T_t\left(S_t^a h_t(j)\right)^{1-\alpha}\left(K_t(j)\right)^{\alpha} \ , \tag{28}$$

where S_t^a is a first-order autoregressive process for labour-augmenting technology. In aggregate $K_t = k_{t-1}$ and, because of symmetry, $K_t(j) = K_t$. Optimization yields standard expressions for real marginal cost and for factor demands that are omitted to conserve space. We assume that manufacturers optimally price their output in local currency for both markets. Maximization of discounted nominal profits with respect to $P_{H,t}(j)$ and $P_{H,t}^*(j)$ yields a pair of standard New Keynesian Phillips curves. In equilibrium all manufacturers are identical and the index j can be dropped. Because land is in fixed supply, in equilibrium we have $k_t = \bar{k}\ \forall t$, where $\bar{k}$ is an exogenous constant. Manufacturers are owned by households, and their profits are transferred to the latter in a lump-sum fashion.

Unions have unit mass and are indexed by j, where individual unions differ by the labour variety that they sell. Unions buy homogenous labor from households at a nominal household wage rate W_t^{hh} set in a competitive labor market. They set the price of their labor variety, the individual producer wage rate $W_t^{pr}(j)$, subject to monopolistic competition and quadratic wage adjustment costs, with manufacturers demanding a composite of labor varieties with elasticity of substitution θ_w. Maximization of discounted nominal profits with respect to $W_t^{pr}(j)$ yields a standard wage Phillips curve. In equilibrium all unions are identical and the index j can be dropped. Unions are owned by households, and their profits are transferred to the latter in a lump-sum fashion.

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

$$\check{y}_t = \check{c}_{H,t} + \check{c}_{H,t}^*\frac{1-n}{n} \ , \tag{29}$$

while real normalized GDP[14] is defined as

$$g\check{d}p_t = \check{c}_t + \check{x}_t - \check{m}_t \ , \tag{30}$$

where real exports and imports are $\check{x}_t = e_t p_{H,t}^* c_{H,t}^*\left((1-n)/n\right)$ and $\check{m}_t = p_{F,t}\check{c}_{F,t}$.

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

3.6. Monetary and Fiscal Policy

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

$$i_t = (i_{t-1})^{m_i} \left(\bar{r}\bar{\pi}^p\right)^{1-m_i} \mathbb{E}_t \left(\frac{\pi^p_{4,t+3}}{\bar{\pi}^p}\right)^{(1-m_i)m_\pi} S_t^{int} \ , \tag{31}$$

where $\pi^p_{4,t} = \left(\pi^p_t \pi^p_{t-1} \pi^p_{t-2} \pi^p_{t-3}\right)^{0.25}$, S_t^{int} is a first-order autoregressive process for monetary policy shocks, and the expression for the steady state real interest rate $\bar{r} = (x/\beta\mu_{dH}) \left(1 - \bar{s}^{h'} \left(\bar{v}^h\right)^2 \vec{d}^H\right)$ follows from combining the first-order conditions for domestic currency deposits of households and retail deposit banks. 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 zero at all times.

3.7. Balance of Payments

There are two cross-border links between Home and Foreign. First, households in both countries trade Home and Foreign goods. Second, banks in both countries maintain interbank asset and liability positions with each other in Home and Foreign currencies. Households do not maintain cross-border financial positions. The current account, in real normalized terms, is given by

$$\begin{aligned} & \check{\ell}^b_{H,t} + e_t \check{d}^b_{F,t} - \check{d}^b_{H,t} - e_t \check{\ell}^b_{F,t} \\ = \ & \frac{1}{x}\left(r^b_{\ell H,t}\check{\ell}^b_{H,t-1} + r^b_{dF,t} e_{t-1}\check{d}^b_{F,t-1} - r^b_{dH,t}\check{d}^b_{H,t-1} - r^b_{\ell F,t} e_{t-1}\check{\ell}^b_{F,t-1}\right) + \check{x}_t - \check{m}_t \ , \end{aligned} \tag{32}$$

where $\check{\ell}^b_{H,t} + e_t \check{d}^b_{F,t} - \check{d}^b_{H,t} - e_t \check{\ell}^b_{F,t}$ is the net foreign asset position. Gross foreign asset positions can evolve completely independently of the net foreign asset position, because banks can lend to create interbank deposits in the same way in which they lend to create retail deposits.

4. Calibration

We use a combination of US and international data, and parameters from the literature, to calibrate the model. The US is a frequently used benchmark and has good data availability. However, it is atypical in one important respect - its currency lies at the centre of international trade in goods and assets, so that it relies much less than most countries on foreign currencies. Therefore, for some parameters relating to the use of foreign currencies we use non-US values to calibrate the model. We use a small open economy setup that is nevertheless symmetric in that all calibration targets other than those relating to country size (goods and currency market home bias) are identical across countries. For our analysis of impulse responses we calibrate the model so that Home matches the share of the UK in the world economy, $n = 0.0325$. For our analysis of key puzzles in open economy macroeconomics we calibrate the model, for comparability with other studies, so that Home matches the average share of the US in the world economy between 2000 and 2016, $n = 0.25$. Except where necessary because of size asymmetries across countries, our discussion only refers to the calibration of Home.

4.1. Real Sector Parameters

Productivity growth x is calibrated at 2% in annual terms. The equilibrium real interest rate $\bar{r}$ and the CPI inflation target $\bar{\pi}^p$ are calibrated at 3% and 2% in annual 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 steady state share of Foreign goods in the Home consumption basket to 14% by adjusting the goods market home bias parameter b^c, and by adjusting the corresponding parameter for Foreign to account for the difference in country sizes while maintaining a steady state real exchange rate of 1. The elasticity of substitution θ_c between domestic and foreign goods is set to 1.5, a common value in the open economy macro literature. We set the elasticity of labour supply η to 1 and the habit parameter ν to 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 that land accounts for around one half of the income attributed to capital in the national accounts, capital in turn accounting for around 40% in the most recent data. This means that the labour share in our model effectively represents the income shares of labour and physical capital. We adjust the endowment of land $\bar{k}$ in order to normalize the steady state real price of land $\bar{q}$ to 1. For price and wage stickiness, we use the estimation results in Christiano et al. (2014), which are based on a Calvo (1983) setup, to compute the equivalent Rotemberg (1982) parameters as $\phi_p = 105$ and $\phi_w = 212$.[15] Price and wage gross markups μ_p and μ_w are set to 1.1. Our parameterization of the monetary policy rule is also taken from the estimates of Christiano et al. (2014), with interest rate smoothing and inflation feedback parameters of $m_i = 0.85$ and $m_\pi = 2.4$.

4.2. Financial Sector Parameters

The first subset of financial sector calibration targets relates to prudential regulation and the riskiness of banks and their borrowers. The capital adequacy ratio γ is set to 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 also the additional supervisory requirements, as these do not apply to all banks and/or at all times. Note that in our setup banks will end up holding some capital above the regulatory minimum to protect themselves against the risk of violating the MCAR. We set the actual steady state capital adequacy ratio to 11%, by adjusting banks' dividend payout parameter δ^b. We set the cumulative steady state share of banks that violate the Basel minimum in any quarter $\bar{F}^b$ to 2.5% in steady state, close to the approximate historical frequency of systemic banking crises in Jorda et al. (2011), by adjusting the bank riskiness parameter σ^b. Household steady state bankruptcy rates on domestic and foreign currency loans, $\bar{F}^k_H$ and $\bar{F}^k_F$, respectively, are set to 1.5% by adjusting the loss-given-default parameters ξ_H and ξ_F. This matches the findings of Brooks and Ueda (2011) for non-financial listed US companies, and also approximately matches the historical average of per-capita default rates reported in Albanesi et al. (2017).

The second subset of financial sector calibration targets relates to steady-state interest-rate spreads. We first discuss banks' asset-side rates and then turn to liability-side rates. To facilitate the exposition, Figure 3 provides a graphical representation of steady-state interest rates in our model. We set the parameter ζ, the Basel risk weight on interbank claims, to zero. The risk weight was

[15] Christiano et al. (2014) also allow for indexation to past inflation. However, at least for price stickiness, their weight on indexation is close to zero.

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 risk weight implies spreads between interbank lending rates and the short-term policy rate of 24 basis points for Home currency loans to Foreign banks (not reported in Figure 3) and 21 basis points for Foreign currency loans to Home banks (*Interbank Lending Rate* in Figure 3).[16] This is close to the 16 basis points average spread between the 1-month LIBOR and the effective Federal Funds rate over the period 2000-2016. To exactly match that spread would have required setting ζ to a slightly negative value. The marginal cost of funds for domestic currency wholesale loans equals the domestic policy rate (*Domestic Currency Wholesale Deposit Rate* in Figure 3), while the marginal cost of funds for foreign currency wholesale loans equals the foreign currency interbank lending rate (*Foreign Currency Wholesale Deposit Rate* in Figure 3).

To calibrate the remaining lending spreads, we use a data set of "maturity-adjusted credit spreads" (MACS) for all listed non-financial firms in the US.[17] These are spreads between the cost of borrowing for a given firm and an equal-maturity risk free interest rate. We recall that in the model the wholesale lending rate corresponds to the interest rate that would be charged to a notional zero-risk corporate borrower. A model-consistent calibration for wholesale lending spreads is therefore the spread between the average commercial paper rate paid by the very best blue-chip (AAA) non-bank corporates and the policy rate. Over the sample period 2000-2016 we compute this as 66 basis points, and we calibrate the wholesale spread on domestic currency loans at this value by adjusting the MCAR parameter χ (*Domestic Currency Wholesale Lending Rate* in Figure 3). The wholesale lending spread on foreign currency loans also contains a regulatory spread of 66 basis points, but there are two additional spread components. The first is due to the fact that the marginal cost of funds for foreign currency loans equals the foreign currency interbank lending rate, which as mentioned above is 21 basis points higher than the policy rate. The second is a small monetary spread that is due to the necessity to hold some foreign currency interbank liquidity in the absence of a lender of last resort in foreign currency. We calibrate this spread at 10 basis points, by adjusting the steady state willingness-to-lend parameter for foreign currency loans $\bar{\kappa}_F$. The total wholesale spread for foreign currency loans therefore equals 97 basis points (*Foreign Currency Wholesale Lending Rate* in Figure 3).

External finance premia or retail lending spreads, which are the spreads between the retail and wholesale lending rates, are calibrated by adjusting the steady state borrower riskiness parameters $\bar{\sigma}^k_H$ and $\bar{\sigma}^k_F$. The data counterpart is the difference between the MACS of all firms in the data set and the MACS of AAA-rated firms only, at matching maturities of 3 months. In our data set this difference is equal to 167 basis points[18], which we use to calibrate the spread on domestic currency retail loans. This yields a domestic currency retail lending rate of 5.33% (*Domestic Currency Retail Lending Rate* in Figure 3). The spread on foreign currency retail loans is calibrated at 135 basis points, so that the foreign currency retail lending rate is also equal to 5.33% (*Foreign Currency Retail Lending Rate* in Figure 3). The lower retail spread for foreign currency loans relative to domestic currency loans is justified by the fact that foreign currency loans tend to be taken out by larger corporates that are more creditworthy than the average domestic currency borrower.

Turning to liability-side rates, the steady state spread between the domestic policy rate and the domestic currency interbank deposit rate is calibrated at -10 basis points by adjusting the spread

[16] The slight asymmetry is due to the effects of different country sizes.

[17] The data are available from the authors on request.

[18] As a useful cross-check we compared this number with the average BAA-AAA spread from Moody's over the same period, which equals 108 basis points. The discrepancy is due to the fact that in the universe of all firms the average firm has a worse rating than BAA.

parameter μ^b_{dH}. This calibration is based on interpreting the interbank deposit rate as LIBID, and noting that the historic spread between US LIBID and the Fed Funds rate was around -10 basis points over the period 1990Q3-2008Q3, prior to the effective zero lower bound period. The steady state spreads between the policy rate and retail deposit rates in both currencies are calibrated by adjusting the spread parameters μ_{dH} and μ_{dF}. The average spread between the US policy rate and the effective interest rate on household checking accounts (obtained from FDIC data) over the period 1998Q3-2008Q3 equalled around -300 basis points.[19] However, in our model deposits include a much wider range of bank liabilities, including wholesale deposits which attract rates much closer to the policy rate. To approximate the average convenience yield of total financial sector liabilities to non-banks, we therefore calibrate this spread at - 150 basis points. This is very similar to Ashcraft and Steindel (2008), who compute, for the single year 2006, a spread of 134 basis points between the average rate of US commercial banks' portfolio of treasury and agency securities on the one hand and average rate on their complete portfolio of liabilities on the other hand.

The third subset of parameters determines the size of the financial system along various dimensions. We set the ratio of cross-border gross interbank positions to GDP to 20%, and assume that this is equally split between domestic and foreign currency positions. A 20% ratio roughly corresponds to the average value for the US, but the currency split is more representative of European banking systems. We calibrate these ratios by adjusting the parameters φ_b and ϑ_b of the interbank money demand functions in both countries. 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 prior to the GFC. 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 steady-state willingness-to-lend parameter for domestic currency loans $\bar{\kappa}_H$.

The fourth subset of parameters concerns the demand for bank deposits. We set the steady state share of Foreign currency deposits in total Home household deposits to 6% by adjusting the Home deposits home bias parameter b^d, and by adjusting the corresponding parameter for Foreign to account for the difference in country sizes. The 6% ratio is in line with UK household balance sheet data in the ONS Blue Book for the end of 2015, the latest available datapoint. In steady state foreign currency retail loans must equal foreign currency retail deposits, due to FXMR and the fact that foreign currency interbank loans and deposits are calibrated to be equal to each other steady state. 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. With $\theta_d = 1.5$ the implied interest semi-elasticity of the demand for domestic currency deposits equals around 9, a reasonable value in light of the literature, which finds values ranging from 3 to 11 (Burnside (2011)).

For comparison with our MUIP baseline model we also calibrate a UIP baseline model. Its calibration is identical except for the elasticity of substitution between domestic and foreign currency deposits, which approximates the UIP case of infinite elasticity by setting $\theta_d = 2500$. Impulse responses for the UIP model will only be shown for the components of the UIP condition and for GDP, exchange rates and the current account, mainly because the currency composition of bank loans and bank deposits approaches indeterminacy as θ_d approaches infinity.

[19] This spread has been significantly compressed during the ZLB period, but we exclude this period because we do not consider it representative of normal conditions in the banking sector.

5. 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 convenience yield in addition to a financial yield. Third, the transactions services provided by two currencies are imperfect substitutes, such that their relative convenience and financial yields depend on their relative demands and supplies. The implication of our theory is that an increase in credit supply in one currency ceteris paribus reduces the relative convenience yield of that currency and therefore increases its relative financial yield, which in the literature is known as the excess return.

To test this implication we need two pieces of information. The first is a measure of the excess returns from holding different currencies. The second is a source of exogenous variation in the relative willingness of banks in two currency areas to create currency for their customers.

Our measure of excess returns from holding different currencies is defined as:

$$m_{ij,t}^{h} = \frac{h}{12}\left(i_t^{h,i} - i_t^{h,j}\right) - \left(\ln(E_{t+h}^{ij}) - \ln(E_t^{ij})\right). \tag{33}$$

This is the difference between the *ex-ante* nominal interest rate differential at tenor h, which is measured by taking the difference between country i's and country j's LIBOR at tenor h (denoted $i_t^{h,i} - i_t^{h,j}$), and the *ex-post* log-change in the bilateral nominal exchange rate between country i and country j (denoted E_{t+h}^{ij}) at the same tenor h. This is conceptually close to the MUIP spread m_t in our model.[20]

We use credit supply shocks as the best available measure of money supply shocks, because there are no widely accepted, direct measures of money supply shocks, specifically of shocks to broad aggregates of commercial bank liabilities. Money supply shocks in the sense of, for example, Friedman (1968) correspond more closely to monetary *policy* shocks in modern parlance, and our model predicts that the effects such shocks are very different from those of shocks to broad monetary aggregates. Credit supply shocks can be quantified using changes in regulation or changes in the observed credit supply behavior of the banking sector. In the former case, we would have too few observations for any given country to yield well-determined estimates. We therefore turn to central banks' credit conditions surveys as measures of banks' attitudes towards credit extension.[21] The central banks of the US, euro area, UK and Japan produce quarterly credit conditions surveys which measure, *inter alia*, the terms on which commercial banks are willing to extend credit to the private sector. Each of the four surveys contains a question that asks banks about changes in household sector credit conditions. The four countries generate six unique country pairs and a dataset of approximately three hundred quarter-pair observations. Details of the precise questions asked and the sample period used are contained in the Appendix.

Our regression estimates the effects of exogenous variations in credit/money supply on the excess returns from holding different currencies. Because our predictions for currency returns are inherently relative, they should depend on *relative* credit conditions in the two currency areas. To take this into account we regress, for each pair of countries i and j, credit conditions in country i (CCS_i) on credit conditions in country j (CCS_j), and we use the residual from this regression (denoted

[20] We abstract from the regulatory spread s_t^* here, mainly because, as in the model, this term is likely to be small, and to exhibit little variation, for the shocks we are seeking to identify.

[21] Ciccarelli et al. (2015), among others, have used these surveys for identification purposes.

ε_{ij}^{CCS}) as our measure of relative credit conditions in the ij country pair. This variable is defined so that *an increase in* ε_{ij}^{CCS} *is a tightening in credit conditions in country* i *relative to country* j. Our model predicts that such a tightening induces a relative scarcity in country i's currency, which in turn will increase its relative convenience yield, which equals the negative of its holding-period excess return, or the negative of the MUIP spread between i and j. In other words, our model predicts a negative response of the MUIP spread to ε_{ij}^{CCS}.

To flexibly estimate this response we specify the following local projection model, following Jorda (2005):

$$m_{ij,t+s}^{h} = \alpha_{ij} + \beta_s^h \varepsilon_{ij,t}^{CCS} + \epsilon_{ij,t} \tag{34}$$

Here $m_{ij,t+s}^{h}$ is the MUIP spread at tenor h, measured starting s months after the shock—in other words, the excess return on currency i assets vis-a-vis that of currency j between periods $t+s$ and $t+s+h$. We estimate (34) using the Pesaran and Smith (1995) mean group estimator.

Table 1 shows the estimates of β_s^h for tenors of $h = 3, 6, 12$ months and horizons $s = 0, 1, ..., 4$ quarters for a one standard deviation increase in $\varepsilon_{ij,t}^{CCS}$. The table shows that a tightening of financial conditions typically leads to a fall in the MUIP spread, meaning a reduction in the excess return on domestic currency, as predicted by our model. As regards statistical significance, in about half of the cases the regression coefficients β_s^h are significant at the 5 percent level and, in some cases, at the 1 percent level. As regards economic significance, the regression coefficients β_s^h capture the impact of a one standard deviation increase in relative credit conditions ($\varepsilon_{ij,t}^{CCS}$) on the MUIP spread ($m_{ij,t+s}^{h}$). Taking as an example the 3-month tenor at a 2-quarter horizon, our results show that a one standard deviation increase in $\varepsilon_{ij,t}^{CCS}$ leads to a cumulative fall of 1.10% in the MUIP spread. This is an economically meaningful and sizeable effect. Finally, we note that the R^2 of the regressions are relatively low, between 0.03 and 0.09, a common finding in the empirical literature on exchange rates. The interpretation of our results is therefore that when shocks to $\varepsilon_{ij,t}^{CCS}$ do hit, they lead to sizeable movements in the spread, but there are many other factors that can affect this spread.

The first-order autocorrelation coefficient of the relative credit conditions index $\varepsilon_{ij,t}^{CCS}$ equals 0.77. We will use this as our calibration of the persistence of credit supply shocks, meaning shocks to the willingness to lend and to borrower riskiness. We do not have independent estimates for the persistence of credit demand shocks, and will for illustrative purposes assume the same value of 0.77.

6. Simulation Results

In this section we study the model economy's properties by way of illustrative impulse responses. Most figures show two sets of results, one for the baseline MUIP model (black solid line) and one for the corresponding UIP model (red dotted line). The main exception is Figure 5, which compares the baseline MUIP model with alternatives that vary the key parameter θ_d of the MUIP model.[22] For the other figures our discussion focuses on the MUIP case and then where necessary discusses differences to the UIP case. All impulse responses only show the effects of shocks on the Home economy, because for all shocks presented here the effects on Foreign are small.

All impulse response functions follow a common format. The bottom left 4x2 section shows all components of banks' balance sheets except equity. The bottom right 4x2 section shows (apart

[22] The other exception is Figure 10, where we were unable to obtain convergence for the UIP case.

from the effective purchase price p_t^h) all components of the nominal and real MUIP conditions together with the levels of real and nominal exchange rates. The remaining panels show real variables and inflation. To conserve space the figures leave out many variables that are interesting but not essential to understand the main arguments. When we find it necessary to comment on such variables, for example lending spreads or Basel capital adequacy ratios, we will report the relevant magnitudes in the text.

Figures 4-5 study a shock that reduces the supply of Home currency. Figure 4 studies the baseline shock to $\kappa_{H,t}$ and $\kappa_{H,t}^*$, which reduces the global Home currency credit supply. Figure 5 explores the sensitivity of these baseline results to different but finite elasticities of substitution between domestic and foreign currency θ_d.

Figures 6-8 study two shocks that increase the demand for currency. Figure 6 studies a shock to S_t^{md} that leads to an increase in the demand for the overall liquidity aggregate D_t^{liq} irrespective of currency, which we interpret as a "flight to safety". Figure 7 studies the combined effects of the currency supply shock of Figure 4 and the currency demand shock of Figure 6. Figure 8 studies a shock to S_t^{mm} that leads to an increase in the demand for foreign currency alone, which we interpret as a "flight to the dollar".

Figures 9-12 study standard business cycle shocks, specifically transitory and permanent monetary policy shocks S_t^{int} and $\bar{\pi}^p$ (Figures 9-10), and transitory shocks to consumption demand S_t^c (Figure 11) and to technology S_t^a (Figure 12).

Under financial shocks (Figures 4-8) balance sheet changes are generally large relative to changes in GDP, and to aid interpretation their deviations from steady state are shown in percent of GDP. Under standard business cycle shocks (Figures 9-12) balance sheet changes are generally of a similar order of magnitude as changes in GDP, and to aid interpretation their deviations from steady state are shown in percent terms. We note that, because of their much smaller steady state values, percent changes in foreign currency positions represent much smaller changes relative to GDP (by a factor of 16).

Section 7 will study the ability of the model and its shocks to explain some key puzzles in open economy macroeconomics, with the primary focus on the UIP puzzle. The UIP puzzle originates with Fama (1984), who found that a regression, at a matching horizon of k periods, of future exchange rate changes $\ln(\varepsilon_{t+k})$ on current domestic-foreign interest differentials $\ln(i_{t,k}) - \ln(i_{t,k}^*)$, where the subscript k refers to the tenor of the underlying instrument, has a negative coefficient, while under UIP the regression coefficient is expected to equal 1. Similarly, and equivalently, Engel (2016) regressed k-period currency excess returns $xsr_{t,k} = \ln(i_{t,k}) - \ln(i_{t,k}^*) - \ln(\varepsilon_{t+k})$ on current domestic-foreign interest differentials, and found, consistently with Fama (1984) and with few exceptions, coefficients that are positive and greater than one, while under UIP the regression coefficient is expected to equal 0. In other words, the empirical results demonstrate that when the interest rate on a currency is relatively high, that currency tends to have an appreciating exchange rate and consequently a positive excess return. Section 7 will study the UIP puzzle systematically for every shock in our model, by replicating the Fama (1984) and Engel (2016) regressions. However, because the underlying economics can be discussed more clearly in the context of our impulse responses, we will also comment on this puzzle in the present section, and for discussions of the UIP puzzle we will focus on nominal interest parity. However, we also like to link the discussion of our impulse responses to the level of the exchange rate, and in this context we find it preferable to discuss real rather than nominal interest parity, because the real exchange rate has a known long-run equilibrium value while the long-run value of the nominal exchange rate is path dependent.

6.1. Decrease in Home Currency Supply

Figures 4-5 simulate a shock whereby the willingness of banks to lend and create deposits in Home currency declines due to negative shocks to the parameters $\kappa_{H,t}$ and $\kappa^*_{H,t}$. We note that the impulse responses of willingness-to-lend shocks are very similar to those of the borrower riskiness shocks $\sigma^k_{H,t}$ and $\sigma^{k*}_{H,t}$ that were stressed by Christiano et al. (2014), except that risk shocks have a larger negative impact effect on bank net worth. We present only impulse responses for willingness-to-lend shocks to conserve space, and also because they have a more natural interpretation as shocks to the supply of currency provided at the initiative of banks and not triggered by changes in their borrowers' credit risk.[23] Shocks to $\kappa_{H,t}$ and $\kappa^*_{H,t}$ are purely financial shocks that drive the exchange rate, with goods markets responding to rather than triggering events in financial markets.

6.1.1. Baseline Simulation

In the real economy, the willingness-to-lend shock leads to a persistent shortage of monetary liquidity, and thereby to an increase in the effective purchase price of consumption goods that reaches 0.85% on impact. This leads to a drop in GDP of almost 0.6%, and to a drop in the rate of inflation of over 40 basis points. The drop in inflation, through the systematic response of the central bank's policy rate, triggers a drop in the real policy rate of approximately 20 basis points after two years. The foreign real policy rate, due to the small effect of this shock on the foreign economy, remains essentially unchanged.

In the financial sector, the reduction in the willingness of banks to lend in domestic currency leads to a contraction in domestic currency loans of around 7.5% of GDP on impact. Given that domestic currency deposits account for 94% of total steady state deposits, that foreign currency deposits are constrained by FXMR, and that domestic and foreign currency deposits are imperfect substitutes, the main liability-side response to the contraction in bank assets comes from domestic currency deposits, which drop by roughly the same magnitude relative to GDP as domestic currency loans, while foreign currency loans and deposits, which are small in steady state, change (increase) by much less. Willingness-to-lend shocks mostly affect future lending terms, with only small effects on the performance of existing loans. As a result banks' loan losses are minimal and net worth remains nearly constant on impact. The Basel ratio nevertheless improves by 0.75 percentage points on impact, due to strong deleveraging that takes the form of reductions in assets and liabilities at approximately constant net worth. The rapidity of this change is of course made possible by the fact that bank balance sheets are driven by the preferences of banks and their customers over gross balance sheet exposures rather than by their preferences over net flows of physical resources, or savings. Gross positions therefore change by far more than net positions such as net foreign assets, which represent a residual item that equals the netted position across the four interbank balances. It can also be shown that retail lending spreads on domestic currency loans increase by almost 80 basis points immediately following this shock. This is due to increased borrower riskiness caused by a combination of a lower value of available loan collateral (the shock) and a contraction in real activity. But because the deleveraging associated with credit rationing leads to a significant improvement in banks' capital adequacy ratios, wholesale lending spreads decline by about half of the increase in retail lending spreads, so that total lending spreads increase by much less. Therefore, while part of banks' response to the shock does come in the form of higher interest rates on loans, the main response is to quantities, specifically through strong quantity rationing of credit.

[23] We will however report results for borrower riskiness shocks in our analysis of the UIP puzzle in Section 7.

In the MUIP condition, the currency supply shock leads to a scarcity of domestic relative to foreign currency deposits, in other words to an increase of the relative convenience yield of domestic currency deposits, or a drop in the MUIP spread, by around 50 basis points on impact. Because of the increase in their relative convenience yield, the holders of domestic currency deposits are content with a significantly lower financial return, and therefore do not need to be compensated for the drop in the domestic real policy rate, which reaches around 20 basis points at the peak, by an expected real appreciation, with the real exchange rate in fact depreciating almost continuously following the period of the shock. Given that the shock does not change the steady state real exchange rate, this implies that the real exchange rate appreciates on impact, in this case by around 0.4%. In terms of equation (27), the effects of lower domestic relative to foreign real interest rates on the real exchange rate, which tend to depreciate it on impact through UIP effects, are more than offset by lower MUIP spreads, or a higher domestic relative to foreign convenience yield, which tend to appreciate it through MUIP effects.

In other words, ceteris paribus and also in absolute terms a reduced supply of domestic currency appreciates the real exchange rate on impact. This effect is of course as predicted, ceteris paribus, by the literature on the monetary determination of the exchange rate, which argued that *for a given policy rate* a contraction in the money supply must lead to an appreciation of the exchange rate. But while in that literature the relevant money supply was public and narrow money, and its contraction was due to a policy decision, in our model the relevant money supply is private and broad money, and its contraction is due to private commercial decisions.

Under UIP the shock remains contractionary because aggregate liquidity contracts - it is mostly the composition rather than the aggregate quantity of liquidity that changes relative to the MUIP case. In the MUIP condition, the MUIP spread now equals zero at all times, while the movement of the real policy rate remains very similar to the MUIP case, with an initial upward spike because of interest rate smoothing followed by a decline. In this case the holders of domestic currency deposits need to be compensated for lower interest rates by equally large movements in expected exchange rate changes, with an initial depreciation followed by an appreciation. The real exchange rate therefore moves very little on impact, but then depreciates by a maximum of 0.2% before returning to its steady state value.

The exchange rate effects of the shock can be decomposed into the contributions of UIP effects and MUIP effects. Under UIP we only observe the UIP effect, which ceteris paribus calls for an initial depreciation. Under MUIP the MUIP effect is strong enough to more than offset the UIP effect on impact. The nominal and real exchange rates appreciate rather than depreciate on impact, and this implies a smaller current account improvement and therefore a larger contraction of GDP. The differences in real GDP are not large. It can be shown that they increase when monetary policy exhibits less interest rate smoothing, and when nominal rigidities are stronger.

Turning now to the UIP puzzle, the impulse responses for the domestic nominal policy rate (the change in the foreign rate is approximately zero) and expected nominal depreciation show that under UIP the coefficient of the Fama (1984) regression in our model equals one, while under MUIP, as we will confirm formally in Section 7, it is negative. It can also be seen that the coefficient of the Engel (2016) regression of the excess return (the MUIP spread) on the interest differential is positive and greater than one. The reason, as discussed, is the increase in the convenience yield of domestic currency, which requires a lower financial yield on domestic currency, so that a low interest rate on domestic currency can coincide with a depreciation of the domestic currency.

6.1.2. The Role of Currency Substitutability

In Figure 5 we study the same shock as in Figure 4, but in this case we compare the MUIP economy's response under three different assumptions about the substitutability between domestic and foreign currency deposits. The baseline MUIP assumption, shown as the same black solid line as in Figure 4, assumes that $\theta_d = 1.5$, the high-substitutability alternative (HUIP), shown as the red dotted line, assumes that $\theta_d = 5$, and the low-substitutability alternative (LUIP), shown as the blue dashed line, assumes that $\theta_d = 0.25$.

The effects of the shock on domestic currency loans and deposits are similar for different values of θ_d. But the sharp decrease of domestic currency deposits has very different effects on the MUIP spread, which only drops by around 10 basis points on impact under HUIP, compared to 50 basis points under MUIP and 175 basis points under LUIP. This reflects the fact that when substitutability is lower, any given contraction of domestic currency deposits has much stronger effects on the relative scarcity of the two currencies.

Under HUIP the effect on the MUIP spread is modest and the real exchange rate experiences almost no appreciation on impact. Under LUIP, the effects on the MUIP spread are very strong and we observe an impact appreciation of around 1.4%, even though policy rates drop by more over time due to the stronger contractionary effects of the shock. Lower substitutability implies a significantly stronger real contraction because the real appreciation turns an initial improvement in the current account and trade balance under HUIP and MUIP into an initial deterioration. Finally, under low substitutability we observe no substitution towards foreign currency deposits, while there is some substitution under high substitutability. The size of θ_d is ultimately an empirical question, and in future work we hope to shed more light on this critical parameter.

6.2. Increase in Currency Demand

6.2.1. Flight to Safety

Figure 6 simulates a shock whereby domestic households' demand for the overall monetary aggregate persistently increases due to an increase in the parameter S_t^{md} in the transactions cost technology. This is a generalized increase in money demand that does not distinguish between domestic and foreign currencies. We interpret it as a "flight to safety" shock, where households hold on to their existing money balances and in addition have banks create further money balances for them, but where they do not spend this money at the same rate as before. In other words, the velocity of circulation of money declines, and this has contractionary effects on GDP.

In the financial sector, because 94% of steady state domestic monetary liquidity consists of domestic currency bank deposits, the main effect of the increased demand for money is that domestic currency deposits increase by around 7 percent of GDP, while foreign currency deposits increase by around 0.5 percent of GDP. Households obtain the additional deposits by obtaining additional bank loans, with domestic currency loans increasing by around 7 percent of GDP and foreign currency loans by 0.3 percent of GDP. This generalized increase in gross positions on bank balance sheets results in higher leverage for both borrowers and banks. Higher bank leverage is reflected in a sizeable reduction of the Basel ratio by more than 0.5 percentage points. The result is that banks, in order to avoid future regulatory penalties, start to increase their equity by increasing their wholesale lending spreads by around 40 basis points on impact. In addition, higher borrower leverage and thus higher loan-to-value (LTV) ratios increase the riskiness of borrowers, and therefore lead banks to increase their retail lending spreads by another 60 basis points on impact. The level of lending rates therefore also increases initially, but after around four quarters lending rates drop below their long-run values as the policy rate drops to counteract the contractionary effects of the shock.

In the real economy, GDP declines by around 1.4% after one year, triggered by a shortage of money that increases the effective purchase price of consumption goods by more than 3%. The reduction in aggregate demand reduces inflation, and as the nominal policy rate is reduced in response, the real policy rate initially spikes up by around 40 basis points due to interest rate smoothing, but then drops by almost 30 basis points by the end of the second year following the shock. Under UIP, because the foreign real policy rate only changes minimally, this triggers an initial real exchange rate depreciation by around 0.35 percent followed by an appreciation, while the nominal exchange rate is approximately constant on impact and thereafter appreciates. Under MUIP, we observe that this shock represents a relative increase in global demand for domestic currency, because foreign money demand does not change significantly while the increase in domestic money demand heavily favors domestic currency. This results in an increase in the relative scarcity of domestic currency, and therefore in a decrease, by eventually around 10 basis points, in the MUIP spread. This increase in the relative convenience yield of domestic currency means that under MUIP, despite a slightly deeper cut in the policy rate due to a stronger real contraction, the domestic real exchange rate needs to depreciate by less on impact to subsequently make households indifferent between holding domestic and foreign currencies. As a result, the real exchange rate is approximately unchanged on impact while the nominal exchange rate appreciates. To summarize, an increase in demand for domestic currency, similar to a decrease in supply of domestic currency, ceteris paribus (relative to the UIP case) leads to an appreciation of the domestic currency.

The flight to safety shock does not contribute to explaining the UIP puzzle. The reason is that while the relative increase in global demand for domestic currency leads to a drop in the MUIP spread, the size of this effect is not large, reaching less than 10 basis points compared to a drop in the nominal policy rate of around 40 basis points. The lower MUIP spread does reduce the size of the exchange rate appreciation that households require in order to be content to hold a domestic currency that pays a significantly lower interest rate, but the exchange rate still needs to appreciate, so that the regression coefficient of the Fama (1984) regression must be positive, as we will confirm in Section 7. Similarly, while the regression coefficient of the Engel (2016) regression is positive, it is clearly smaller than one, as the MUIP spread drops by considerably less than the interest rate differential. The reason for these results is that the flight to safety shock predominantly represents a contractionary aggregate demand shock that requires a significantly lower policy rate, and that tends to depreciate the exchange rate through standard UIP channels. The MUIP effect due to changes in relative currency demands is present, but it is weak relative to the UIP effect. In this sense, as we will see below, the flight to safety shock is similar to other aggregate demand shocks.

A practically very relevant variation on Figure 6 is a shock whereby a flight to safety is part of a wider deterioration in financial market conditions. This is shown in Figure 7, which assumes that the increase in demand for bank deposits is accompanied by a decrease in the supply of bank deposits as in Figure 4. The result is a significantly deeper real contraction and larger real exchange rate movements. The logic of both Figures 4 and 6 remains intact, but of course balance sheet positions in domestic currency show much smaller overall changes because the increase in demand and decrease of supply of bank deposits approximately cancel each other out. This shock illustrates that purely financial shocks can have especially powerful effects on the real economy when changes in sentiment affect both bankers and their customers.

6.2.2. Flight to the Dollar

Figure 8 simulates a shock whereby domestic households' demand for foreign currency increases due to a decrease in the parameter S_t^{mm} in the monetary aggregate D_t^{liq}. This is a "flight to the dollar" shock, where safety is perceived to be available from foreign but not from domestic currency.

In the MUIP condition, this shock leads to a sharp increase of around 275 basis points in domestic households' relative convenience yield of foreign currency, and therefore to a much higher required relative financial return on domestic currency. Because only a small part of this change in return is obtained through an increase in the domestic interest rate, investors in domestic currency must be compensated by a large expected rate of real exchange rate appreciation. Given an unchanged steady state real exchange rate, on impact the real and nominal exchange rates therefore depreciate by almost 4%. Because foreign households do not experience the same shock to their currency demand, while by equation (26) MUIP spreads need to be approximately arbitraged worldwide, they respond to the change in relative financial returns by increasing their relative holdings of domestic currency deposits, which has the effect of bringing their relative convenience yield into line with that of domestic households.[24]

In the financial sector, we observe a very large switch of around 12% of domestic GDP in the currency composition of domestic households' deposit holdings, away from domestic currency and towards foreign currency. Because the shock is not accompanied by a corresponding change in banks' willingness to extend credit in either currency, the currency composition of loans changes by much less than that of deposits (-1.4% and +0.6%). Foreign currency loans increase when they are, as in Figure 8, converted to domestic currency using the heavily depreciated exchange rate. In foreign currency and in percentage terms, these loans in fact decrease by more than domestic currency loans.

It is important to observe that this shock represents a change in the currency composition of households' gross financial positions, not a movement of physical savings from Home to Foreign. In Home, the direct cross-border effect of households' portfolio reallocation is therefore not on net foreign asset positions but on gross interbank positions. Interbank deposits in both currencies do not exhibit large changes because they are mostly determined by the underlying transactions demand functions. But interbank loans change strongly because domestic banks ceteris paribus experience a currency mismatch following the sharp increase in foreign currency net liabilities vis-à-vis domestic households. These must, due to the FXMR rule, be eliminated through an equal increase in foreign currency net assets vis-à-vis foreign banks. Banks therefore reduce their foreign currency interbank loans from foreign banks by around 10% of domestic GDP. Because the impact change in the net foreign asset position, which consists of the net sum of the four interbank items, is necessarily small because it represents the accumulation over time of physical flows, the decrease in foreign currency interbank loans is matched by an approximately equal decrease in domestic currency interbank loans to foreign banks. In Foreign, banks satisfy their local FXMR rule because the counterpart to the decrease in foreign banks' domestic currency interbank liabilities is the above-mentioned increase in foreign households' domestic currency household deposits, triggered by the increased financial return on domestic currency deposits. Net of loans, the foreign increase (decrease) in net holdings of domestic (foreign) currency deposits equals around 0.2% of foreign GDP, with the much smaller numbers of course reflecting the great difference in country sizes. The final result is that domestic banks' overall balance sheet shrinks by around 10% of GDP. This rapid deleveraging explains an increase in the Basel ratio of almost 1.2 percentage points.

[24] This can be seen in the impulse responses for the foreign economy, which are omitted to conserve space.

In the real economy, GDP increases by around 0.6% on impact. The reason is not an increase in the quantity of monetary liquidity - in fact aggregate liquidity decreases slightly and the effective purchase price of consumption increases accordingly. Rather, it is driven by the 4% real exchange rate depreciation, which boosts the external balance and thereby GDP, and leads to an increase in inflation. The latter triggers the above-mentioned increase in the policy rate, which slightly attenuates the initial depreciation triggered by the MUIP effect.

While under MUIP an increase in demand for foreign currency leads to a depreciation of the domestic currency and an increase in GDP, under UIP, which is shown as the red dotted lines in Figure 8, the shock has no effects at all on prices and allocations. This shock is purely financial, with no direct effects on the real economy such as those observed under standard business cycle shocks or flight to safety shocks, yet under MUIP its indirect effects, through financial and exchange rate markets, trigger significant real effects. We see this as a fundamental contribution of our model.

Figure 8 shows that the flight to the dollar shock can account for the UIP puzzle. The primary and direct effect of the shock is an increase in the relative convenience yield of foreign currency, which is approximately equal to the excess return of domestic currency. Because this shock leads to a strong exchange rate depreciation on impact, it also increases GDP, inflation and the policy rate, but these effects are secondary and much weaker, with the increase in the MUIP spread and in exchange rate appreciation more than ten times larger than the increase in the interest differential. As a result, as we will confirm in Section 7, the regression coefficients of the Fama (1984) and Engel (2016) regressions are negative and large and positive and large, respectively.

6.3. Standard Business Cycle Shocks

6.3.1. Transitory Monetary Policy Shock

Figure 9 studies a transitory but persistent ($\rho^{int} = 0.95$) contractionary shock S_t^{int} to the nominal policy rate. The real interest rate immediately increases by around 180 basis points due to a rapid drop in inflation. In the real economy, this triggers a contraction in consumption demand of about 0.9%. In the financial sector, the size of bank balance sheets is driven by two main factors, changes in demand for credit due to changes in real activity, which does drop in response to the policy rate, and changes in the spread of lending rates over deposit rates, which does not change appreciably. As a result, the effect of the monetary policy shock on the quantities of loans and deposits is roughly in proportion to the drop in GDP. The MUIP spread increases due to a recession-induced drop in the relative demand for domestic currency, which reduces its relative convenience yield. But this effect is small, at only around 3 basis points, relative to the drop in nominal policy rates and in nominal exchange rate depreciation. The reason is that this shock, even more so than the flight to safety shock above, is predominantly a contractionary aggregate demand shock that has strong UIP effects but weak MUIP effects. The impulse responses of the UIP and MUIP models are therefore similar, and are familiar from standard New Keynesian monetary business cycle models. Furthermore, as we will see in Section 7, among all the shocks in the model this is the one least able to address the UIP puzzle.

6.3.2. Permanent Monetary Policy Shock

Figure 10 pursues the lead of Schmitt-Grohé and Uribe (2018), who find that permanent increases in nominal interest rates have the opposite effects of transitory increases, as they lead to a short-run depreciation rather than appreciation, and excess returns that move against rather than in favor of domestic assets. Figure 10, which simulates a one-off permanent 1 percentage point increase in the inflation target $\bar{\pi}^p$, confirms that this is also true in our model. The main effect of this shock is an immediate increase in inflation that temporarily decreases the real interest rate, thereby stimulating consumption and GDP. Furthermore, the lower real interest rate depreciates the real exchange rate through UIP channels, and thereby further stimulates the economy through a current account improvement. The domestic currency excess return falls by around 2 basis points, compared to the 3 basis points increase in Figure 9. The reason can again be found in the relative excess supplies of the two currencies, as the increase in GDP leads to an excess demand and thus a higher relative convenience yield for domestic currency. The magnitudes of these spread differentials of course depend on other aspects of the model calibration, most importantly on the elasticity of substitution between the two currencies (see Figure 5), but their sign is consistent with Schmitt-Grohé and Uribe (2018).

6.3.3. Consumption Demand Shock

Figure 11 studies a transitory but persistent ($\rho^c = 0.7$, with habit persistence adding to persistence) contractionary shock S_t^c to consumption demand. The shock leads to a drop in GDP of around 1% after two quarters, accompanied by a current account improvement of almost 0.2 percent of GDP. The real contraction is accompanied by a drop in marginal cost. As a result the rate of inflation declines by around 35 basis points, and the policy rate responds by dropping by a maximum of 22 basis points in nominal terms, and by a maximum of around 15 basis points in real terms. Under UIP, the drop in the real policy rate (after an initial upward spike due to interest rate smoothing) ceteris paribus leads to a depreciation of the real exchange rate via the UIP channel. Under MUIP this depreciation becomes a small appreciation.

The difference between the UIP and MUIP models is due to the effect on bank balance sheets of the accumulation of net foreign assets. As an increasing share of Home production is exported and paid for by Foreign households, Home households accumulate additional deposits in exchange for goods. As a result they require fewer bank loans (in both currencies) while holding larger deposits (in both currencies), with this imbalance matched by an improving interbank position of Home versus Foreign banks. Because the great majority of Home bank loans and bank deposits is in Home currency, this implies that the relative global supply of Home currency decreases while the relative global demand for Home currency increases. Developments in Foreign mirror those in Home and reinforce the effects on relative currency supplies. Specifically, Foreign households need to pay for additional imports, and to do so they obtain additional loans from Foreign banks. Because the great majority of those loans is in Foreign currency, this implies that the relative global supply of Foreign currency increases. Foreigners spend this additional currency for their imports, so that the relative global demand for Foreign currency decreases. Again, the imbalance is matched by a deteriorating interbank position of Foreign versus Home banks. The change in interbank positions is roughly evenly split between the two currencies, with an increase in Home currency loans by and a decrease in Foreign currency loans to Home banks. However, banks need to continue to satisfy their FXMR rules, and opportunity costs therefore adjust to ensure that the decrease in Foreign currency interbank loans is matched by an increase in Foreign currency retail deposits. As a result, Home households hold an increasing share of their deposits in Foreign currency, while by a similar chain of arguments Foreign households hold a decreasing share of their deposits in Home currency. This, ceteris paribus, decreases the relative convenience yield of Foreign currency, and by equation (27) this leads to an appreciation, ceteris paribus, of the Home currency. The strength of this effect is sufficient to eliminate the initial real exchange rate depreciation that is observed under UIP. This in turn implies a smaller current account improvement than under UIP, and a larger contraction in GDP. However, the difference in real outcomes is very small. The reason is that the shock itself is real, and its direct effect on GDP is much larger than the indirect effect through the exchange rate and the current account.

Through arguments that are by now familiar, this implies that consumption demand shocks are unable to address the UIP puzzle. Specifically, the above-mentioned effects on the MUIP spread do imply that expected exchange rate appreciation does not need the match the decline in domestic policy rates one for one for households to remain content to hold domestic currency. But this effect is small, and as a result, as we will confirm in Section 7, a regression of exchange rate depreciation on the interest rate differential produces a positive and high coefficient, while a regression of the excess return on the interest differential produces a coefficient that is positive but well below 1.

6.3.4. Technology Shock

Figure 12 studies a contractionary and persistent ($\rho^a = 0.95$) shock S_t^a to technology. The shock leads to a drop in GDP of 1% after around one year, accompanied by a current account deterioration of around 0.1 percent of GDP. The real contraction is accompanied by an increase in marginal cost, so that the rate of inflation increases by 100 basis points. In response the real policy rate increases by 25 basis points (after an initial downward spike due to interest rate smoothing). The increase in the real policy rate leads to an appreciation of the real and nominal exchange rate on impact via the UIP channel. However, under MUIP this appreciation is weaker, and consequently the current account deterioration is smaller.

For an explanation, we again turn to bank balance sheets. We note that while in Figure 11 the size of bank balance sheets increases relative to GDP, this is not true for Figure 12, where bank balance sheets decline roughly in line with GDP, but by slightly less than GDP. The reason is that technology shocks, unlike consumption demand shocks, affect the value of collateral directly via their effect on the gross financial return to land, and therefore reduce banks' willingness to lend by approximately as much as GDP.

The difference between the UIP and MUIP models in Figure 12 is due to the combined effect of two factors, the effect of the decumulation of net foreign assets on bank loans and bank deposits and the effect of the real appreciation on the value of existing holdings of foreign currencies.[25] The first factor is familiar from Figure 11 but with the signs reversed. Home current account deficits increase the relative supply of domestic currency, thereby reducing its relative convenience yield and increasing the MUIP spread. The second factor is the effect of the exchange rate appreciation itself. For given loan supplies and deposit demands, this reduces the relative value of Foreign currency holdings in the two economies' MUIP spreads, thereby contributing to the relative excess supply of Home currency and the increase in the MUIP spread. This increase in the MUIP spread, ceteris paribus, by equation (27) tends to depreciate the Home currency, thereby partly offsetting the appreciation that is due to the UIP channel. A smaller appreciation implies a smaller current account deterioration than under UIP, and therefore a smaller contraction in GDP. But as in Figure 11, the difference is small. The reason is the same, namely the fact that the shock itself is real, so that its direct effect on GDP is much larger than the indirect effect through the exchange rate and the current account. We note that both in Figure 11 and 12 monetary effects serve to attenuate

[25] Recall that for the consumption demand shock the change in the real exchange rate is small and can therefore be neglected in our discussion of balance sheets.

the effects of the shock on real exchange rates and current accounts. Finally, for nearly identical reasons as in Figure 11, technology shocks are unable to address the UIP puzzle.

6.4. General Comments

It is useful to discuss the above impulse responses in terms of excess supplies of goods and currencies. We use the technology shock as our point of departure.

For goods, this shock directly leads to a reduction in domestic production, in other words to an excess demand for domestic goods in the world economy. This drives up the prices of domestic goods, which explains the real exchange rate appreciation. For currencies, the shock leads to an excess supply of domestic currency in the world economy. This drives down the convenience yield of domestic currency, which explains the real exchange rate depreciation relative to the UIP case. For any shock, the interaction of these two excess demands determines the overall change in the exchange rate and in real variables. For shocks with predominantly real effects as in those of Figures 11-12 (and also of Figures 6, 9 and 10), the goods market effects are primary, but they do feed back through the financial system to modify the exchange rate, current account and output responses. For shocks with predominantly financial effects as in Figures 4 and 8, the currency market effects are primary, but they do feed back through the real economy to modify the exchange rate and output responses. We consider these clear and traceable feedback effects between goods and currency markets to be a very attractive feature of our model.

The fact that contractionary business cycle shocks do not have more serious effects on the financial sector also requires some further discussion. We have noted that for contractionary technology shocks the value of collateral (land) declines by about the same percentage as GDP. This would not change if the model was enriched by allowing for other common forms of collateral, particularly flow collateral such as corporate revenue or labor income, because they would also tend to decline roughly in proportion to GDP. Because collateral is critical for banks' willingness to lend, in such cases the financial sector will therefore generally contract by approximately as much as the real economy. This changes slightly for contractionary demand shocks, but the differences are not very large. Therefore, scenarios whereby the financial sector contracts sharply but independently of the real economy, and where the financial contraction becomes the driver of a real contraction, require other shocks, particularly financial shocks such as the relative credit supply and currency demand shocks discussed in Figures 4 and 8.

7. Shocks and Puzzles

Table 2 studies the ability of the different shocks of the MUIP model to address a number of puzzles in open economy macroeconomics, with a focus on the UIP puzzle but with some additional statistics on the Meese-Rogoff (1983) and PPP puzzles. The table is based on Table 2 in Itskhoki and Mukhin (2017), and the data column is taken directly from that paper.

We generate Table 2 by running, for each shock separately, 1000 stochastic simulations of 1100 quarters each. For each simulation we discard the first 100 observations and then compute the relevant statistics. The values reported in Table 2 are the means over all 1000 simulations of each statistic, with standard errors reported in brackets.

The table addresses three puzzles in open economy macroeconomics. The UIP puzzle is that according to the UIP relationship an increase in a country's nominal interest rate relative to foreign rates should predict a nominal exchange rate depreciation, while the data do not support this prediction. Specifically, in a regression of exchange rate changes on interest differentials the coefficient on interest differentials is negative (Fama (1984)), which means that an increase in the domestic interest rate is associated with an appreciation, but this regression generally has a very low R^2. Alternatively, in a regression of currency excess returns on interest differentials the coefficient on interest differentials is positive and greater than one (Engel (2016)), which means that an increase in the domestic interest rate is associated with a positive excess return on the domestic currency. The Meese and Rogoff (1983) exchange rate disconnect puzzle is that the best empirical predictor of the future nominal exchange rate is the current nominal exchange rate, while macroeconomic fundamentals do not robustly contribute to explaining future exchange rate changes. Specifically, nominal exchange rate changes are very volatile and exhibit close to zero autocorrelation. The PPP puzzle is that the real exchange rate is highly correlated with the nominal exchange rate, with very similar volatility, and that it exhibits very high autocorrelation (Rogoff (1996)).

For the UIP puzzle, the top half of Table 2 presents the regression coefficient of the interest differential β_{Fama} and the R^2 of the Fama (1984) regression, as well as the regression coefficient β_{Engel} of the interest differential of the Engel (2016) regression and the ratio of standard errors of the interest differential and the rate of exchange rate depreciation. As discussed above, in empirical studies β_{Fama} is generally found to be negative, with an R^2 close to zero, β_{Engel} is found to be positive and greater than one, and the ratio of standard errors is close to zero. We find that the model's predominantly real shocks, including the flight to safety, consumption demand, technology and monetary policy shocks, are not consistent with any of these four results, with β_{Fama} of 0.63 or above, R^2 of at least 0.12, and a ratio of standard errors of at least 0.38. On the other hand the currency demand or flight to the dollar shock, similar to the results of Itskhoki and Mukhin (2017), is mostly consistent with these results, with a highly negative β_{Fama}. The sole exception may be the still relatively high R^2 of 0.09. The two currency supply shocks, the willingness-to-lend shocks and borrower riskiness shocks, are also mostly consistent with these results, with a β_{Fama} of, respectively, -0.23 and -0.12, and extremely low R^2. The sole exception here may be the still relatively high ratio of standard errors of, respectively, 0.27 and 0.30.

For the Meese-Rogoff and PPP puzzles, the bottom half of Table 2 presents the autocorrelation coefficient of the rate of nominal exchange rate depreciation, which is very close to zero in the data, the correlation coefficient between changes in nominal and real exchange rates, which is very close to 1 in the data, the ratio of standard errors of changes in nominal and real exchange rates, which is also very close to 1 in the data, and finally the autocorrelation coefficient of the real exchange rate, which equals around 0.95 in the data. We find that the model's predominantly real shocks are able to account for the high autocorrelation of the real exchange rate, mainly because these shocks are calibrated as being highly persistent. However, these shocks cannot account for the other statistics, with significantly positive autocorrelation of nominal exchange rate depreciation of at least 0.18 and a correlation between nominal and real exchange rate depreciation of between 0.60 and 0.84. The relative currency demand and currency supply shocks do less well on the autocorrelation of the real exchange rate, with coefficients around 0.7, but it can be shown that this changes when these shocks are calibrated as being more persistent. On the other hand, these shocks do well for the other statistics, with significantly negative (but not too large in absolute value) autocorrelation of exchange rate depreciation of around -0.12 and a correlation between nominal and real exchange rate depreciation of 0.96 or higher. All of these shocks are therefore very promising candidates to improve the performance of open economy models in several dimensions.

8. Conclusions

The monetary theory of exchange rate determination was very popular among academics and policymakers in the 1970s and 1980s, but it has since been mostly abandoned in favor of UIP-based theories. In this paper we argue that this may have been premature, both because UIP-based theories have not been significantly more successful empirically and because the monetary theory did have important theoretical merits. However, at the time these merits were outweighed by two shortcomings. The first is the assumption of fixed interest rates that do not respond systematically to the state of the economy. The second is the assumption that the supply of currencies is exogenous, and can be represented by narrow monetary aggregates that are determined by central banks, rather than being endogenous and represented by broad monetary aggregates that are determined by the profit-maximizing decisions of commercial banks and their customers. We argue that not only the first but also the second of these shortcomings can be addressed, and that the theory's merits can thereby be salvaged, and can be used to significantly improve upon exclusively UIP-based theories, by creating hybrid models that incorporate key insights from both theories. This also has the potential of addressing the lack of empirical success of both theories.

We offer a modern open economy DSGE model that is built around such a hybrid model of exchange rate determination, and we refer to this as the monetary UIP (MUIP) model. In this model the relative demands and supplies of different currencies are important determinants of deviations from uncovered interest parity, and are therefore an important co-determinant of exchange rates, along with relative interest rates and relative demands and supplies of goods as in UIP models. This co-determinant gains in importance as the substitutability between the two currencies as a means of payment decreases, and as the importance of shocks to the relative demands and supplies of currencies increases relative to that of shocks to the relative demands and supplies of goods. Especially for this latter category of shocks there are major differences in the behavior of MUIP and UIP models. For standard business cycle shocks the differences between the two models are smaller but nevertheless significant, with monetary effects dampening the effects of business cycle shocks on the real exchange rate and on current accounts. The general observation is that in this model exchange rate determination is driven jointly by the relative demands and supplies of both goods and currencies, with interactions and feedback effects between the two that are present for all shocks.

These results have the potential to improve the empirical performance of open economy macroeconomic models in several dimensions, including through the introduction of well-designed proxies for relative currency demands and credit supplies in reduced form regressions, and through the introduction of structural shocks to relative currency demands and credit supplies that allow the models to address several well-known puzzles in open economy macroeconomics, most importantly the UIP puzzle.

Appendix

The credit conditions surveys used for the US, UK, euro area and Japan are all conducted on a quarterly basis. The Bank of England's survey has been conducted since 2007, encompasses around 30 lenders, and accounts for around 75-85% of total loans outstanding.[26] The US Federal Reserve's Senior Loan Officer Opinion Survey has been conducted since 1967, and currently encompasses 80 domestic lenders and 24 US agencies of foreign banks.[27] The Bank of Japan's survey has been conducted since 2000, encompasses 50 lenders, and accounts for 76% of total loans outstanding.[28] The euro area's Bank Lending Survey (BLS) has been conducted since 2003, and encompasses around 150 banks representing all euro area countries.[29]

The survey questions that were used for the purpose of our paper are listed below:

- UK - Question 5: How have the following price and non-price terms on approved new loan applications by households changed over the latest 3 months relative to the previous 3 months. Of which: spreads on prime lending.
- US - Question 13a: Over the past three months, how have your bank's credit standards for approving applications from individuals for mortgage loans to purchase homes changed? (Please consider only new originations as opposed to the refinancing of existing mortgages.)
- Japan - Question 7: Over the past three months, how have your bank's credit standards for approving applications for loans from firms and households changed?
- Euro area - Question 12b: Over the past three months, how have your bank's terms and conditions for new loans to households for house purchase changed?

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[26] See https://www.bankofengland.co.uk/quarterly-bulletin/2007/q3/the-bank-of-england-credit-conditions-survey.

[27] For further information about the US Federal Reserve's Senior Loan Officer Opinion Survey please see https://www.federalreserve.gov/data/sloos.htm.

[28] See http://www.boj.or.jp/en/statistics/outline/note/notest33.htm/#cdab1100.

[29] For more detailed information regarding the BLS please see the user guide.

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Figure 1: Overview of the Model Economy

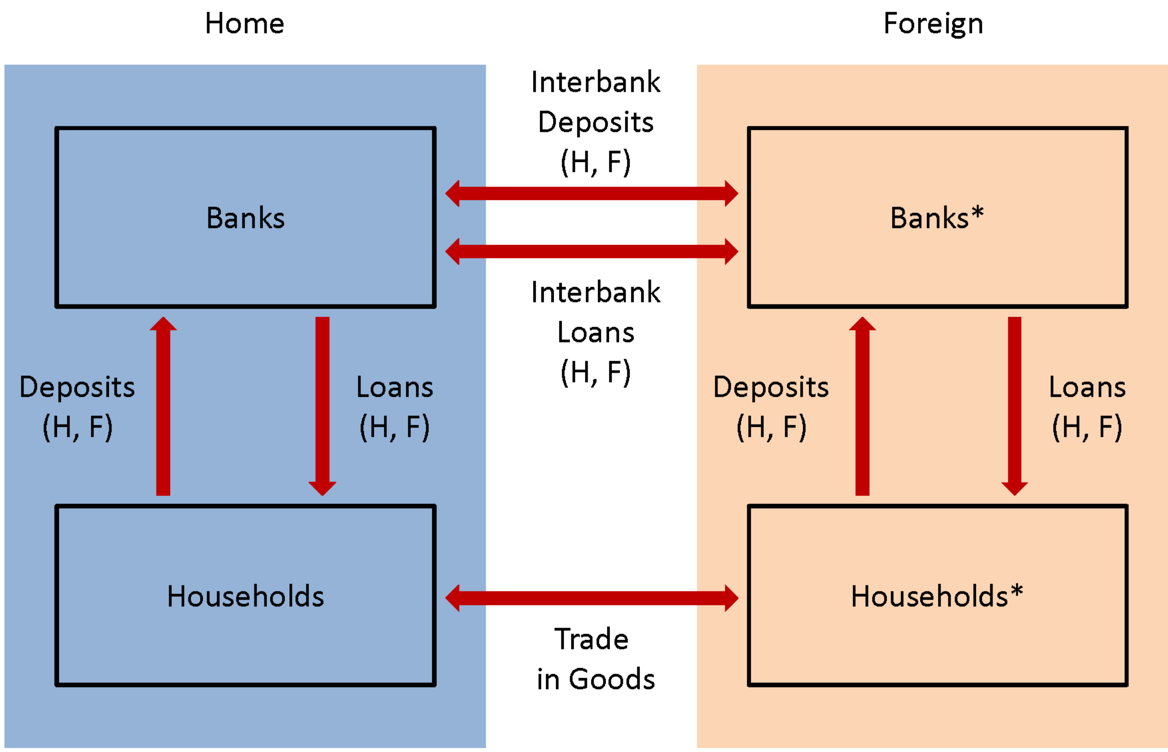


Figure 2: Interest Rate and Convenience Yield on Money

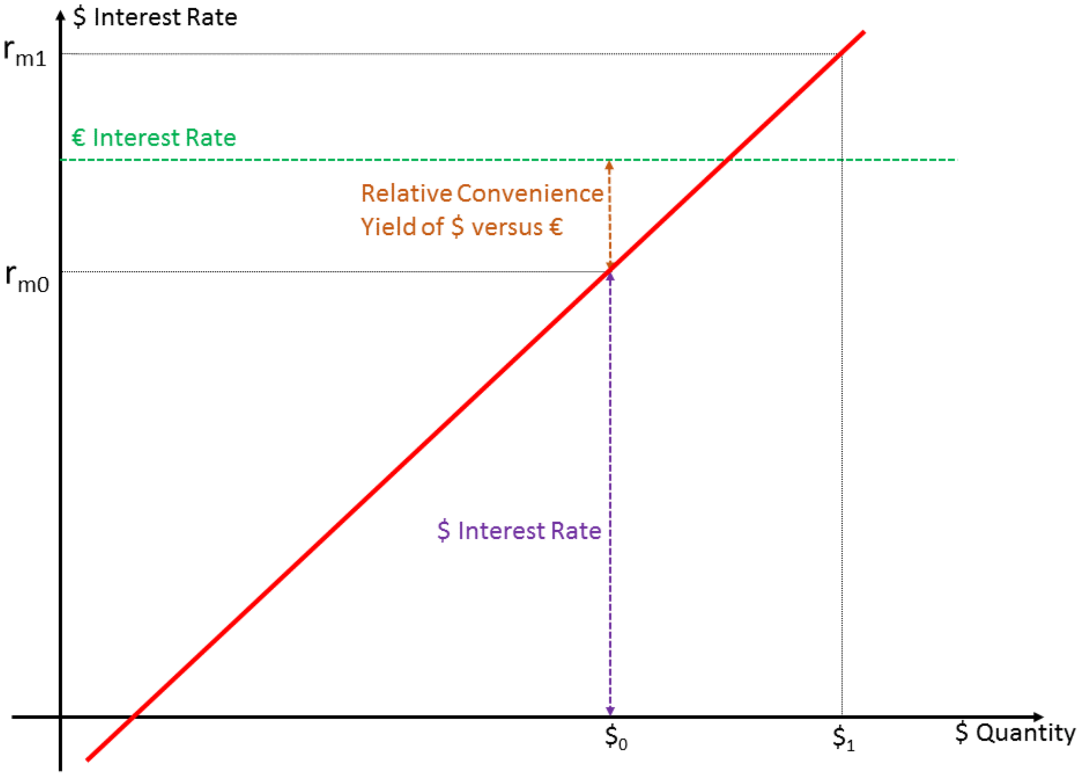


Figure 3: Calibration of Interest Rates

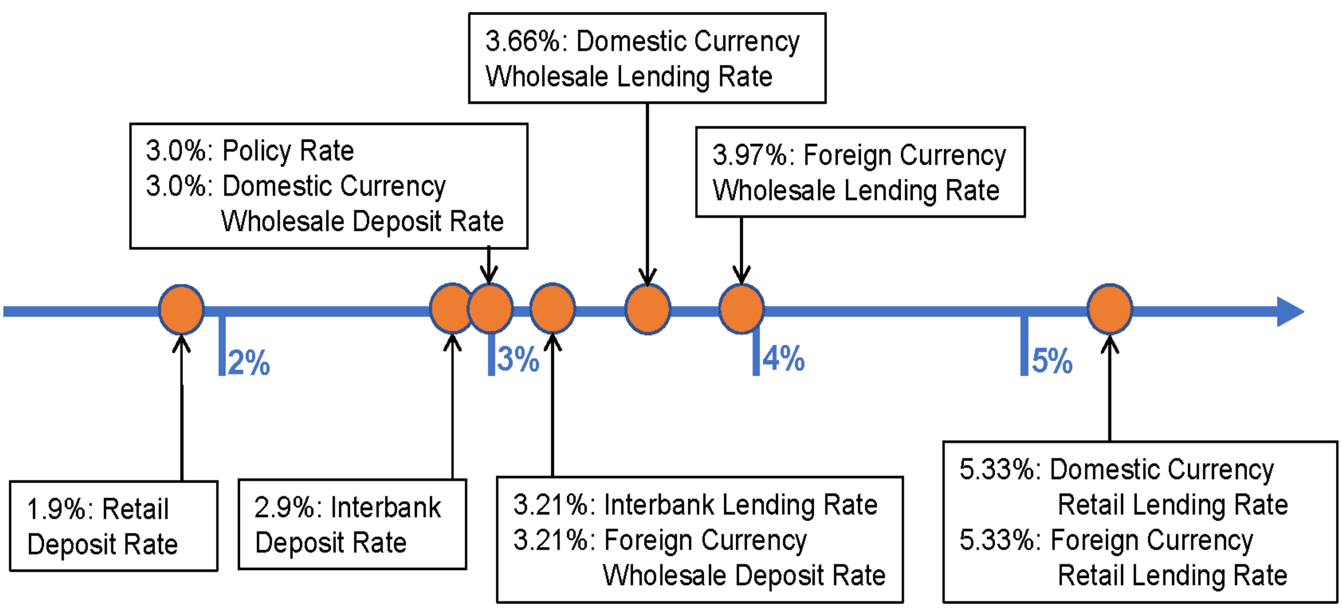
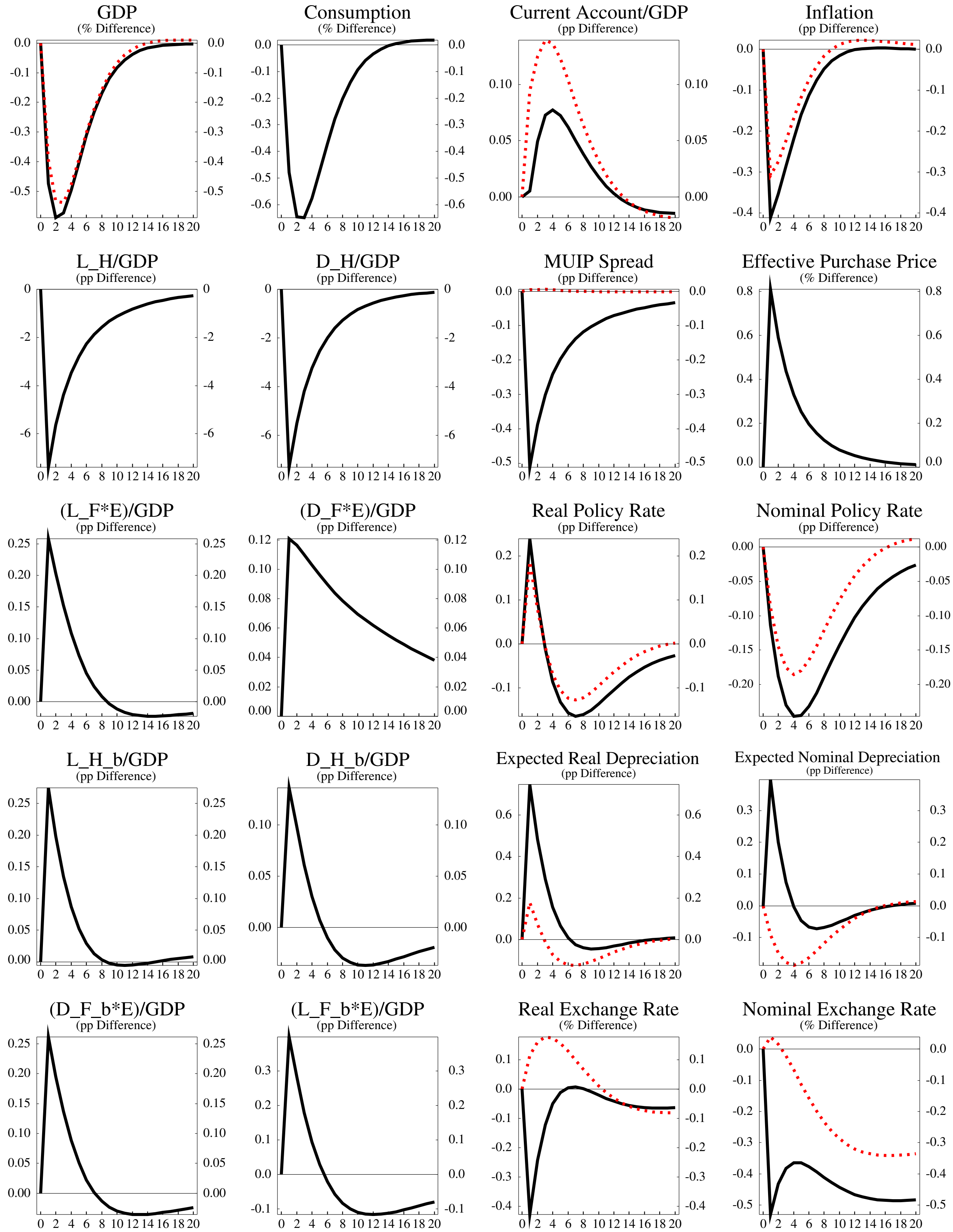
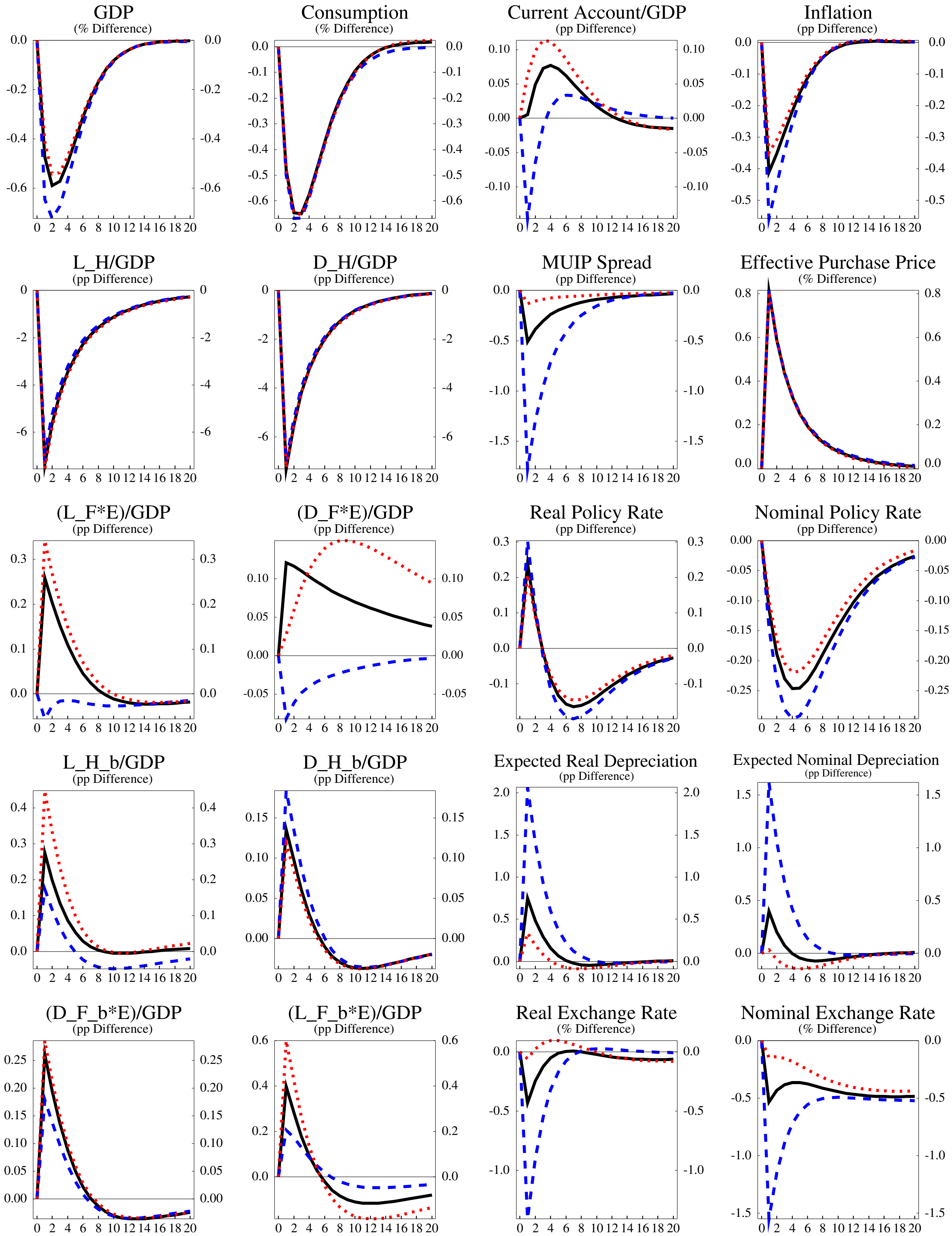


Figure 4: Decrease in Home Currency Supply



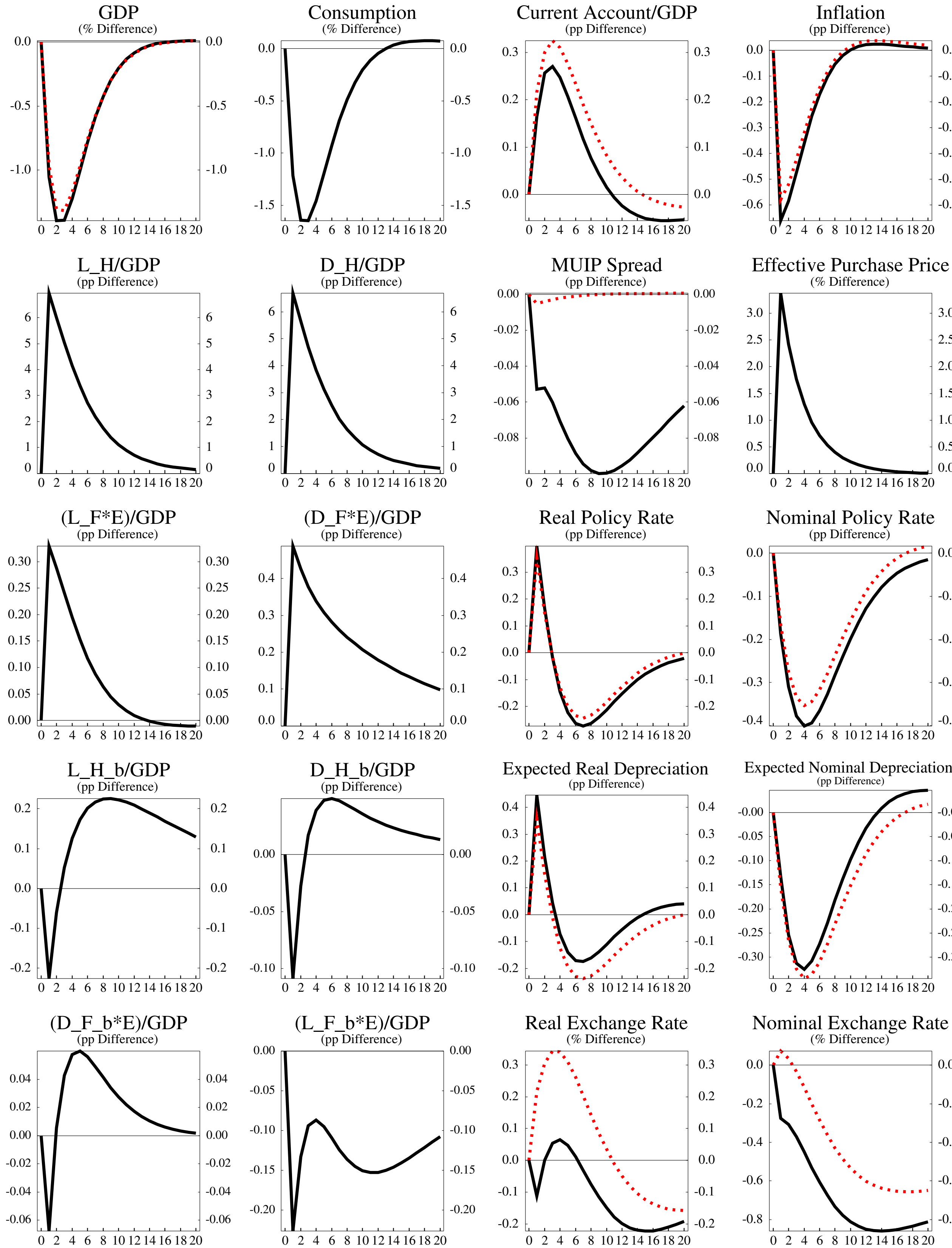
Solid Lines (black) = Baseline Calibration, Dotted Lines (red) = UIP

Figure 5: Decrease in Home Currency Supply - Different θ_d



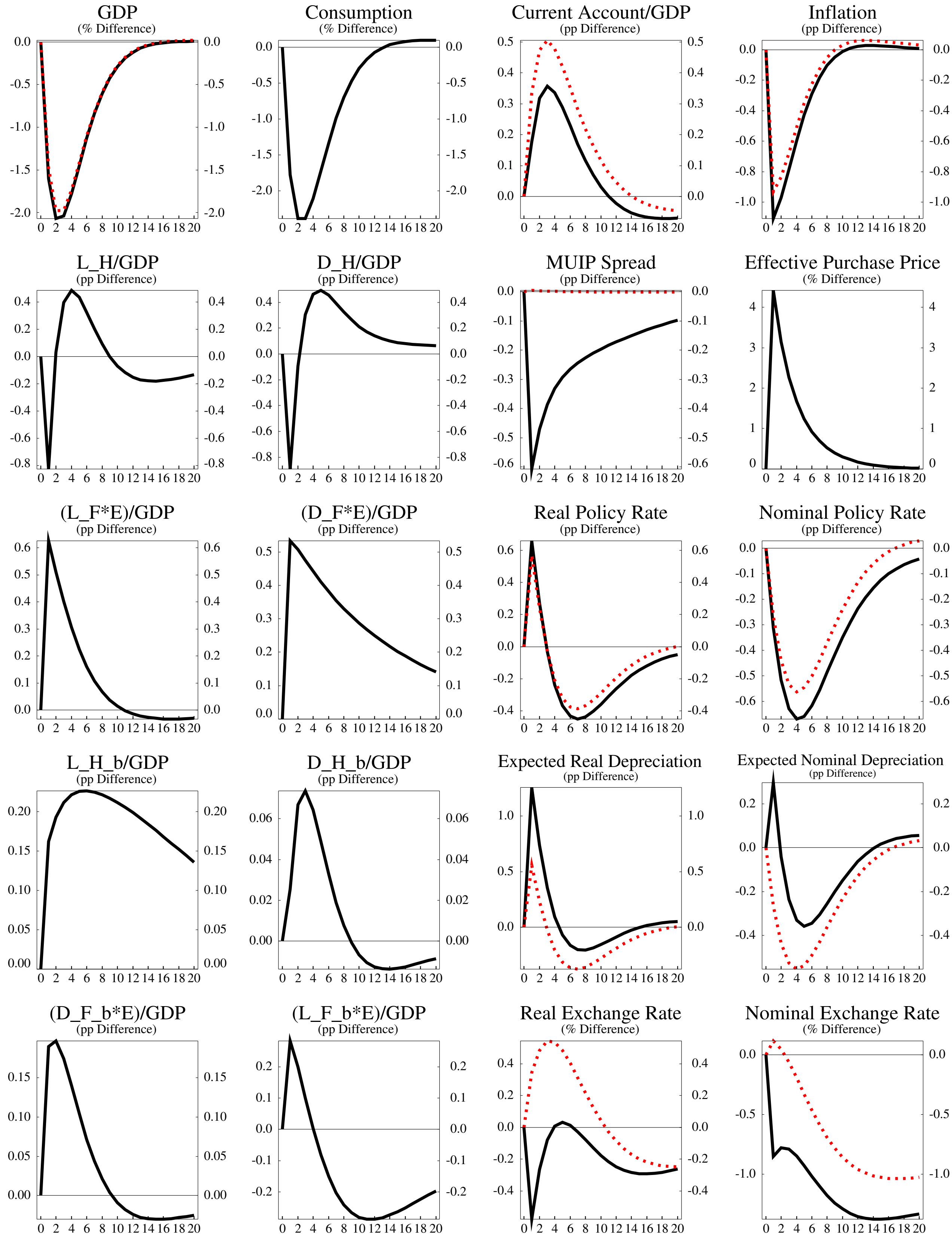
θ_d: Solid Lines (black) = 1.5, Dashed Lines (blue) = 0.25, Dotted Lines (red) = 5

Figure 6: Increase in Currency Demand - Flight to Safety



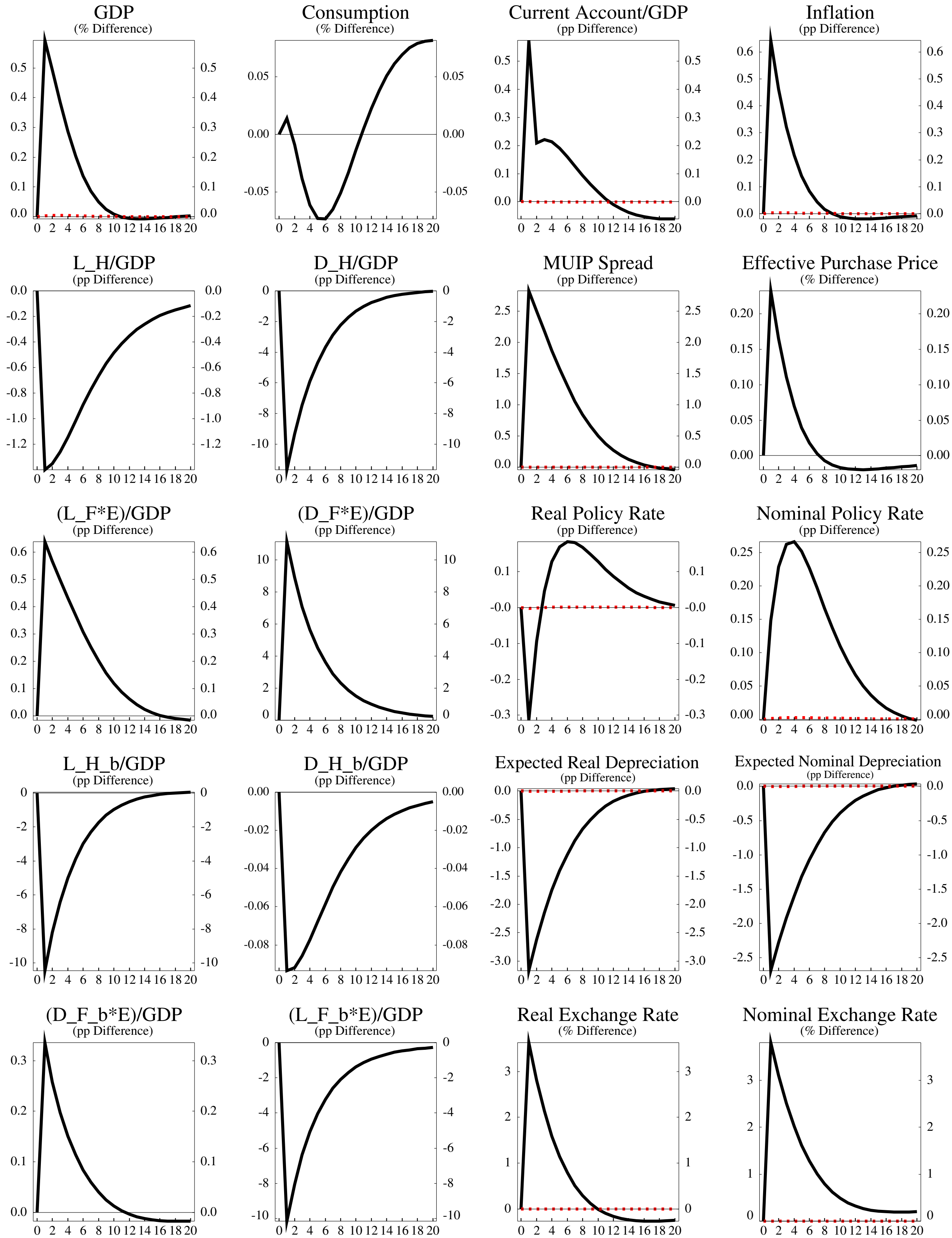
Solid Lines (black) = Baseline Calibration, Dotted Lines (red) = UIP

Figure 7: Flight to Safety and Decrease in Home Currency Supply



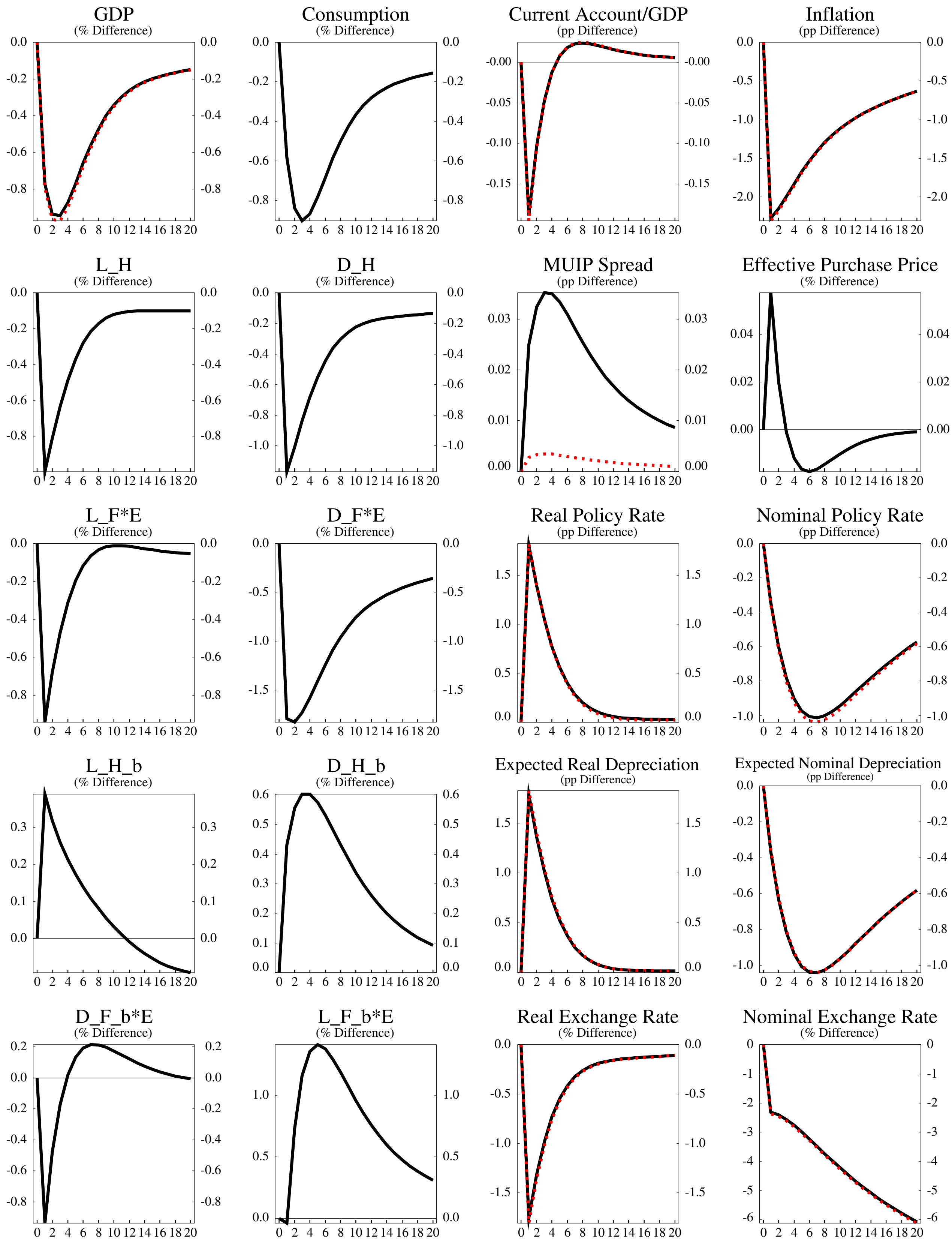
Solid Lines (black) = Baseline Calibration, Dotted Lines (red) = UIP

Figure 8: Increase in Currency Demand - Flight to the Dollar



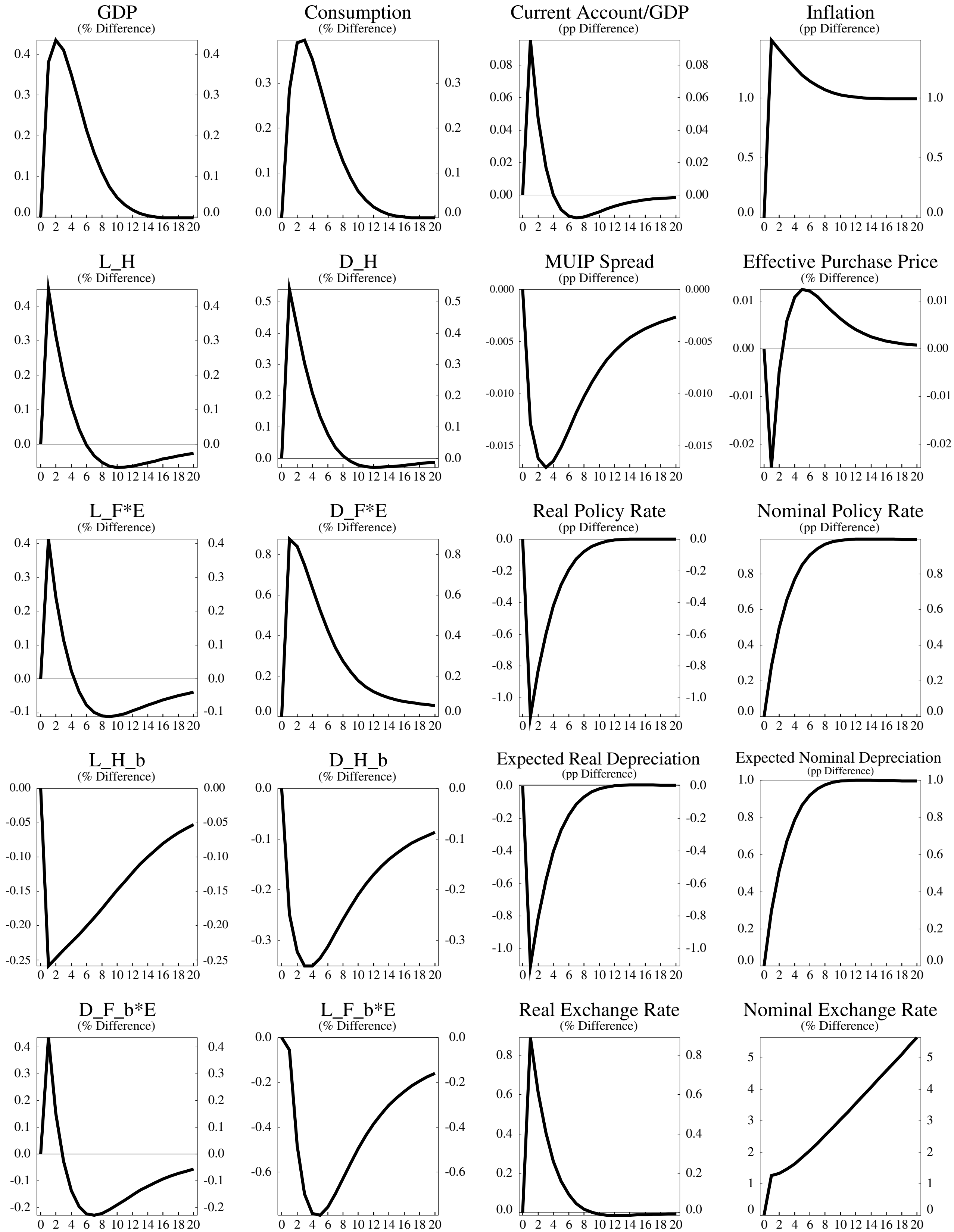
Solid Lines (black) = Baseline Calibration, Dotted Lines (red) = UIP

Figure 9: Transitory Monetary Policy Shock



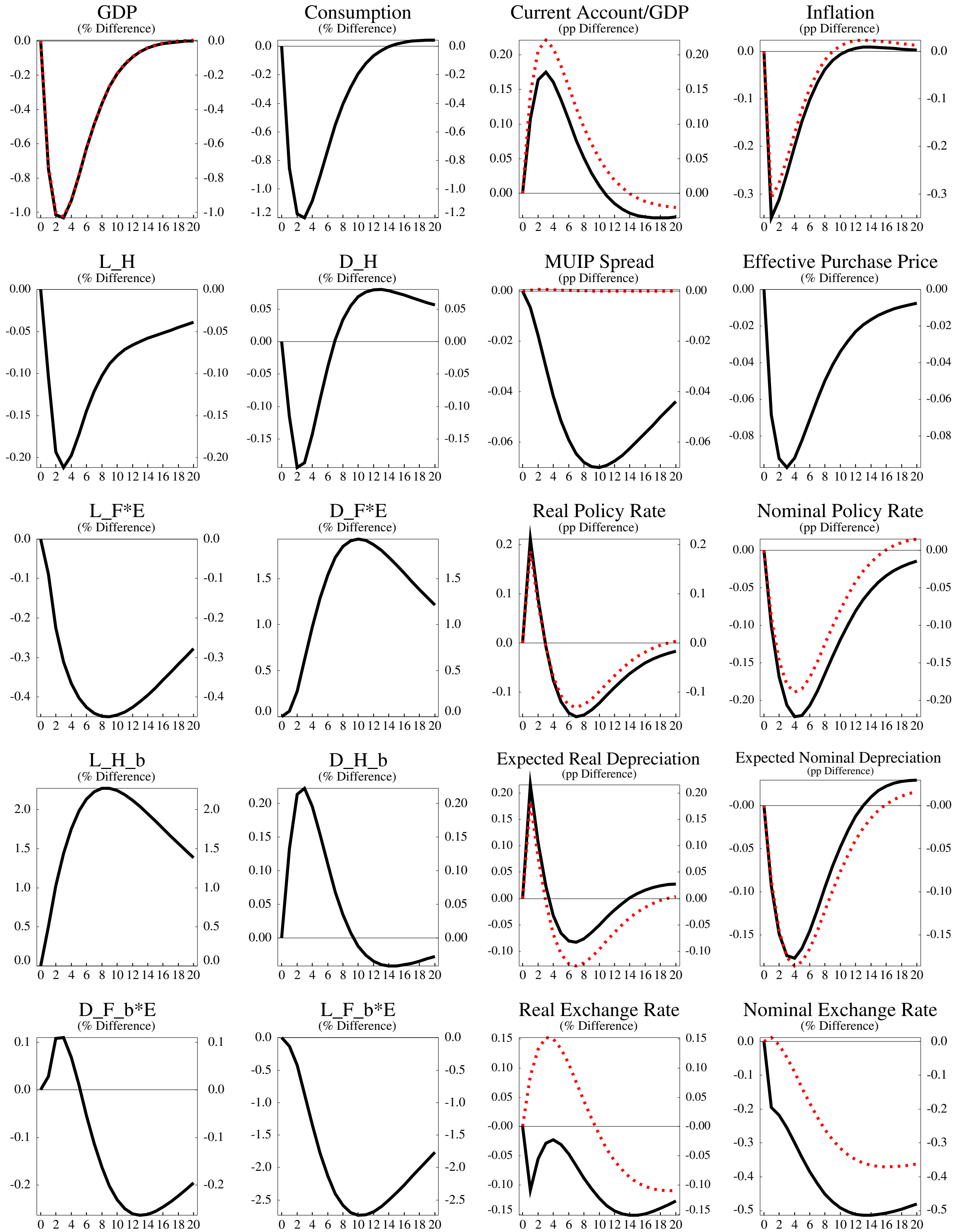
Solid Lines (black) = Baseline Calibration, Dotted Lines (red) = UIP

Figure 10: Permanent Monetary Policy Shock



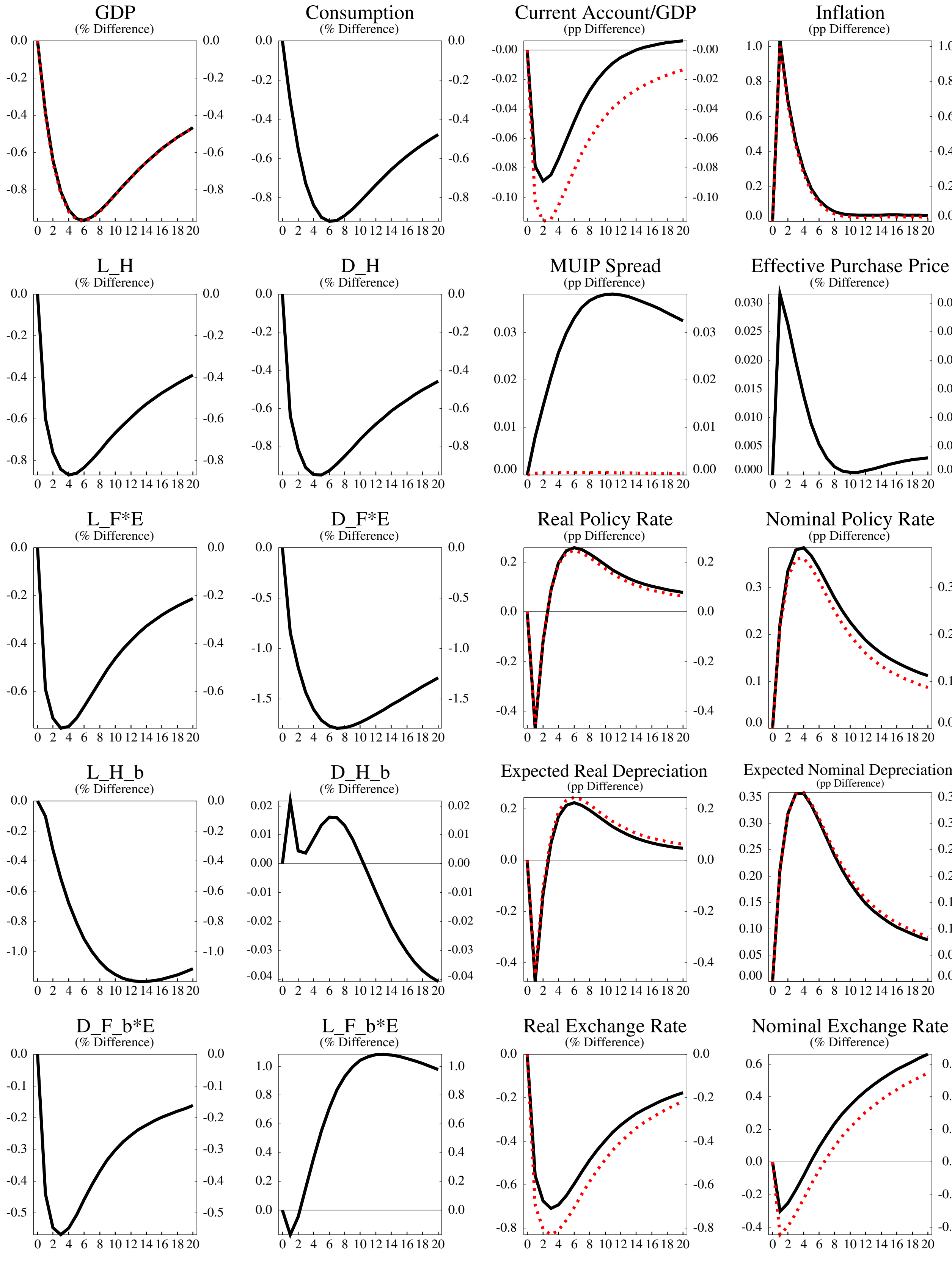
Solid Lines (black) = Baseline Calibration

Figure 11: Contractionary Consumption Demand Shock



Solid Lines (black) = Baseline Calibration, Dotted Lines (red) = UIP

Figure 12: Contractionary Technology Shock



Solid Lines (black) = Baseline Calibration, Dotted Lines (red) = UIP

Table 1: Local Projection of MUIP Wedge on Relative Credit Conditions

Panel A: 3-month tenor ($m^3_{ij,t+s}$)

Horizon (s)	0	1	2	3	4
$\varepsilon^{CCS}_{ij,t}$	0.12	-0.33	-1.10***	-1.04***	0.34
	(0.39)	(0.33)	(0.19)	(0.13)	(0.35)
Obs.	308	303	297	291	285
R-squared	0.018	0.015	0.040	0.036	0.016

Panel B: 6-month tenor ($m^6_{ij,t+s}$)

Horizon (s)	0	1	2	3	4
$\varepsilon^{CCS}_{ij,t}$	-0.18	-1.77***	-2.12***	-0.84*	0.73
	(0.73)	(0.37)	(0.29)	(0.49)	(0.69)
Obs.	303	297	291	285	279
R-squared	0.030	0.044	0.076	0.030	0.033

Panel C: 12-month tenor ($m^{12}_{ij,t+s}$)

Horizon (s)	0	1	2	3	4
$\varepsilon^{CCS}_{ij,t}$	-2.90***	-2.50**	-1.65	-0.53	-0.07
	(0.70)	(0.98)	(1.02)	(1.25)	(1.21)
Obs.	291	285	279	273	267
R-squared	0.085	0.085	0.058	0.045	0.043

(Data: Credit conditions surveys are computed using data from national Central Banks; MUIP wedges are computed using data from Datastream).

($\varepsilon^{CCS}_{ij,t}$ = relative credit conditions survey measure; $m^h_{ij,t+s}$ MUIP wedge at tenor h; estimates are obtained with the xtmg (robust) estimator in Stata)

Table 2: Shocks and Puzzles

	Data	$\kappa^{(*)}_{H,t}$	$\sigma^{k(*)}_{H,t}$	S^{mm}_t	S^{md}_t	S^a_t	S^c_t	S^{int}_t
β_{Fama}	$\lessapprox 0$	-0.23 (0.11)	-0.12 (0.10)	-7.85 (0.89)	0.70 (0.03)	0.88 (0.05)	0.63 (0.04)	0.99 (0.08)
β_{Engel}	$\gtrapprox 1$	1.23 (0.11)	1.12 (0.10)	8.85 (0.89)	0.30 (0.03)	0.12 (0.05)	0.37 (0.04)	0.01 (0.08)
R^2_{Fama}	0.02	0.00 (0.00)	0.00 (0.00)	0.09 (0.01)	0.28 (0.04)	0.39 (0.02)	0.12 (0.03)	0.15 (0.04)
$\sigma\left(i_t - i^*_t\right)/\sigma\left(\varepsilon_t\right)$	0.06	0.27 (0.02)	0.30 (0.02)	0.04 (0.00)	0.75 (0.03)	0.71 (0.05)	0.56 (0.03)	0.38 (0.03)

UIP Puzzle (standard errors in parentheses)

	Data	$\kappa^{(*)}_{H,t}$	$\sigma^{k(*)}_{H,t}$	S^{mm}_t	S^{md}_t	S^a_t	S^c_t	S^{int}_t
$\rho(\varepsilon_t)$	0.00	-0.11 (0.03)	-0.11 (0.03)	-0.13 (0.03)	0.38 (0.05)	0.27 (0.04)	0.24 (0.05)	0.18 (0.05)
$corr\left(\varepsilon^{\text{real}}_t, \varepsilon_t\right)$	0.98	0.97 (0.00)	0.96 (0.00)	1.00 (0.00)	0.60 (0.02)	0.84 (0.02)	0.81 (0.01)	0.80 (0.03)
$\sigma\left(\varepsilon^{\text{real}}_t\right)/\sigma\left(\varepsilon_t\right)$	0.99	0.90 (0.00)	0.89 (0.00)	0.97 (0.00)	0.58 (0.02)	1.50 (0.03)	0.63 (0.01)	0.74 (0.02)
$\rho(e_t)$	0.95	0.70 (0.03)	0.70 (0.03)	0.68 (0.02)	0.97 (0.01)	0.96 (0.01)	0.96 (0.01)	0.75 (0.02)

Meese-Rogoff and PPP Puzzles (standard errors in parentheses)

$\sigma(\cdot)$ = standard error, $\rho(\cdot)$ = first-order autocorrelation, $corr(\cdot,\cdot)$ = correlation coefficient