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Keywords: monetary policy, Collateral constraints, carry trade, Currency mismatches, Spillovers

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1 Introduction

The large swings in capital flows during the global financial crisis and the recurrent concerns voiced by emerging markets (EMs) about US monetary policy have stimulated a vigorous debate on whether financially integrated countries can retain monetary independence. This issue is gaining additional prominence as emerging markets face an extraordinary withdrawal of capital flows due to the Covid-19 pandemic. According to Mundell's trilemma (Mundell, 1963; Obstfeld, Shambaugh and Taylor, 2005), central banks in EMs can control domestic monetary conditions and ensure macroeconomic stability provided that the exchange rate is flexible. However, growing skepticism against this view has been expressed by both academics and policymakers. The influential work of Rey (2013, 2016) shows that the global financial cycle transmits also to countries with flexible exchange rates, affecting credit aggregates and lending spreads. In the same vein, a growing literature documents that a tightening in international monetary and financial conditions has contractionary effects in EMs, drying up liquidity and increasing borrowing costs (Bruno and Shin, 2015; Dedola, Rivolta and Stracca, 2017; Choi et al., 2017; Iacoviello and Navarro, 2019; Bräuning and Ivashina, 2019; Miranda-Agrippino and Rey, 2019; Kalemli-Özcan, 2019).

These concerns have led to new models that better capture the vulnerabilities of EMs to foreign shocks and identify novel trade-offs for monetary policy (Obstfeld, 2015). A first set of models focuses on the role of currency mismatches in EMs' balance sheets (Ottonello, 2015; Aoki, Benigno and Kiyotaki, 2016; Farhi and Werning, 2016; Akinci and Queralto, 2018). By depreciating the exchange rate, monetary easing in EMs tightens borrowing constraints and distorts consumption.[1] Therefore, monetary policy faces a trade-off between output stabilization and consumption smoothing. A second stream of the literature analyzes the implications of the Dominant Currency Paradigm, i.e. the preponderance of US dollar invoicing in international trade (Gopinath et al., 2019; Egorov and Mukhin, 2019). When export prices are sticky in US dollars, monetary policy is unable to stimulate external demand and has to trade off output stabilization with preventing large deviations in the law of one price.

In these models, central banks face novel trade-offs between competing objectives, but monetary easing remains expansionary. Therefore, as discussed in Gourinchas (2018), the implications of the trilemma are largely validated. First, monetary policy retains the ability to control domestic financial conditions and aggregate demand if the exchange rate is flexible. This is consistent with Mundell (1963)'s argument that "monetary policy has a strong effect on unemployment under flexible exchange rates"—losing effectiveness only under fixed exchange rates. Second, in these models, EMs should still respond to the contractionary effects from tighter global financial conditions in line with the trilemma's prescription, by easing monetary policy and letting the exchange rate depreciate. This is the case especially when considering that tighter global financial conditions

[1] The interaction between monetary policy and collateral constraints is also analyzed in Fornaro (2015), but in a model where monetary easing relaxes domestic constraints.

tend to reduce inflation in EMs because of the contractionary effects on output, as documented for example in Dedola, Rivolta and Stracca (2017) and Choi et al. (2017).

However, the empirical evidence suggests that EMs tend to increase policy rates in response to a tightening in US monetary policy or an increase in the VIX, even if they have flexible exchange rates (Obstfeld, Shambaugh and Taylor, 2005; Aizenman, Chinn and Ito, 2016; Han and Wei, 2018). Table 1 further documents this aspect. We regress policy rates for a sample of EMs with flexible exchange rates over Taylor-rule determinants and measures of global financial and monetary conditions.[2] The results reveal that, even after controlling for expected inflation and the output gap, central banks in EMs tend to hike policy rates when the VIX or US policy rates increase. The results are robust to using quarterly or monthly data, excluding one country at a time, and estimating the regressions in first differences as in columns (4) and (6).

Table 1: Policy rate responses in EMs to global liquidity and monetary shocks

	(1)	(2)	(3)	(4)	(5)	(6)
	Quarterly data				Monthly data	
VARIABLES	Level	Level	Level	First diff.	Level	First diff.
Expected inflation	1.25***	1.23***	1.17***	0.47***	1.17***	0.16***
	(0.06)	(0.05)	(0.04)	(0.08)	(0.07)	(0.05)
Output gap	0.15	0.19*	0.03	-0.02		
	(0.09)	(0.09)	(0.09)	(0.05)		
VIX		0.04***	0.04***	0.02***	0.03***	0.01***
		(0.01)	(0.01)	(0.00)	(0.01)	(0.00)
U.S. policy rate			0.41***	0.17*	0.40***	0.13**
			(0.09)	(0.09)	(0.08)	(0.05)
Constant	0.85***	0.13	-0.01	-0.06***	0.08	-0.01***
	(0.25)	(0.30)	(0.29)	(0.01)	(0.35)	0.00
Observations	1,230	1,230	1,230	1,200	3,582	3,288
R-squared	0.67	0.68	0.74	0.19	0.67	0.04
Number of countries	19	19	19	19	19	19

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

[2]The sample includes Brazil, Chile, China, Colombia, Czech Republic, Hungary, India, Indonesia, Malaysia, Mexico, Peru, Philippines, Poland, Romania, Russia, South Africa, Korea, Thailand, and Turkey. We use data from 2000 onward, both at quarterly and monthly frequency, excluding periods when the exchange rate is fixed according to the "coarse classification code" 1 in Ilzetzki, Reinhart and Rogoff (2019). The regressions are estimated with country-fixed effects. We use measures of expected inflation over the next 12 months constructed with monthly data from Consensus Forecast. Forecasters are asked each month about their projections for the current and the next year. We create indicators of inflation over the next 12 months by taking a weighted average of the current and next year forecasts based on the remaining months in the year. For example, in the month of September our averages use a weight of 3/12 for the current year and 9/12 for the following one. The output gap is estimated using the HP filter. The US policy rate uses Wu and Xia (2016) shadow rate to account for changes in monetary policy during the zero lower bound period.

The Covid-19 pandemic provides additional evidence in line with these findings. While in March the United States cut policy rates by 150 basis points to the zero lower bound, EMs have lowered policy rates by only about 50 basis points. This is despite the fact that EMs are not constrained by the zero lower bound. Confronted with massive capital outflows, several EM central banks have instead resorted to unconventional monetary tools, such as asset purchases to compensate for the loss of foreign liquidity and support the domestic banking sector.

In this paper, we provide a theory that can account for these empirical findings and provides a novel mechanism through which global financial and monetary shocks can destabilize EMs. We show that the interaction between capital flows and domestic collateral constraints can undermine monetary transmission in EMs by giving rise to an open-economy "Effective Lower Bound". The ELB is an interest rate threshold below which monetary easing becomes contractionary. The ELB constraints the ability of monetary policy to boost aggregate demand, placing an upper bound on the level of output achievable through monetary stimulus. Notably, this is the case even in countries with flexible exchange rates. This provides a crucial departure from Mundell's trilemma according to which central banks should be able to set interest rates freely and control domestic output if the exchange rate if flexible. The ELB can occur at positive rates and thus act as a more stringent constraint to monetary policy than the zero lower bound (ZLB). We also show that the ELB is affected by global monetary and financial conditions. A tightening of the global financial cycle leads to an increase in the ELB which can induce EMs to increase policy rates in line with the empirical evidence.

The ELB may emerge under various circumstances whenever monetary policy affects the tightness of collateral constraints. To illustrate this point, we provide two different models which capture the most prominent vulnerabilities of EMs, as voiced by policymakers and academics. In the first model, we show that the ELB may arise because monetary policy transmission in EMs can be undermined by carry-trade capital flows that respond to interest rate differentials with the US.[3] As discussed in Blanchard et al. (2016), this is a common concern among policymakers in EMs which has become more acute over time given that foreign investors have increased their presence in EMs' capital markets. The left chart in Figure 1 shows that the share of EM government bonds in local currency held by foreigners has increased threefold since 2005.[4] Therefore, if foreign investors pull out of EMs when central banks lower domestic rates, this can significantly drain domestic liquidity. This type of vulnerability is at play even when government bonds are denominated in local currency. This feature is generally absent from existing models that focus on the risks posed by

[3]Empirical analyses of carry-trade capital flows are presented in Lustig and Verdelhan (2007), Brunnermeier, Nagel and Pedersen (2008), Lustig, Roussanov and Verdelhan (2011), Menkhoff et al. (2012), and Corte, Riddiough and Sarno (2016).

[4]Data are from the Global Debt Monitor Database provided by the Institute of International Finance and are available until the fourth quarter of 2019. We include all available countries that are also considered in the regression results reported in 1. The right chart shows the foreign-currency debt held by both the financial and non-financial corporate sector.

currency mismatches.

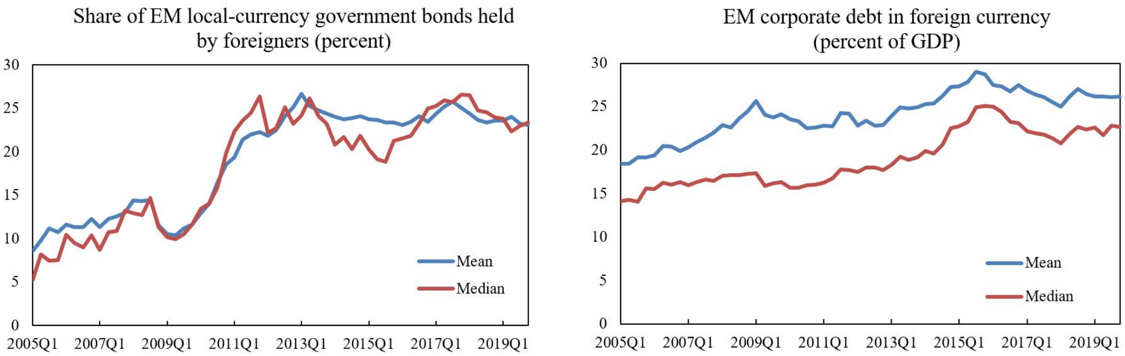

Figure 1: Emerging markets' vulnerabilities to global financial conditions

Our first model features a small open economy populated by domestic borrowers and savers. Banks intermediate domestic deposits to provide domestic loans and purchase government bonds but are subject to a leverage constraint. Government bonds are in local currency and are partly held by foreign investors whose demand is increasing in the excess return of the bonds over foreign assets. In the model, monetary easing in EMs triggers capital outflows since it reduces the excess return on domestic bonds. When the bank leverage constraint does not bind, monetary easing retains conventional expansionary effects since banks absorb the bonds sold by foreigners by expanding their balance sheets. However, if the domestic policy rate is reduced too much, capital outflows become large enough that domestic banks reach their leverage constraint. Once banks are constrained, further monetary easing can become contractionary. This is because to absorb the bonds liquidated by foreigners, in equilibrium banks have to reduce domestic credit. If this credit crunch is sufficiently severe, monetary easing becomes contractionary giving rise to the ELB.

In a second model, we show that the ELB can also emerge because of currency mismatches. This is a proverbial concern in EMs given a large amount of foreign-currency debt as illustrated in the right panel of Figure 1. In the model, currency mismatches are held by domestic banks that borrow internationally in foreign currency and lend domestically in local currency. Banks are again subject to a leverage constraint that limits domestic lending to a certain multiple of bank capital. When the leverage constraint is not binding, monetary accommodation is expansionary. However, if the policy rate declines enough, the leverage constraint becomes binding because the exchange rate depreciation erodes bank capital. From this point onward, if foreign-currency debt is sufficiently large, additional monetary easing becomes contractionary since banks can no longer freely intermediate foreign funds to provide domestic loans.

A crucial aspect of our theory is that a tightening in global financial and monetary conditions raises the ELB by reducing capital flows to EMs or eroding bank capital due to the exchange rate depreciation. The increase in the ELB can in turn push EMs into a recession while central banks are forced to increase policy rates consistently with the evidence in Table 1. Notably, once the ELB binds, EMs lose control over domestic output. Central banks are forced to keep policy rates at the ELB, while domestic output becomes determined by global financial and monetary cycle. This is the case even in countries with flexible exchange rates, providing a crucial departure from Mundell's trilemma.

We also analyze the implication of the ELB for the ex-ante conduct of monetary policy when financial conditions are supportive and domestic collateral constraints do not bind. The model shows that the ELB gives rise to a novel inter-temporal trade-off for monetary policy since a tighter ex-ante monetary stance lowers the ELB in the future by reducing financial vulnerabilities. This has three key implications. First, to lower the ELB in the future and create more monetary space to offset possible shocks, central banks should be keep a relatively tight monetary stance when financial conditions are loose by running economy below potential. Second, monetary policy becomes less effective in stimulating output even when financial conditions are loose. This is because the stimulative effect of monetary easing is partially offset by the expectation of a tighter future monetary stance due to the increase in the ELB. Third, EMs should increase policy rates in response to a tightening of the global financial cycle even if the ELB is not currently binding. Therefore, the monetary policy responses in Table 1 could be driven even just by concerns that the ELB may bind in the future if global financial conditions deteriorate further.

The model provides a rationale for using a broad range of policy tools to ease the constraints imposed by the ELB. The effectiveness of these tools and the channels through which they operate depend on the determinants of the ELB.[5] Balance-sheet operations by the central bank, including quantitative easing and foreign exchange intervention, are quite effective if the ELB is due to carry-trade capital flows since they increase liquidity in the banking sector. Capital controls are instead helpful in case of currency mismatches to decouple the exchange rate from domestic monetary conditions. Interestingly, forward guidance is unable to ease the constraints imposed by the ELB, despite being quite effective at least in theory against the ZLB. This is because the ELB is an endogenous interest threshold that increases if the central bank commits to a looser monetary stance in the future.

The existence of the ELB hinges on the idea that in some instances monetary easing in EMs can be contractionary. There are several reasons to entertain such a possibility. First, policymakers in emerging countries do express this kind of concern. For example, they fear that a reduction in policy rates may trigger severe capital outflows, leading to contractionary rather than expansionary

[5]There is a large literature that analyzes the role of capital controls and macro-prudential regulation for open economies using real models, for example Jeanne and Korinek (2010), Bianchi (2011), Benigno et al. (2013) Benigno et al. (2016), and Korinek and Sandri (2016). The rationale for intervention is generally linked to pecuniary externalities that affect the tightness of collateral constraints. We complement this literature by showing that these policy tools can also be helpful to alleviate the constraints posed by the ELB. See Farhi and Werning (2016) and Korinek and Simsek (2016) for theories of how macro-prudential policies may help to overcome the ZLB.

effects, a symmetric argument to one discussed in Blanchard et al. (2016). Second, the idea of contractionary monetary easing gained prominence already during the 1997 financial crisis in East Asia, when many feared that monetary easing could be contractionary because of the balance-sheet effects arising from currency mismatches (Krugman, 1999; Aghion, Bacchetta and Banerjee, 2000, 2001; Céspedes, Chang and Velasco, 2004; Christiano, Gust and Roldos, 2004).[6] Third, the notion that monetary easing can be contractionary at low interest rates is being analyzed even in the case of advanced economies because of the impact on bank profitability (Brunnermeier and Koby, 2016; Eggertsson et al., 2019).[7] If anything, concerns about monetary transmissions should be more severe in EMs given volatile capital flows and pervasive financial frictions.

The paper is structured as follows. We present the model with carry-trade capital flows in section 2 and the model featuring currency mismatches in section 3. We summarize key findings and avenues for future research in the concluding section.

2 The ELB under carry-trade capital flows

In this section, we develop a model in which the ELB can emerge because of the effects of monetary policy on carry-trade capital flows. In the model, monetary easing lowers the expected return of domestic assets vis-à-vis foreign assets and generates capital outflows. By draining liquidity from the domestic financial market, capital outflows can cause a credit crunch that reduces aggregate demand and output. Hence, monetary easing can become contractionary giving rise to the ELB.

2.1 Model setup

The model features a small open economy, called Home, populated by heterogeneous households that smooth consumption by saving and borrowing. Domestic financial intermediaries, called banks, collect deposits from savers, provide loans to borrowers, and buy Home-currency government bonds. Banks are subject to a leverage constraint that may prevent them from fully satisfying the domestic demand for credit. Foreign funds alleviate this constraint by absorbing part of the supply of government bonds.

We present the model in a recursive infinite-horizon formulation. When solving it, we will assume that the model is in steady state from time 2 onward and focus on the equilibrium in the first

[6] We depart from this literature by analyzing environments in which monetary policy affects whether domestic constraints bind or not which is essential to generate the ELB. In Céspedes, Chang and Velasco (2004) and Christiano, Gust and Roldos (2004), if monetary easing is contractionary because collateral constraints bind, monetary policy can still achieve any desired level of output by raising rather than lowering policy rates. This is no longer possible in our framework since an increase in policy rates eventually makes collateral constraints loose at which point further interest rate hikes have conventional contractionary effects.

[7] See Altavilla, Boucinha and Peydró (2018) and Goodhart and Kabiri (2019) for empirical analyses of the effects of low interest rates on bank profitability.

two periods, time 0 and 1.[8] Furthermore, we will make some simplifying parametric assumptions to obtain tractable analytical solutions that illustrate the key mechanisms of the model. In Appendix A we show that the results hold in richer versions of the model without parametric restrictions. We start by presenting the model in its most simple form, considering only the role of conventional monetary policy. In section 2.3, we incorporate fiscal and unconventional monetary policy tools to understand how they can help overcome the restrictions imposed by the ELB.

2.1.1 Household and corporate sector

The economy is populated by two types of households, borrowers and savers, each with measure one. Borrowers and savers have identical preferences but heterogeneous income streams that determine whether they save or borrow. Households choose consumption to maximize the inter-temporal utility function

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \ln C_t^i \tag{1}$$

where β is the inter-temporal discount factor and the superscript $i = \{b, s\}$ denotes borrowers and savers, respectively. The consumption index C_t^i is defined as $C_t^i = \left(C_{H,t}^i\right)^{1-\alpha} \left(C_{F,t}^i\right)^{\alpha}$, where the parameter $\alpha \in (0,1)$ reflects the degree of trade openness, and $C_{H,t}^i$ and $C_{F,t}^i$ are consumption aggregators of Home and foreign goods.

Borrowers are subject to the following budget constraint

$$P_t C_t^b + L_{t-1} I_{t-1}^L = \Pi_t^b + L_t$$

where P_t is the aggregate price level, L_t are loans which carry the interest rate I_t^L, and Π_t^b is borrowers' total disposable income. Savers face a similar budget constraint

$$P_t C_t^s + D_t = \Pi_t^s + D_{t-1} I_{t-1}^D$$

where D_t are bank deposits that are remunerated at the interest rate I_t^D. Domestic households smooth consumption based on the Euler equations

$$\begin{aligned} 1 &= \beta I_t^L \mathbb{E}_t \left[P_t C_t^b / \left(P_{t+1} C_{t+1}^b \right) \right] \\ 1 &= \beta I_t^D \mathbb{E}_t \left[P_t C_t^s / \left(P_{t+1} C_{t+1}^s \right) \right] \end{aligned}$$

and allocate spending on Home goods according to $P_{H,t} C_{H,t}^i = (1-\alpha) P_t C_t^i$. Similarly, foreign households, whose variables are denoted with an asterisk, smooth consumption according to

[8] Alternatively, we could cast our model in an overlapping generation structure where borrowers live for three periods in which they borrow, roll over, and repay. Such formulation yields similar results at the cost of analytical tractability.

$1 = \beta I_t^* \mathbb{E}_t \left[P_t^* C_t^* / \left(P_{t+1}^* C_{t+1}^* \right) \right]$ and spend on domestic goods an amount equal to $P_{H,t}^* C_{H,t}^* = \alpha P_t^* C_t^*$. We denote domestic aggregate consumption and income by dropping the household-type superscript, so that $C_t = C_t^b + C_t^s$ and $\Pi_t = \Pi_t^b + \Pi_t^s$. We assume that households own all domestic firms and banks. Therefore, Π_t is the Home-currency value of domestic production plus banks dividends net of taxes. We leave the details of how the value of domestic production is split between wages and profits unrestricted since they are not essential for the results of the model. That is, we do not specify how labor supply and wages are determined, nor the ownership structure of firms.

The production sector is composed of a continuum of monopolistically competitive firms which use labor to produce differentiated varieties of the domestic tradable good.[9] Firms set prices for goods sold domestically in local currency and for goods sold abroad in foreign currency, $P_{H,t}$ and $P_{H,t}^*$ respectively. The assumption that export prices are fixed in foreign currency is consistent the widespread use of the US dollar in trade invoicing (Gopinath et al., 2019) which limits exchange rate pass-through and thus the ability of monetary policy to stimulate exports. The model can easily incorporate the alternative assumption of export prices being fixed in local currency, as we do in our second model based on currency mismatches. We assume that prices are pre-determined and fully rigid at time 0 and 1, normalized to 1. Prices are instead fully flexible from time 2 onward so that monetary policy has no real effects on the steady state of the model.

2.1.2 Financial markets

The domestic banking sector is composed of a measure one of identical financial intermediaries that collect deposits from savers, provide loans to borrowers, and buy government bonds. The balance sheet of the banking sector is

$$N_t + D_t = L_t + B_t + R_t$$

where N_t denotes bank networth, B_t the holdings of government bonds, and R_t the reserves held at the central bank. All assets are denominated in the Home currency and there is no default. Hence, bank networth evolves according to $N_{t+1} = L_t I_t^L + B_t I_t^B + R_t I_t - D_t I_t^D$, where I_t^B is the yield on government bonds and I_t is the monetary policy rate, i.e. the remuneration rate on reserves.

We assume that banks are subject to a leverage constraint which prevents assets from exceeding a multiple of networth

$$L_t + \lambda B_t \leq \phi N_t \tag{2}$$

where $\phi > 1$ and $\lambda \in (0,1)$. This constraint requires banks to hold a minimum capital buffer against their assets. Specifically, each bank must hold in capital at least a fraction $1/\phi$ of its portfolio of loans and a fraction λ/ϕ of its holding of government bonds. The assumption $\lambda < 1$ implies

[9] Since firms produce differentiated varieties of the Home good, indexed by $j \in [0,1]$, the consumption aggregator for domestic goods is $C_{H,t} = \left(\int_0^1 C_{H,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$, where $\varepsilon > 1$ is the elasticity of substitution among varieties. A similar aggregator applies to $C_{H,t}^*$.

that government bonds have a lower capital charge than loans. This leverage constraint can be rationalized on the basis of regulatory requirements which generally provide a preferential treatment to government bonds. Alternatively, it can be micro-founded on the basis of the agency friction that arises between depositors and bankers when the latter can divert assets. In this case, equation (2) is the incentive compatibility constraint that makes asset diversion unprofitable when creditors are able to recover a higher fraction of their credit if invested in loans than in in bonds.[10] Finally, one could interpret the leverage constraint as a reduced-form way of modeling the portfolio choice of banks in an environment in which assets have different default risk, with loans being riskier than bonds.[11]

Banks act competitively and, since asset returns are riskless, they simply choose their balance sheets to maximize period-by-period networth subject to the leverage constraint. A no-arbitrage condition between household deposits and central bank reserves implies that the deposit rate is equal to the policy rate $I_t^D = I_t$. Lending rates and bond yields can instead increase above the policy rate because of the leverage constraint. The first order conditions for loans and bonds require that

$$\begin{aligned} I_t^L &= I_t + \mu_t \\ I_t^B &= \lambda I_t^L + (1-\lambda) I_t \end{aligned}$$

where $\mu_t \geq 0$ is the shadow cost of the constraint (2). If the leverage constraint does not bind, $\mu_t = 0$, lending and bond rates are equal to the policy rate I_t, so that any monetary policy change transmits one-for-one to all rates. If instead the constraint binds, the lending rate increases above the policy rate to ensure market clearing in the loan market. This gives rise to a credit spread that hinders the transmission of monetary policy.

The leverage constraint restricts the ability of the banking sector to provide credit to borrowers and the government. Furthermore, it implies that capital flows influence credit conditions in EMs even if foreign investors cannot directly provide loans to Home households.[12] When the bank

[10] Formally, assume that each banker can run away with her assets. If she does so, her creditors are able to recover only a fraction $1-1/\phi$ of their credit, when invested in loans, and a fraction $1-\lambda/\phi$ of their credit, when invested in bonds. Savers are willing to deposit in the bank if and only if the following incentive compatibility condition holds:

$$\left(I_t^L - \frac{\phi-1}{\phi} I_t\right) L_t + \left(I_t^B - \frac{\phi-\lambda}{\phi} I_t\right) B_t \leq N_t I_t + L_t \left(I_t^L - I_t\right) + B_t \left(I_t^B - I_t\right)$$

where the left-hand side of the inequality is the banker's return if she runs away with the assets, while the right-hand side is her return if she does not.

[11] Notice that, although we do not explicitly allow banks to borrow from foreign investors, we do not impose any restriction on the sign of B_t. Indeed, when $B_t < 0$ banks issue bonds that are perfect substitute of government bonds and effectively borrow from foreign investors. The implications of the model are unchanged since the collateral constraint still limits the substitutability between foreign funds and domestic deposits. However, the interpretation of the leverage constraint changes. In this scenario λ represents the benefit, measured in terms of bank capital, of borrowing from abroad vis-à-vis borrowing domestically.

[12] This form of market segmentation can be rationalized on the basis of information asymmetries between borrowers and their creditors. Unlike domestic banks, foreign investors do not have the necessary idiosyncratic knowledge to screen

leverage constraint binds, banks can absorb the government bonds sold by foreigners during a capital outflow only by restricting domestic credit. Through this channel, capital flows play a crucial role in the transmission mechanism of monetary policy that we will characterize in the solution of the model.

Turning now to foreign investors, these act as international financial intermediaries by borrowing from foreign households at the rate I_t^* to finance the purchase of Home bonds B_t^f . Their aggregate balance sheet is given by $B_t^f + e_t B_t^* = 0$, where e_t is the nominal exchange rate between the Home and foreign currency, defined as the Home price of one unit of foreign currency. Therefore, an increase in e_t captures a depreciation of the Home currency. Foreign investors earn an expected return, expressed in foreign currency, equal to

$$V_t^* = B_t^* \mathbb{E}_t \left[\frac{e_t}{e_{t+1}} I_t^B - I_t^* \right]$$

In the spirit of Gabaix and Maggiori (2015), and similar to the case of domestic banks, we assume that the intermediation capacity of foreign investors is limited by an agency friction due to the risk of fund diversion. After borrowing from foreign households, rather than purchasing Home bonds, foreign investors can purchase other international assets and divert a fraction $\gamma_t B_t^f$ of their proceeds. Creditors can prevent investors from diverting funds by constraining their balance sheets to satisfy the following incentive compatibility condition

$$\mathbb{E}_t \left[\frac{e_t}{e_{t+1}} I_t^B - I_t^* \right] \geq \gamma_t B_t^f I_t^* \tag{3}$$

where the left and right-hand side expressions are the expected foreign-currency return for investors in case they invest in Home government bonds or divert funds, respectively. Since the return from diverting funds is increasing in the size of the investors' balance sheets, the incentive compatibility constraint is always binding.

Foreign demand for domestic government bonds is thus increasing in the expected excess return over foreign assets according to the following schedule

$$B_t^f = \frac{1}{\gamma_t} \mathbb{E}_t \left[\frac{e_t}{e_{t+1}} \frac{I_t^B}{I_t^*} - 1 \right] \tag{4}$$

The parameter $\gamma_t \geq 0$ controls the severity of the agency friction and determines the size of the intermediaries' balance sheets. It can be considered as an inverse measure of their risk-bearing capacity. The higher is γ_t, the higher is the required compensation per unit of risk. As $\gamma_t \uparrow \infty$, foreign demand shrinks to zero no matter the size of the excess return of domestic bonds. Vice

and monitor information-intensive assets, such as loans. Government bonds, on the other hand, only require a general knowledge of the Home economy that is more readily available to foreign investors.

versa, as $\gamma_t \downarrow 0$, the risk-bearing capacity is so high that any expected excess return is arbitraged away. In this case, Uncovered Interest Parity (UIP) holds as $I_t^B e_t / e_{t+1} \to I_t^*$. As we shall see when characterizing the model equilibrium, this formulation, with $\gamma_t > 0$, generates carry-trade dynamics which link domestic monetary policy and capital flows.[13]

2.1.3 Public sector

The public sector includes the central bank and the government. The central bank conducts monetary policy by setting the remuneration rate on reserves, I_t. We first focus on the role of conventional interest rate policy, considering the limit for $R_t \downarrow 0$ and thus abstracting from possible balance-sheet operations by the central bank. In Section 2.3, we relax this assumption and allow the central bank to use balance-sheet tools such as quantitative easing and foreign exchange intervention.

Turning to fiscal policy, we start by assuming that the government simply rolls over the stock of public debt, B_t^g, that comes due each period, such that

$$B_t^g = B_{t-1}^g I_{t-1}^B$$

In Section 2.3, we extend the model to include other fiscal tools and study their impact on the equilibrium of the model. We will also consider the effect of macroprudential policies and capital controls.

Regarding policymakers' goal, a welfare-maximizing social planner would face trade-offs between multiple objectives in this environment since the model incorporates several inefficiencies.[14] The recent monetary literature reviewed in the introduction aims to characterize similar trade-offs that significantly complicate optimal monetary policy. Rather than analyzing these trade-offs, in this paper we show that in an open economy with financial frictions monetary authorities may not be able to achieve even the unique goal of output stabilization. This is the case even if the exchange rate is flexible, in sharp contrast with the trilemma.

[13]This is not the case in the specification used by Gabaix and Maggiori (2015), $B_t^F = \mathbb{E}_t \left[e_t - I_t^* e_{t+1} / I_t \right] / \gamma_t$, where monetary policy has no effects on capital flows. The key difference is that our model features foreign intermediaries that care about returns denominated in foreign currency. Gabaix and Maggiori (2015) assume instead that intermediaries maximize the returns expressed in the currency of the country where the investment takes place. This rather subtle difference has important implications for the elasticity of the exchange rate to changes in interest rates. In Gabaix and Maggiori (2015) a policy rate cut generates a proportional depreciation of the exchange rate that leaves the expected return on domestic bonds relative to foreign assets unchanged. As we shall see below, our formulation implies instead a lower responsiveness of the exchange rate so that monetary easing reduces the excess return of domestic bonds over foreign assets, triggering capital outflows.

[14]Other than the output gap, in our model an objective function derived from a second-order welfare approximation would also include the UIP gap, the gap in the law of one price for Home goods, and the gap in the borrowers' Euler equation. Because prices are assumed to be fully rigid in period 0 and 1, there is no welfare cost of price dispersion.

2.2 Model equilibrium

The model is closed by imposing market clearing conditions for domestic goods, $Y_t = C_{H,t} + C^*_{H,t}$, and government bonds, $B^g_t = B_t + B^f_t$, plus the usual transversality conditions for the budget constraints of the households and the government.

We derive analytical solutions for time 0 and 1, assuming that from time 2 onward the economy is in steady state, with $I_t\beta = 1$, free of nominal and financial frictions. Specifically, in steady state the bank leverage constraint does not bind and UIP holds, i.e. $\gamma = 0$. Variables without time subscripts denote steady-state levels. To ease notation and simplify the solution, we focus on the limit for $\beta \uparrow 1$ which implies that in steady state agents spend all their disposable income, $PC^i = \Pi^i$. This assumption allows us to remove wealth effects, both at the household and country level, that clutter the algebra without affecting the key insights of the analysis. We generalize the model results to the case in which $\beta < 1$ in Appendix A.4.

To pin down the steady-state equilibrium a nominal anchor is needed. We follow the conventional approach to set nominal spending equal to the level of money supply, so that $PC = M$. This can be rationalized with a cash-in-advance constraint or money in the utility function. Using market clearing, which equates aggregate income in the Home economy with spending on Home goods, $\Pi = (1-\alpha)M + e\,\alpha M^*$, the steady-state exchange rate is equal to $e = M/M^*$. Since the supply-side of the economy is unrestricted, the steady-state level of output, Y, is undetermined and can be set to 1 without loss of generality. For convenience, we also normalize domestic and foreign money supply to 1.[15]

In the next section, we characterize the equilibrium in period 1, solving for the conditions under which the ELB arises and showing how the ELB is affected by global financial and foreign monetary conditions. We will then solve for the equilibrium at time 0, assuming that the bank leverage constraint does not bind, to analyze how monetary authorities should set policy rates when financial conditions are loose while considering that the ELB may bind in the future.

2.2.1 Model equilibrium at time 1

The level of domestic output at time 1 is determined by the consumption of Home goods by domestic and foreign households. Using ω to denote the share of total domestic output which is appropriated by borrowers in steady state, i.e. $\omega = \Pi^b/\Pi$, output at time 1 can be expressed as

$$Y_1 = (1-\alpha)\left(\frac{\omega}{I^L_1} + \frac{1-\omega}{I_1}\right) + \frac{\alpha}{I^*_1} \tag{5}$$

[15] In steady state the quantity equation of money holds, such that $P_H = M/Y$. Hence, our normalization implies $P_H = 1$. This is consistent with a monetary policy rule that takes prices at time 0 and 1 as given and sets M to minimize inflation between time 1 and 2. Alternatively, one could assume that prices are fully rigid and set at time 0 to maximize steady-state profits, after the central bank announces M.

The first term on the right-hand side captures the consumption of domestic households, where the lending and policy rates control the consumption of borrowers and savers, respectively. The second term represents foreign demand for domestic goods which is not affected by the exchange rate because export prices are set in foreign currency.[16]

Unconstrained equilibrium Consider first the model implications when the bank leverage constraint does not bind. When banks are unconstrained, lending rates are equal to the policy rate $I_1^L = I_1^B = I_1$. The transmission channel of monetary policy is flawless since changes in the policy rate are passed one-for-one to lending rates. In this case, a policy rate cut not only increases savers' consumption by lowering the deposit rate, but it also stimulates borrowers' consumption by reducing lending rates. Hence, monetary easing is expansionary, raising domestic demand and output.

The effect a policy rate cut on capital flows is less clear-cut. On the one hand, monetary easing boosts import consumption, thus leading to an increase in the demand for foreign funds, holding the exchange rate constant. On the other hand, monetary accommodation reduces bond yields since $I_1^B = I_1$ and thus curbs the supply of foreign capital for a given level of the exchange rate. To restore equilibrium in the market for foreign funds, the exchange rate must depreciate. The effect on capital flows depends on the magnitude of the depreciation or, more specifically, on the elasticity of the exchange rate with respect to the policy rate. If the elasticity is larger than one, a reduction in the policy rate causes a proportionally larger depreciation of the exchange rate which increases the excess return on domestic bonds over foreign assets and attracts more inflows. If instead the elasticity is lower than one, a policy rate cut reduces the return of domestic bonds and therefore triggers capital outflows.

By equating the demand and supply for foreign funds, we can show that the elasticity of the exchange rate with respect to the policy rate when the bank leverage constraint does not bind is equal to

$$\varepsilon_I^e = 1 - \left(\frac{\gamma_1}{I_1 + \gamma_1 \alpha}\right)^2 \frac{\alpha \mathbb{B}_1^f I_1^*}{e_1} \tag{6}$$

where $\mathbb{B}_1^f = B_0^f I_0$ is the foreign debt of the country at the beginning of time 1, equal to the value of Home bonds held by foreign investors. Note that throughout the paper we denote pre-determined variables at the beginning of each period using double-struck letters . Expression (6) shows that the elasticity of the exchange rate with respect to domestic monetary policy is equal to 1 if γ_1 goes to 0 in the limit. In other words, if there are no frictions in international financial markets so that UIP holds, a reduction in the domestic policy rate is matched with a proportional depreciation of the exchange rate which leaves capital flows unchanged.[17]

[16] The second model based on currency mismatches considers the alternative assumption of export prices being set in local currency.

[17] These results are contingent on the model assumption that the intra and inter-temporal elasticities of substitution are

On the contrary, if foreign investors require a premium to hold domestic bonds, the value of the exchange rate is below the UIP level and it depreciates by less in response to domestic monetary easing. This implies that a domestic policy rate cut reduces the excess return on domestic bonds triggering capital outflows. The model can transparently illustrate this aspect since it allows for a closed-form solution of foreign bond holdings at the end of period 1:

$$B_1^f = \frac{\mathbb{B}_1^f}{1+\gamma_1 \alpha / I_1} \tag{7}$$

Equation (7) shows that, if the country is a net debtor and γ_1 is strictly positive, the equilibrium stock of foreign capital is proportional to the domestic policy rate. Therefore, capital flows display carry-trade dynamics. An increase in the domestic policy rate raises the foreign-currency return on domestic assets and attracts more inflows. Vice versa, monetary easing reduces the return of domestic bonds and triggers capital outflows. As explained above, this is because in equilibrium the exchange rate responds less than one-for-one to interest rate changes. Thus, the foreign-currency return of domestic assets moves with the domestic policy rate.

As long as banks are unconstrained, the capital outflow triggered by monetary easing does not impair monetary transmission. Domestic banks absorb the bonds sold by foreign investors by increasing leverage, without crowding out domestic lending. Banks increase leverage by collecting more deposits. This is possible because monetary easing is expansionary, increasing aggregate income and thus deposit supply. Therefore, when the leverage constraint does not bind, foreign financing can be freely substituted with domestic financing without impairing the transmission of monetary policy.

However, monetary easing can eventually push banks against their leverage constraint as they continue to increase the holdings of government bonds while foreigners pull out of the country. The speed at which bank leverage increases in response to a reduction in the domestic policy rate depends not only on the strength of capital outflows but also on the effect of monetary easing on loan demand. The latter is given by

$$L_1 = \mathbb{L}_1 + \frac{\omega}{I_1^L} - \Pi_1^b \tag{8}$$

where $\mathbb{L}_1 = L_0 I_0^L$ is the outstanding stock of loans at the beginning of time 1. Monetary easing has ambiguous effects on loan demand. On the one hand, by lowering lending rates, it stimulates borrowers' consumption, ω / I_1^L. On the other hand, by boosting output and export revenues, it raises borrowers' income, Π_1^b. If the former effect prevails, monetary easing raises loan demand which in turn accelerates the increase in bank leverage. This happens if borrowers face positive income growth between period 1 and 2, as shown in Appendix A.3. If instead monetary easing increases

equal to 1. In Appendix A.5 we generalize the results to elasticities different from 1.

borrowers' income more than consumption, loan demand declines slowing down the increase in bank leverage.

To focus on the role of capital flows in moving banks against the leverage constraint and to allow for an analytical solution of the model, we assume that monetary policy has neutral effects on loan demand. We do so by setting $\Pi_1^b = \omega/I_1$ in which case borrowers' credit demand in the unconstrained region simplifies to $L_1 = \mathbb{L}_1$ and does not respond to changes in monetary policy. In Appendix A.3 we show how the results generalize to a setting where monetary policy affects credit demand depending on the borrowers' income growth profile.

Constrained equilibrium

Using equations (2) and (8), and the market clearing condition for government bonds, we can rewrite the leverage constraint in the following way:

$$B_1^f \geq \underline{B}_1^f \tag{9}$$

where $\underline{B}_1^f \equiv \mathbb{B}_1^g + (\mathbb{L}_1 - \phi \mathbb{N}_1)/\lambda$ measures the financial capital shortfall of the Home country. This is the minimum amount of foreign capital that the country needs to attract to satisfy the demand for credit from the private and public sectors, $\mathbb{L}_1 + \mathbb{B}_1^g$, at the prevailing policy rate.[18]

If the country has no capital shortfall, the bank leverage constraint does not bind irrespective of the domestic monetary policy rate since the banking sector can meet alone the demand for domestic credit without need for foreign capital. On the other hand, if the capital shortfall is too high, the leverage constraint always binding since the country is not able to attract enough foreign capital to satisfy the domestic demand for credit even at high policy rates. Equation (7) shows indeed that monetary tightening increases capital inflows only up to $\mathbb{B}_1^f$. For intermediate levels of capital shortfall, formally $\underline{B}_1^f \in \left(0, \mathbb{B}_1^f\right)$, the leverage constraint is occasionally binding depending on the domestic policy rate. By using (7) and (9), the interest rate level at which the constraint becomes binding is given by

$$\bar{I}_1 = \frac{\alpha \gamma_1}{\mathbb{B}_1^f / \underline{B}_1^f - 1} \tag{10}$$

The interest rate threshold $\bar{I}_1$ is endogenous to the characteristics of the country and the state of global financial conditions. $\bar{I}_1$ is increasing in the country's capital shortfall, $\underline{B}_1^f$, since bonds have to pay a higher yield to attract sufficient capital inflows. It is also increasing in the tightness of global financial conditions, γ_1, as foreigners demand a higher compensation to hold domestic bonds. $\bar{I}_1$ is instead declining in the initial level of external debt, $\mathbb{B}_1^f$. This is because a larger pre-existing stock

[18]The bank leverage constraint limits the "financial capacity" of the small open economy, that is the ability of its banking sector to collect deposits and transform them into credit. Hence, the country needs to attract foreign capital. In our model domestic and foreign funds are imperfect substitute. Deposits absorb financial capacity since they need to be intermediated by banks before they can be used to finance loans or government bonds. Instead, foreign capital can directly buy government bonds without requiring domestic financial intermediation, which is a scarce resource.

of foreign debt depreciates the exchange rate which raises the foreign-currency return on domestic bonds and increases capital inflows.

If the policy rate declines below $\bar{I}_1$, capital outflows generate a credit crunch. In equilibrium, banks have to absorb the government bonds liquidated by foreigners and this is possible only through a contraction in credit supply since the leverage constraint binds. This requires the lending rate to increases above the policy rate, generating a lending spread that hinders the transmission of monetary policy.

The behavior of the lending rate when the policy rate falls below $\bar{I}_1$ can be characterized by considering the following equation which ensures that the level of foreign bond holdings, on the left-hand side, is consistent with the domestic leverage constraint, on the right-hand side:

$$\frac{1}{1+\gamma_1\alpha/I_1^B}\left[\mathbb{B}_1^f+\alpha\frac{I_1^L-I_1}{I_1^B}\left(\frac{\lambda(1-\omega)}{I_1}-\frac{\omega(1-\lambda)}{I_1^L}\right)\right]=\underline{B}_1^f+\frac{\omega}{\lambda}\left(\frac{1}{I_1^L}-\frac{1}{I_1}\right)$$

with $I_1^B=\lambda I_1^L+(1-\lambda)I_1$. Using the implicit function theorem, the left derivative of the lending rate, evaluated at $\bar{I}_1$, is given by

$$\left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-}=1-\frac{1}{\lambda+\frac{\omega\left[\mathbb{B}_1^f/\left(\alpha\lambda\underline{B}_1^f\right)-1\right]+\lambda}{\gamma_1\underline{B}_1^f}} \tag{11}$$

This derivative is less than one, capturing the fact that, when banks are constrained, the lending rate rises above the policy rate since capital outflows limit the ability of banks to expand credit. The emergence of a lending rate spread impairs the transmission of monetary policy, as changes in the policy rate are no longer transmitted one-for-one to borrowers.

In fact, the behavior of capital flows not only hinders the transmission of monetary policy but can even reverse it.[19] To see this, note that the derivative (11) can be negative. This happens if global financial conditions are sufficiently tight, i.e. γ_1 is high. In this case, capital outflows are more sensitive to a reduction in the domestic policy rate as shown in equation (7). Monetary easing tightens domestic financial conditions so severely that the lending rate rises. This situation is illustrated in the left chart of Figure 2 where declines in policy rates below $\bar{I}_1$ lead to higher lending rates. Bond yields also increase above the policy rate because of the no-arbitrage condition between loans and bonds. However, in equilibrium monetary easing continues to reduce bond yields leading to capital outflows.[20]

While the increase in the lending rate reduces borrowers' consumption, monetary easing con-

[19] See also Blanchard et al. (2017) for a model in which capital outflows can have contractionary effects on the domestic economy because they increase borrowing costs.

[20] Formally, in the constrained region bond yields respond to monetary policy as follows $\left.\frac{\partial I_1^B}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-}=\lambda\left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-}+1-\lambda=\frac{\lambda+\omega_2\left[\mathbb{B}_1^f/\left(\alpha\lambda\underline{B}_1^f\right)-1\right]}{\lambda\left(1+\gamma_1\underline{B}_1^f\right)+\omega_2\left[\mathbb{B}_1^f/\left(\alpha\lambda\underline{B}_1^f\right)-1\right]}\geq 0$. Furthermore, capital inflows respond according to $\left.\frac{\partial B_1^f}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-}=$

tinues to stimulate savers' demand since the deposit rate declines in line with the policy rate. When the former effect prevails, monetary easing generates a contraction in aggregate demand and output. This occurs if monetary easing triggers a sufficiently strong increase in the domestic lending rate and if borrowers account for a sufficiently large share of aggregate demand. Formally, by differentiating equation (5) and using equation (11), we can show that monetary easing below $\bar{I}_1$ becomes contractionary if

$$\gamma_1 \underline{B}_1^F (\omega - \lambda) > \omega \left(\frac{\mathbb{B}_1^F}{\alpha \lambda \underline{B}_1^F} - 1 \right) + \lambda \tag{12}$$

The condition above requires γ_1 to be sufficiently high, capturing tight global financial conditions. In this case, domestic monetary easing leads to faster capital outflows and thus a more rapid increase in the domestic lending rate. Condition (12) also requires that borrowers account for a sufficiently high share of aggregate spending, captured by the parameter ω.[21]

When condition (12) holds, $\bar{I}_1$ becomes an Effective Lower Bound that we denote with I_1^{ELB}. In this case, the relationship between the domestic policy rate and output is non-monotonic, as shown in the right chart of Figure 2. Monetary easing is expansionary if banks are unconstrained but becomes contractionary when the bank leverage constraint binds. Since both a reduction and an increase in the policy rate around I_1^{ELB} lead to a contraction in aggregate demand the ELB places an upper bound on the amount of aggregate demand and thus output that monetary policy can achieve. The central bank is indeed unable to raise output above the level associated with the ELB, Y_1^{ELB}. Notably, the ELB can occur at positive interest rates and thus act as a more stringent constraint to monetary policy than the zero lower bound.

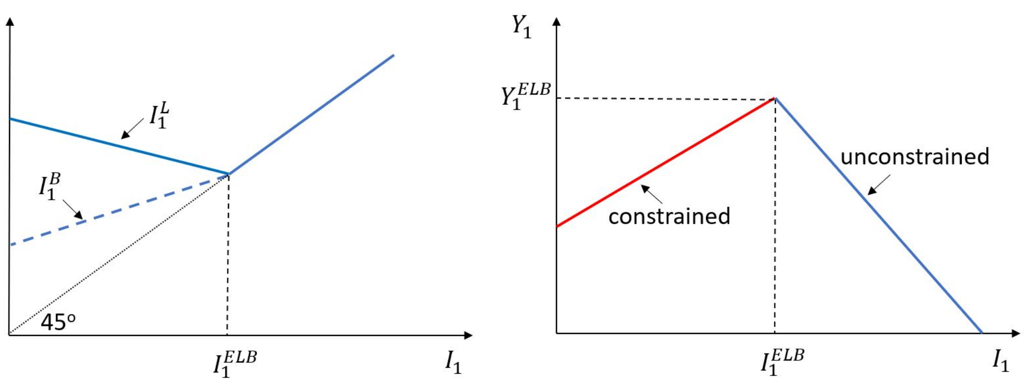

Figure 2: Monetary policy and the ELB.

$\frac{\omega}{\lambda} \left(\frac{\mathbb{B}_1^f / \underline{B}_1^f}{I_1 + \alpha\gamma_1} \right)^2 \left(1 - \frac{\partial I_1^L}{\partial I_1} \Big|_{I_1 = \bar{I}_1}^{-} \right) > 0.$

[21] Note also that the capital charge on government bonds λ should not be too high. This may seem counter-intuitive since in the unconstrained region a higher value of λ pushes banks more rapidly against their leverage constraint. However, once the leverage constraint binds, if bonds have a high capital charge, banks are reluctant to buy them from foreigners while curbing domestic credit. This implies that monetary easing in the constrained region leads to a steeper increase in bond yields and a weaker rise in lending rates.

The ELB makes financially integrated economies highly vulnerable to changes in global financial and monetary conditions. For example, central banks can be unable to preserve macroeconomic stability when foreign liquidity dries up. This is illustrated in Figure 3. The left chart considers the effects of a tightening in global financial conditions. By triggering capital outflows, an increase in γ_1 raises the ELB, as shown by equation (10), and lowers the maximum attainable level of output. If Y_1^{ELB} falls below the desired level of output, the ELB becomes a binding constraint for monetary policy. The central bank is forced to increase the policy rate together with the ELB while the economy suffers a contraction. The positive comovement between the tightness of global financial conditions and domestic policy rates is consistent with the empirical evidence provided in Table 1, whereby emerging markets tend to hike rates when the VIX increases. Once the ELB binds, the central bank loses control of domestic demand since it is forced to set policy rates at the ELB. The level of output is thus pinned down by the ELB which in turn is determined by global financial conditions. These implications can rationalize the evidence provided in Rey (2013, 2016) whereby global financial conditions drive credit conditions in small open economies even under flexible exchange rates.

Note that these effects are at play despite the exchange rate is flexible, a stark violation of Mundell's trilemma. According to Mundell (1963), monetary policy in countries with open capital accounts retains the ability to control output provided that the exchange rate is flexible. On the contrary, our framework illustrates that the interaction between capital flows and domestic collateral constraints—by giving rise to the open-economy ELB—can prevent monetary authorities from preserving macroeconomic stability. This is the key distinguishing feature of our model from the existing literature. In other words, exchange rate flexibility is not a sufficient condition to ensure monetary independence in financially integrated economies.

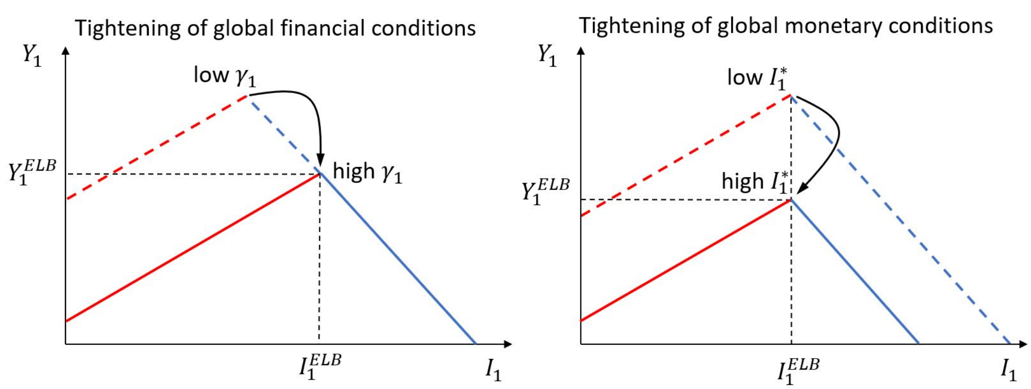

Figure 3: Global financial and monetary shocks in the presence of carry traders.

The ELB poses concerns also in reference to global monetary shocks, as illustrated in the right chart of Figure 3. Since export prices are sticky in foreign currency, an increase in the foreign policy rate I_1^* curbs foreign demand for Home goods and reduces the maximum attainable level of output

Y_1^{ELB} . The foreign policy rate does not change the level of the ELB because it does not affect capital flows, as shown in equation (7). However, as discussed in Appendix A.5, this result is due to our assumption of unitary elasticities of inter and intra-temporal substitution. If foreign households' intertemporal elasticity of substitution is less than 1, a foreign monetary tightening reduces capital inflows and increases the ELB, with similar effects to an increase in γ_1.[22]

While we have analyzed the effects of changes in γ_1 and I_1^* separately, it is important to recognize that global financial and monetary conditions tend to be correlated. For example, Kalemli-Özcan (2019) shows that a tightening in US monetary policy increases risk-premia in emerging markets as captured in our model through an increase in γ_1. Therefore, the responses illustrated in Figure 3 are likely to occur simultaneously in the real world, compounding their effects and increasing the likelihood that the ELB may bind.

2.2.2 Model equilibrium at time 0

We now characterize the model equilibrium at time 0 to explore how monetary policy decisions are affected by the possibility that the ELB may bind in the future. As discussed in section 2.1.3, we give monetary authorities the unique goal to stabilize output in each period at the level that prevails in the frictionless steady state Y, which we normalize to 1. Furthermore, we assume that at time 0 international financial conditions are favorable, that is γ_0 is low, so that the bank leverage constraint does not bind and monetary policy operates in a conventional manner.

From the perspective of time 0, agents expect global financial conditions at time 1 to vary according to a binary distribution. With probability ρ, γ_1 is sufficiently high that the ELB binds forcing the central bank to set $I_1 = I_1^{ELB}$.[23] With the remaining probability the realization of γ_1 is low, zero for simplicity, in which case the central bank is unconstrained and can set its policy rate to keep output at the desired steady-state level. All other variables are at time 1 are deterministic.

We start by analyzing how monetary policy at time 0 affects the level of the ELB at time 1. As shown in equation (10), the ELB depends on the time-0 equilibrium through the impact on the time-1 state variable $\mathbb{B}_1^f/\underline{B}_1^f$. This ratio can be written as

$$\frac{\mathbb{B}_1^f}{\underline{B}_1^f} = \frac{B_0^f}{B_0^g - (\phi N_0 - L_0)/\lambda}$$

[22]Let $1/\sigma$ be foreign households' intertemporal elasticity of substitution. Then their Euler equation, assuming rigid prices, is $C_1^* = \left(I_1^*\right)^{-1/\sigma} C^*$. Then capital inflows and the ELB are given by

$$B_1^f = \frac{\mathbb{B}_1^f - \left[\left(I_1^*\right)^{\frac{\sigma-1}{\sigma}} - 1\right]\alpha/I_1}{1+\alpha\gamma_1\left(I_1^*\right)^{\frac{\sigma-1}{\sigma}}/I_1} \qquad I_1^{ELB} = \frac{\alpha\left(\gamma_1 + 1/\underline{B}_1^f\right)\left(I_1^*\right)^{\frac{\sigma-1}{\sigma}} - \alpha/\underline{B}_1^f}{\mathbb{B}_1^f/\underline{B}_1^f - 1}$$

Thus, if $\sigma > 1$, a foreign monetary policy tightening reduces capital inflows and increases the ELB.

[23]Formally, we assume that, with probability ρ, $\gamma_1 = \overline{\gamma}_1$ where $\overline{\gamma}_1$ satisfies condition (12) and $Y_1^{ELB} < Y$.

where we used $\mathbb{B}_1^g = B_0^g I_0$ and $\mathbb{N}_1 = N_0 I_0$. Therefore, monetary policy at time 0 affects the time-1 ELB through the effects on capital inflows, B_0^f, and domestic lending, L_0. Higher capital inflows at time 0 reduce the ELB since they increase the stock of external debt with which the country enters time 1. This leads to a more depreciated exchange rate at time 1 which strengthens foreign demand for government bonds. On the contrary, a higher of domestic credit at time 0 raises the ELB since it increases the amount of loans that have to be refinanced at time 1.

Therefore, to understand how time-0 monetary policy affects the ELB at time 1, we need to examine its impact on capital inflows and domestic credit. Assume that borrowers enter period 0 with no pre-existing debt and have no income at time 0, $\Pi_0^b = 0$, so they borrow to consume. Then, capital inflows and domestic credit at time 0 are given by

$$
\begin{aligned}
B_0^f &= \mathbb{E}_0\left[\frac{1}{e_1}\right] \frac{\mathbb{B}_0^f - \frac{\alpha}{I_0}\left(\frac{1}{\mathbb{E}_0[1/e_1]} - \frac{1}{\mathbb{E}_0[I_1]}\right)}{\mathbb{E}_0\left[\frac{1}{e_1}\right] + \frac{\alpha\gamma_0}{I_0}} \\
L_0 &= \frac{\omega}{I_0 \mathbb{E}_0[I_1]}
\end{aligned}
$$

where $\mathbb{B}_0^f$ are the initial holdings of government bonds by foreigners. To understand the impact of time-0 monetary policy on B_0^f and L_0, start by holding the expectations of the time-1 interest rate and exchange rate constant. It is easy to see that a monetary policy tightening at time 0 increases capital inflows and reduces the demand for domestic loans.[24] Both forces tend to lower the ELB at time 1. If we now allow expectations to adjust, the impact of I_0 on L_0 and B_0^f becomes weaker, but retains the same sign as shown in Appendix A.1. Therefore, the level of the ELB at time 1 is negatively correlated with the policy rate at time 0

$$
\partial I_1^{ELB} / \partial I_0 < 0 \tag{13}
$$

This result has important consequences. First, it implies that the existence of the ELB weakens monetary policy transmission even in earlier periods when it is not binding. To see this, note that the level of output at time 0 is given by

$$
Y_0 = \frac{1-\alpha}{I_0 \mathbb{E}_0[I_1]} + \frac{\alpha}{I_0^* I_1^*}
$$

A reduction in I_0, by raising the ELB, leads to the expectation of tighter future monetary policy, $\mathbb{E}_0[I_1]$. In turn, the expectation of higher interest rates in the future reduces household consumption at time 0, weakening the expansionary effects of monetary easing. Therefore, the expectation that

[24] An increase in I_0 raises both the demand for and the supply of foreign capital. The first effect is captured by the term at the numerator of B_0^f (notice that $\mathbb{E}_0[I_1] - \mathbb{E}_0[1/e_1] = \rho I_1^{ELB} \overline{\gamma}_1 \mathbb{B}_1^f / \left(1 + \overline{\gamma}_1 \mathbb{B}_1^f\right)$ is positive), while the second effect is captured by the term at the denominator and is proportional to γ_0.

the ELB may bind in the future hinders monetary transmission even in earlier periods when financial conditions are loose.

Second, the negative correlation between ex-ante monetary policy and the ELB gives rise to a novel inter-temporal trade-off for monetary policy. Even when financial conditions are loose, monetary authorities should bear in mind that interest rate decisions have implications for the ELB in the future. A looser monetary stance to stimulate output at time 0 comes at a cost of raising the ELB in the future, reducing monetary space to respond to future shocks.

To study how the central bank resolves this inter-temporal trade-off, assume that the foreign interest rates I_0^* and I_1^* are equal to 1. To keep output at the level prevailing in the steady state, domestic policy rates should be equal to $I_0 = 1/\mathbb{E}_0[I_1]$ and $I_1 = 1$. Consider the following loss function $\mathscr{L}$ that penalizes deviations from the inverse of these desired policy rates

$$\mathscr{L} = (I_0 - 1/\mathbb{E}_0[I_1])^2 + \mathbb{E}_0\left[(I_1 - 1)^2\right]$$

By considering the inverse of the interest rates, we obtain a first order condition that is linear in the policy rate at time 0. Assume that the central bank has no commitment, so that it sets $I_1 = 1$ if $\gamma_1 = 0$. Then, the policy rate that minimizes the central bank's loss function, denoted by $\tilde{I}_0$ satisfies the following first order condition

$$\left(\tilde{I}_0 - 1/\mathbb{E}_0[I_1]\right)\left(1 + \rho\frac{\partial I_1^{ELB}}{\partial I_0}/\mathbb{E}_0[I_1]^2\right) = -\rho\left(I_1^{ELB} - 1\right)\frac{\partial I_1^{ELB}}{\partial I_0} \tag{14}$$

Given equation (13) and that $I_1^{ELB} > 1$ since the ELB binds at time 1 with probability *rho*, the term on the right hand side is positive. This implies that the optimal interest rate at time 0 is above the level that would be consistent with output stabilization, so that $\tilde{I}_0 > 1/\mathbb{E}_0[I_1]$. To alleviate the constraints imposed by ELB at time 1, the central bank has therefore an incentive to keep an overly tight monetary stance at time 0. In other words, the central bank finds it optimal to keep the economy below the desired level of output at time 0 to increase monetary space and support output in case the ELB binds at time 1.

The link between ex-ante monetary policy and the future ELB has also important implications for the policy responses to global financial shocks at time 0. In the previous section, we showed that a tightening in global financial conditions at time 1 raises the ELB. As as a result, the ELB may bind and force the central bank to increase policy rates. We now show that the central bank finds it optimal to increase policy rates in response to a tightening in global financial conditions even at time 0, when the ELB does not bind. This is because tighter financial conditions increase concerns about the ELB binding in the future, prompting the central bank to preserve monetary space by tightening monetary policy ex-ante.

To formally establish this result, we analyze the optimal response of the policy rate at time 0 to an increase in γ_0 by applying the implicit function theorem to equation (14). Consider the limit case in which the probability ρ that the ELB binds at time 1 becomes infinitesimally small. We can then show that the sign of the derivative of the policy rate $\tilde{I}_0$ over γ_0 is given by

$$\text{sign}\left(\frac{\partial \tilde{I}_0}{\partial \gamma_0}\right) \xrightarrow{\rho \downarrow 0} \text{sign}\left(-\frac{\partial I_1^{ELB}}{\partial I_0}\left(2+\frac{I_1^{ELB}}{I_1^{ELB}-1}+\frac{\alpha\overline{\gamma}_1}{I_1^{ELB}}\right)+\frac{I_1^{ELB}}{1+\alpha\gamma_0}\right)$$

Considering equation (13), the right-side expression above is positive. Therefore, the central bank responds to a tightening in global financial conditions at time 0 by increasing the policy rate, even if the probability that the ELB binds at time 1 is infinitesimally small.

The intuition is that, holding monetary policy constant, a tightening in global financial conditions reduces capital inflows at time 0 and raises the ELB at time 1, thus lowering the associated level of output. Note that a higher ELB at time 1 leads also to lower output at time 0 since it implies a tighter expected monetary stance. If the central bank neglects the inter-temporal linkages between ex-ante monetary policy and the future ELB, it would respond by lowering policy rates at time 0 to support the current level of output. However, if monetary policy internalizes the inter-temporal linkages arising from the ELB, the optimal response is to increase policy rates at time 0 to limit the increase in the ELB at time 1. In other words, when global liquidity dries up, central banks should take preemptive action by hiking policy rates to preserve monetary space in case the ELB becomes binding in the future.

These findings imply that the empirical results presented in Table 1—that EMs hike rates when global financial conditions deteriorate—does not necessary reflect a binding ELB. According to the model, the observed policy tightening may simply be driven by the fear that the ELB may bind in the future. Notably, the model shows that these responses can arise even if the likelihood that the ELB binds in the future is very low.

2.3 Policies to escape the ELB

In this section we expand the model to include a broad range of policy tools that may help overcome the ELB. We consider both fiscal policy and capital controls that imply the following budget constraint for the government

$$B_t^g = \mathbb{B}_t^g - T_t - \chi_t B_t^f$$

where T_t are lump-sum taxes on domestic households and χ_t is a tax on foreign capital inflows. We also analyze the role of forward guidance, the impact of a recapitalization of the banking sector, and the effects of changes in the balance sheet of the central bank which is given by

$$N_t^{cb} + R_t = B_t^{cb} + e_t X_t$$

where N_t^{cb} is networth, R_t are domestic reserves, B_t^{cb} are holdings of government bonds, and X_t are foreign reserves. We analyze primarily the effects of these tools at time 1 when the ELB binds, but also consider how some of them can be used preemptively at time 0. We discuss the results in intuitive terms referring the reader to Appendix A.2 for formal derivations.

Regarding fiscal policy, since the ELB arises because public debt crowds out private lending, it may seem obvious that an increase in government taxes to reduce debt should alleviate the ELB. However, this is not necessarily the case since a tax-based fiscal consolidation has two effects. On the one hand, the reduction in public debt relaxes the bank leverage constraint in proportion to the capital requirement on government bonds λ. On the other, a tax increase raises loan demand because of a Ricardian equivalence effect: despite higher taxes at time 1, borrowers want to maintain the same level of consumption by borrowing more. The aggregate demand for loans thus increases in line with the tax burden imposed on borrowers, T_t^b/T_t, for each unit of additional tax revenues. If $T_t^b/T_t > \lambda$, a tax-based fiscal consolidation ends up tightening collateral constraints, raising the ELB, and lowering output.

Fiscal consolidation can also be undertaken by taxing foreigners with a levy on capital inflows, χ_t . However, this reduces foreign holdings of government bonds, forcing banks to further curtail private lending to finance public debt. To lower the ELB, it is instead optimal to subsidize capital inflows, setting $\chi_1 < 0$. This entails an increase in public debt, but the effect is overall positive, lowering the ELB.

The model has also rich implications for the role of balance-sheet operations by the central bank. To relax the bank leverage constraint, central banks can deploy quantitative easing which involves the purchase of government bonds by the central bank, B_1^{cb}, against the increase in central bank reserves R_1. By doing so, the central bank acts as a financial intermediary for government bonds, thus releasing liquidity into the banking sector that can be used to extend credit to the private sector. Quantitative easing is thus an effective tool to lower the ELB and stimulate output. Note that this is the case even if part of the gains from quantitative easing are eroded by the actions of carry traders since, by lowering yields on government bonds, quantitative easing exacerbates capital outflows.

The central bank can also alleviate the ELB by intervening in the foreign exchange market. Consider first the case of an unsterilized intervention, whereby the central bank exchanges foreign reserves, X_1, with domestic reserves, R_1. According to the model, the central bank should respond to a tightening in global financial conditions by purchasing foreign reserves. This depreciates the current level of the exchange rate, creates the expectation of a future appreciation and thus stimulates capital inflows. Notably, this is contrary to conventional wisdom which prescribes selling foreign reserves to prop up the currency when capital account pressures emerge.

If the central bank sterilizes the intervention by selling or purchasing government bonds, the conventional prescription applies, as for example analyzed in Amador et al. (2017), Cavallino (2019), and Fanelli and Straub (2019). The central bank should sell foreign reserves while purchasing government bonds. However, this is not because it is optimal to support the exchange rate. The sterilized sale of reserves alleviates the ELB because it involves the purchase of domestic government bonds, acting as a form of quantitative easing. This increases liquidity in the domestic banking sector and stimulates domestic credit supply, in line with the transmission channels of foreign exchange intervention analyzed in Chang (2018).

Turning to forward guidance, this is captured in the model through a change in the steady-state level of money supply M. Forward guidance is quite effective in providing stimulus when the economy is at the ZLB, as for example analyzed in Krugman, Dominquez and Rogoff (1998), Svensson (2003), and Eggertsson and Woodford (2003). A pledge by the central bank to provide stronger monetary stimulus in the future can indeed increase current domestic spending. Does this logic apply also to the ELB? The answer is no because, unlike the ZLB, the ELB is an endogenous interest rate threshold that moves with forward guidance. An increase in M announced at time 1 does increase spending for a given policy rate I_1, but it also increases the time-1 ELB. This is because higher M leads to a more depreciated exchange rate in steady state, reducing the foreign-currency return on domestic bonds and generating capital outflows. In the model, the overall effect of forward guidance is to increase the ELB, while leaving the level of output at the ELB unchanged.

A policy tool that is instead effective in overcoming the ELB is the recapitalization of the banking sector, as also analyzed in the context of credit easing policies by Negro et al. (2011), Gertler and Karadi (2011) Kollmann, Roeger and in't Veld (2012), Gertler, Kiyotaki and Queralto (2012) and Sandri and Valencia (2013). Bank recapitalization relaxes the ELB even if it is financed entirely with lump-sum taxes on borrowers which can be captured in the model through an increase in loan repayments at the beginning of period 1, $\mathbb{L}_1$. While lump-sum taxes increase one-to-one loan demand by borrowers, they increase lending supply by a greater factor thanks to bank leverage, i.e. $\phi > 1$. A bank recapitalization can thus lower the ELB and increase monetary space.

For what concerns preemptive intervention at time 0, fiscal consolidation has similar effects than at time 1. In particular, fiscal consolidation can lower a future ELB only if the tax burden imposed on borrowers is smaller than the capital charge on government bonds, i.e. $T_0^b/T_0 < \lambda$. Taxes on capital inflows have instead ambiguous effects. On the one hand, they reduce public debt, thus lowering the ELB. On the other hand, they reduce capital inflows, thus raising the ELB. The overall effect depends on the parameters of the model and in particular on the probability that the ELB may bind in the future. Finally, foreign exchange intervention can also be helpful at time 0 since it can lower the ELB by depreciating the exchange rate and attracting more inflows. Notice that, since the banks leverage constraint is not binding at time 0 domestic assets are perfect substitute for banks. Hence, unlike at time 1, foreign exchange intervention has the same effect regardless of whether it is sterilized or not.

3 The ELB and currency mismatches

In this section we present a second model to show that the ELB can also emerge because of the exposure of the domestic financial sector to currency mismatches.[25] By depreciating the exchange rate, monetary easing reduces bank networth and tightens the leverage constraint, possibly leading to a domestic credit crunch and output contraction. As in the previous model, this gives rise to an ELB that places an upper bound on the level of output achievable through monetary accommodation. Other papers, in particular Céspedes, Chang and Velasco (2004), Christiano, Gust and Roldos (2004), and more recently Gourinchas (2018), already developed models in which collateral constraints associated with currency mismatches can generate contractionary effects from monetary easing. However, in those models monetary policy can still achieve any level of output since it does not affect whether constraints are binding or not. When constraints bind, monetary policy can increase output without bounds by simply raising policy rates as much as needed. This is no longer possible in our framework, since monetary policy affects whether constraints bind or not. In particular, raising rates eventually relaxes collateral constraints, at which point further interest rate hikes become contractionary.

3.1 Model setup

Consider a small open economy in which households consume domestic and foreign goods. All households are borrowers and raise domestic currency loans from local banks. The corporate sector mirrors the previous model, except that foreign prices are now rigid in local currency. This leads to an additional expenditure-switching channel through which monetary easing stimulates demand for domestic goods by depreciating the exchange rate.

Unlike the previous model, we dispense from carry-trade capital flows by ruling out frictions in international financial markets so that UIP holds. Furthermore, we assume that banks finance themselves internationally by issuing foreign-currency debt. The balance sheet of the banking sector is given by

$$N_t + e_t D_t^* = L_t + R_t$$

where D_t^* is foreign-currency debt and the other variables are defined as in the previous model. Bank networth evolves according to

[25] We could also assume that unhedged currency exposures are borne by domestic non-financial firms. Firms in emerging markets have indeed increased considerably the issuance of dollar bonds since the global financial crisis, as for example documented in Acharya et al. (2015) and McCauley, McGuire and Sushko (2015). We assume that currency mismatches are held by banks for symmetry with the previous model and because of these two considerations. First, even if currency mismatches are concentrated in the non-financial corporate sector, an exchange rate depreciation tends to ultimately generate losses in the financial sector, as firms default on their loans. Second, there is compelling empirical evidence (Caballero, Panizza and Powell, 2015; Bruno and Shin, 2015) that non-financial firms in emerging markets have behaved recently like financial intermediaries, by issuing dollar debt at low rates while holding large positions in domestically denominated financial assets.

$$N_{t+1} = L_t I_t^L + R_t I_t - e_{t+1} D_t^* I_t^*$$

As before, banks are subject to a leverage constraint that limits lending to a certain multiple of networth:

$$L_t \leq \phi N_t \tag{15}$$

with $\phi \geq 1$. We abstract in this model from the role of government debt by assuming that banks can hold any amount of sovereign bonds, thus setting $\lambda = 0$.

Banks act competitively and choose assets and liabilities to maximize networth. No arbitrage between central bank reserves and foreign currency debt implies the UIP condition, $\mathbb{E}_t \left[(e_t I_t - e_{t+1} I_t^*) \left(I_{t+1} + \phi \mu_{t+1} \right) \right] = 0$, where μ_{t+1} is the shadow cost of the leverage constraint. Furthermore, the first order condition with respect to domestic lending implies $I_t^L = I_t + \mu_t$. If the leverage constraint is not binding, the domestic lending rate is equal to the policy rate. If instead the constraint binds, the lending rate has to increase above the policy rate to equalize the demand for loans with the constrained credit supply. The central bank conducts monetary policy by setting the interest rate on reserves. As in the previous model, we first abstract from the central bank's balance sheet by considering the limit of the model for $R_t \downarrow 0$.

3.2 Model equilibrium

We solve the equilibrium following the solution approach in the previous model. We assume that the economy is in steady state from time 2 onward and consider the limit for $\beta \uparrow 1$, in which case the exchange rate is pinned down by domestic and foreign money supply. We generalize the model results to the case in which $\beta < 1$ in Appendix B.2. As before we normalize the prices of Home goods at time 0 and 1, the steady-state Home and foreign money supply, and the domestic steady-state output to 1. This implies that the steady-state exchange rate is also equal to 1, $e = 1$. We first characterize the conditions for the existence of the ELB at time 1 and then analyze the implications for monetary policy at time 0.

3.2.1 Model equilibrium at time 1

The level of output at time 1 is equal to

$$Y_1 = \frac{1-\alpha}{I_1^L} + e_1 \frac{\alpha}{I_1^*} \tag{16}$$

The first and second terms on the right-hand side capture the consumption of Home goods by domestic and foreign households, respectively. If banks are unconstrained, the lending rate is equal to the policy rate, $I_1^L = I_1$, and monetary easing stimulates output through two channels. First, it boosts spending by domestic households by reducing lending rates. Second, it raises foreign demand through the depreciation of the exchange rate which is equal to $e_1 = I_1^*/I_1$.

Because of currency mismatches, the exchange rate depreciation associated with monetary easing leads to an erosion of bank networth which is given by

$$N_1 = \mathbb{L}_1 - e_1 \mathbb{D}_1^*$$

where $\mathbb{L}_1 \equiv L_0 I_0$ and $\mathbb{D}_1^* \equiv D_0 I_0^*$ are the loans and foreign-currency liabilities of the banking sector at the beginning of time 1. The networth loss leads to a tightening of the collateral constraint (15) that becomes binding if the domestic policy rate becomes sufficiently low. Once the leverage constraint binds, banks lose the ability to freely intermediate foreign capital into domestic lending. Additional monetary easing forces banks to reduce domestic lending as networth declines and the economy experiences capital outflows through a reduction in bank foreign liabilities. To preserve equilibrium in the credit market, the lending rate has to increase above the policy rate according to the following equation

$$I_1^L = \frac{\alpha}{(\phi-1)\,\mathbb{L}_1 - e_1\left(\phi \mathbb{D}_1^* - \frac{\alpha}{I_1^*}\right)} \tag{17}$$

The expression above shows that, when banks are constrained, monetary easing affects the lending rate through the impact on the exchange rate. On the one hand, the depreciation reduces credit supply by eroding bank networth. On the other hand, it reduces credit demand by raising export revenues. If the former effect prevails, which occurs when foreign-currency debt is high enough to satisfy $\phi \mathbb{D}_1^* > \alpha / I_1^*$, monetary easing leads to an increase, rather than a decline, in the lending rate. This is needed to preserve market clearing in the credit market.

The increase in the lending rate leads to a contraction in domestic spending. This negative effect on domestic demand has to be compared with the positive effect that monetary easing retains on foreign demand through the depreciation of the exchange rate. By substituting equation (17) in equation (16 we find that the contractionary effect on domestic spending outweighs the expansionary effect on foreign demand if foreign-currency debt is sufficiently high to satisfy

$$\phi \mathbb{D}_1^* > \frac{\alpha}{(1-\alpha)\,I_1^*} \tag{18}$$

When this condition is met, once the leverage constraint binds, monetary easing becomes contractionary giving rise to the following ELB

$$I_1^{ELB} = \frac{\phi \mathbb{D}_1^* I_1^*}{(\phi-1)\,\mathbb{L}_1} \tag{19}$$

The ELB prevents the central bank from increasing output above $Y_1^{ELB} = 1/I_1^{ELB}$.

The level of ELB depends on the extent of currency mismatches on banks' balance sheets, captured by the proportion of foreign-currency debt relative to domestic-currency loans. If mismatches are sufficiently severe, the ELB can occur at positive interest rates, thus acting as a stronger constraint for monetary policy than the zero lower bound.

The ELB is affected by global monetary conditions. An increase in the foreign policy rate depreciates the domestic currency, raises the ELB, and reduces the maximum level of output that monetary policy can achieve. This is illustrated in Figure 4. If collateral constraints are not binding, changes in foreign monetary policy do not affect domestic output since they are offset by exchange rate movements.[26] Note that this is true even in the presence of currency mismatches, but only as long as constraints do not bind. However, by depreciating the domestic currency, an increase in foreign policy rates leads to an erosion in bank networth that tightens collateral constraints and raises the ELB. Therefore, for a large enough increase of the foreign policy rate, the ELB binds and forces the domestic central bank to raise policy rates in line with the empirical evidence presented in Table 1.

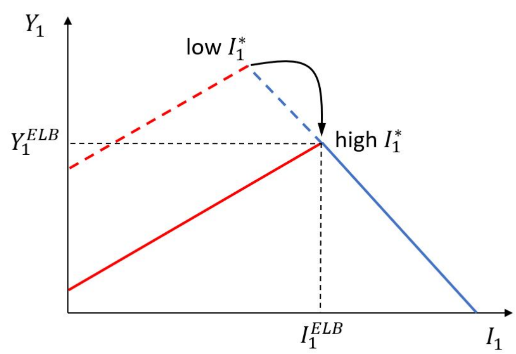

Figure 4: Foreign monetary shocks under currency mismatches.

3.2.2 Model equilibrium at time 0

We now characterize the model equilibrium at time 0 under the assumption that the bank leverage constraint does not bind. This is to analyze how the possibility that the ELB may bind in the future affects monetary policy even when domestic financial conditions are loose. In doing so, we assume that the only stochastic element at time 1 is the foreign monetary policy rate I_1^*. Specifically, we assume that with positive probability, ρ, the foreign interest rate I_1^* is sufficiently high that the ELB binds, forcing the central bank to set the policy rate at the ELB. With probability $1-\rho$, I_1^* is sufficiently low that the ELB does not bind, in which case the domestic monetary authority can maintain output at its steady-state level by setting the policy rate at $I_1 = 1$. As shown below, to

[26] As shown in Appendix B.2, changes in foreign monetary policy can have effects on the domestic economy even when constraints are not binding if we allow for wealth effects by assuming $\beta < 1$. However, as long as constraints do not bind, the effects on domestic output can be offset with appropriate changes of the domestic policy rate.

account for important transmission channels of monetary policy linked to currency mismatches, we allow the domestic inter-temporal discount factor at time 0, β_0, to differ from one.

Consider first how monetary policy at time 0 affects the ELB at time 1 by impacting the balance sheets of the banking sector at time 1. The equilibrium levels of foreign-currency debt and domestic-currency loans at the beginning of time 1 are given by

$$\mathbb{D}_1^* = \mathbb{D}_0^* I_0^* + \frac{1-\beta_0}{\beta_0} \frac{\alpha}{\mathbb{E}_0\left[I_1^*\right]} \tag{20}$$

$$\mathbb{L}_1 = \mathbb{L}_0 I_0 + \frac{1-\beta_0}{\beta_0} \frac{\alpha}{\mathbb{E}_0\left[I_1\right]} \tag{21}$$

To understand the impact of time-0 monetary policy, start by holding constant the expected domestic interest rate at time 1, $\mathbb{E}_0\left[I_1\right]$. In this case, a domestic monetary tightening at time 0 increases the loan repayments for banks at time 1, $\mathbb{L}_1$, since it leads to higher lending rates. At the same it does not generate an increase in foreign-currency debt, $\mathbb{D}_1^*$, which is insensitive to movements in the domestic policy rate.[27] Therefore, monetary tightening at time 0 leads to a reduction in the time-1 ELB as defined in equation (19). If $\beta_0 < 1$, the impact on the ELB is magnified once we consider the effects that monetary policy at time 0 has on $\mathbb{E}_0\left[I_1\right]$. The first-round reduction in the ELB leads to a decline in the expected level of the time 1 interest rate, $\mathbb{E}_0\left[I_1\right]$ which in turn increases loan demand at time 0 as shown in equation (21). This raises loan repayments at the beginning of time 1 and further lowers the ELB.

As in the model with carry-trade capital flows, the negative correlation between the time-0 policy rate and the time-1 ELB generates an inter-temporal trade-off for monetary policy. Greater easing at time 0 reduces the space for monetary stimulus in the future by raising the ELB. This calls for keeping a relatively tight monetary stance—keeping the economy below the desired level of output—when global monetary conditions are favorable to have more monetary space in the future. Furthermore, the negative correlation between ex-ante monetary policy and the ELB tends to weaken the transmission of monetary policy even when the ELB does not bind. To see this, note that time-0 output is given by

$$Y_0 = \frac{1-\alpha}{\beta_0 I_0 \mathbb{E}_0\left[I_1\right]} + e_0 \frac{\alpha}{I_0^* \mathbb{E}_0\left[I_1^*\right]}$$

where the exchange rate is $e_0 = I_0^* \mathbb{E}_0\left[I_1^*\right] / \left(I_0 \mathbb{E}_0\left[I_1\right]\right)$. The stimulative effect of a policy rate cut at time 0 is partially offset by an expected tightening of future monetary policy $\mathbb{E}_0\left[I_1\right]$ due to the increase in the ELB. This weakens the impact on domestic demand since current consumption depends not only on the current interest rate, but also on the expected future monetary stance.

[27] Changes in loan demand are accommodated through changes in the domestic-currency value of foreign-currency debt. For example, monetary easing leads to an exchange rate depreciation which increases the domestic-currency value of foreign-currency debt in line with the increase in domestic credit demand.

Furthermore, the increase in $\mathbb{E}_0[I_1]$ reduces foreign demand since it limits the depreciation of the time-0 exchange rate e_0.

The model provides also interesting insights about the ongoing debate on whether central banks in major advanced economies, notably the Fed, should internalize the effects of their monetary policy decisions on EMs. As shown in Figure (4), a tightening in the foreign policy rate increases the ELB and can push EMs into a recession. This seems to suggest that if foreign central banks care about the welfare of EMs, they should refrain from increasing rates sharply when EMs confront a binding ELB. For example, if currency mismatches are associated with US dollars, the Fed should accept some domestic overheating to limit the adverse effects that a sharp monetary tightening would impose on EMs.

However, if the Fed is expected to follow this course of action, EMs have a perverse incentive to accumulate more foreign-currency debt. As shown in equation (20), foreign liabilities are inversely proportional to the expected tightness of foreign monetary policy $\mathbb{E}_0[I_1^*]$ if EMs are relatively impatient, so that $\beta_0 < 1$. The model can therefore rationalize the growing concerns that EMs may be unable to insulate themselves from US monetary conditions, even if they have flexible exchange rates, because of the ELB. However, it also shows that any commitment by the Fed to refrain from sharp policy rate increases to protect EMs would be partially ineffective because it would led to an endogenous increase in foreign-currency borrowing.

There are two ways to limit this accumulation of additional foreign-currency debt. First, the expectation of a looser US monetary stance if the ELB binds in EMs could be offset with the promise of a tighter US monetary stance if the ELB does not bind. Doing so would prevent a reduction in the expected tightness of future US monetary policy $\mathbb{E}_0[I_1^*]$ and thus avoid incentives for additional borrowing. Note that this policy implies a commitment by the Fed to keep a more stable US dollar, hiking policy rates less when the US economy overheats and cutting them more moderately when the economy contracts. Second, policy makers in EMs can avoid additional foreign-currency debt by adopting macro-prudential regulations. We analyze the role of these tools and other policies in the next section.

3.3 Policies to escape the ELB

In this section, we consider several policy tools that can be used to escape the ELB. As in the model with carry-trade capital flows, forward guidance is unable to deal with the ELB even when it arises because of currency mismatches. This is because the promise of a looser future monetary stance leads to an immediate depreciation of the exchange rate that tightens the bank leverage constraint. Formally, an increase in M through forward guidance raises the ELB, while leaving the upper bound on the level of output attainable through monetary policy, Y_1^{ELB}, unchanged. Balance-sheet operations by the central bank are also ineffective in this model since the exchange rate is pinned down by the UIP condition and not by quantity equations.

To lower the ELB due to currency mismatches, policymakers can rely on the recapitalization of the banking sector which relaxes collateral constraints. Capital controls can also be effective since they can sever the link between the exchange rate and domestic monetary conditions. In particular, the government can stimulate capital inflows and support the domestic exchange rate by providing banks with a subsidy χ_1 on foreign currency debt. This places a wedge in the UIP condition, $e_1 = e_2(1-\chi_1)I_1^*/I_1$, that leads to an appreciate of the exchange rate, relaxes the ELB, and allows for greater monetary stimulus. The model provides also a rationale for using macro-prudential capital controls. As shown in Appendix B.1, by taxing capital inflows at time 0, policymakers can reduce the amount of foreign currency debt carried into period 1 and thus lower the time-1 ELB.

4 Conclusion

In this paper, we showed that the interaction between capital flows and domestic collateral constraints can undermine the transmission of monetary policy by giving rise to an open-economy Effective Lower Bound. The ELB is an interest rate threshold below which monetary easing becomes contractionary. This places an upper bound on the level of output achievable through monetary accommodation even if the exchange rate is flexible.

The ELB is affected by global financial and monetary conditions. A reduction in global liquidity increases the ELB which can prompt central banks in emerging markets to increase policy rates while economic activity contracts, in line with the empirical evidence. Once the ELB binds, output is determined by international financial conditions even in countries with flexible exchange rates. This provides a crucial departure from Mundell's trilemma according to which monetary policy in open economies should retain the ability to stabilize output under flexible exchange rates.

We showed that the ELB emerges when monetary policy affects whether domestic collateral constraints are binding or not, a novel feature in the open-economy literature. This can occur, for example, due to carry-trade capital flows. In this case, monetary easing determines an outflow of capital which requires the domestic banking sector to absorb the bonds liquidated by foreigners. This pushes banks against their leverage constraints at which point banks have to reduce domestic credit to continue to buy the bonds shed by foreigners. Because of this credit crunch, monetary easing becomes contractionary if policy rates are lowered below the ELB.

An ELB can be present also because of currency mismatches. If the banking sector borrows abroad in foreign currency and lends domestically in local currency, monetary easing reduces bank networth and moves banks closer to their leverage constraint. Once the constraint binds, further monetary easing forces banks to reduce domestic credit and becomes contractionary if currency mismatches are sufficiently severe.

The existence of the ELB implies also a novel inter-temporal trade-off for monetary policy since the level of the ELB is affected by past monetary policy decisions. More specifically, a tighter ex-ante monetary stance reduces financial vulnerabilities and lowers the level of the ELB in the future, thus creating more monetary space to offset possible shocks. This observation has important normative implications since it calls for keeping a somewhat tighter monetary stance when financial conditions are supportive to lower the ELB in the future.

Finally, the models have rich implications for the use of alternative policy tools that can be deployed to overcome the ELB and restore monetary transmission. In particular, the presence of the ELB calls for an active use of the central bank's balance sheet, for example through quantitative easing and foreign exchange intervention. Furthermore, the ELB provides a new rationale for capital controls and macro-prudential policies, as they can be successfully used to ease the tensions between domestic collateral constraints and capital flows. Fiscal policy can also help to overcome the ELB, while forward guidance is ineffective since the ELB increases with the expectation of looser monetary conditions in the future.

Looking ahead, the paper calls for more research along two fronts. First, it would be helpful to provide additional empirical evidence about the existence of the ELB. In principle, this would require showing that monetary easing is contractionary when domestic or international financial conditions are tight, for example as many argued during the Asian financial crisis. However, episodes of contractionary monetary easing are likely to be quite limited since, as described in the model, central banks would not want to lower policy rates below the ELB. It may thus be preferable to focus on how the ELB distorts the response of monetary policy to external shocks in line with the suggestive evidence presented in the introduction. Second, future research can analyze the implications of the ELB using quantitative DSGE models. This would shed light on the exact circumstances under which the ELB may arise, on its level, and strength of the inter-temporal trade-off for monetary policy arising from the ELB.

References

Acharya, Viral, Stephen Cecchetti, José De Gregorio, Şebnem Kalemli-Özcan, Philip R. Lane, and Ugo Panizza. 2015. "Corporate Debt in Emerging Economies: A Threat to Financial Stability?" *Committee on International Economic Policy and Reform.*

Aghion, Philippe, Philippe Bacchetta, and Abhijit Banerjee. 2000. "A Simple Model of Monetary Policy and Currency Crises." *European Economic Review*, 44(4-6): 728 – 738.

Aghion, Philippe, Philippe Bacchetta, and Abhijit Banerjee. 2001. "Currency Crises and Monetary Policy in an Economy with Credit Constraints." *European Economic Review*, 45(7): 1121–1150.

Aizenman, Joshua, Menzie D. Chinn, and Hiro Ito. 2016. "Monetary policy spillovers and the trilemma in the new normal: Periphery country sensitivity to core country conditions." *Journal of International Money and Finance*, 68: 298–330.

Akinci, Ozge, and Albert Queralto. 2018. "Exchange Rate Dynamics and Monetary Spillovers with Imperfect Financial Markets." *Federal Reserve Bank of New York Staff Reports, no. 849.*

Altavilla, Carlo, Miguel Boucinha, and José-Luis Peydró. 2018. "Monetary policy and bank profitability in a low interest rate environment." *Economic Policy*, 33(96): 531–586.

Amador, Manuel, Javier Bianchi, Luigi Bocola, and Fabrizio Perri. 2017. "Exchange rate policies at the zero lower bound." National Bureau of Economic Research.

Aoki, Kosuke, Gianluca Benigno, and Nobuhiro Kiyotaki. 2016. "Monetary and financial policies in emerging markets." *Unpublished paper, London School of Economics*.

Benigno, Gianluca, Huigang Chen, Christopher Otrok, Alessandro Rebucci, and Eric R Young. 2013. "Financial crises and macro-prudential policies." *Journal of International Economics*, 89(2): 453–470.

Benigno, Gianluca, Huigang Chen, Christopher Otrok, Alessandro Rebucci, and Eric R Young. 2016. "Optimal capital controls and real exchange rate policies: A pecuniary externality perspective." *Journal of Monetary Economics*, 84: 147–165.

Bianchi, Javier. 2011. "Overborrowing and Systemic Externalities in the Business Cycle." *American Economic Review*, 101(7): 3400–3426.

Blanchard, Olivier, Jonathan D. Ostry, Atish R. Ghosh, and Marcos Chamon. 2016. "Capital Flows: Expansionary or Contractionary?" *American Economic Review*, 106(6): 565–69.

Blanchard, Olivier, Jonathan D. Ostry, Atish R. Ghosh, and Marcos Chamon. 2017. "Are Capital Inflows Expansionary or Contractionary? Theory, Policy Implications, and Some Evidence." *IMF Economic Review*, 65(3): 563–585.

Bräuning, Falk, and Victoria Ivashina. 2019. "US monetary policy and emerging market credit cycles." *Journal of Monetary Economics*.

Brunnermeier, Markus K., and Yann Koby. 2016. "The "Reversal Interest Rate": An Effective Lower Bound on Monetary Policy." *Manuscript*.

Brunnermeier, Markus K, Stefan Nagel, and Lasse H Pedersen. 2008. "Carry trades and currency crashes." *NBER macroeconomics annual*, 23(1): 313–348.

Bruno, Valentina, and Hyun Song Shin. 2015. "Capital flows and the risk-taking channel of monetary policy." *Journal of Monetary Economics*, 71: 119–132.

Caballero, Julian, Ugo Panizza, and Andrew Powell. 2015. "The Second Wave of Global Liquidity: Why are Firms Acting like Financial Intermediaries?" *CEPR Working Paper 10926*.

Cavallino, Paolo. 2019. "Capital Flows and Foreign Exchange Intervention." *American Economic Journal: Macroeconomics*, 11(2): 127–170.

Céspedes, Luis Felipe, Roberto Chang, and Andrés Velasco. 2004. "Balance Sheets and Exchange Rate Policy." *The American Economic Review*, 94(4): 1183–1193.

Chang, Roberto. 2018. "Foreign Exchange Intervention Redux." National Bureau of Economic Research.

Choi, Woon Gyu, Taesu Kang, Geun-Young Kim, and Byongju Lee. 2017. "Global liquidity transmission to emerging market economies, and their policy responses." *Journal of International Economics*, 109: 153–166.

Christiano, Lawrence J., Christopher Gust, and Jorge Roldos. 2004. "Monetary Policy in a Financial Crisis." *Journal of Economic Theory*, 119(1): 64–103.

Corte, Pasquale Della, Steven J Riddiough, and Lucio Sarno. 2016. "Currency premia and global imbalances." *The Review of Financial Studies*, 29(8): 2161–2193.

Dedola, Luca, Giulia Rivolta, and Livio Stracca. 2017. "If the Fed sneezes, who catches a cold?" *Journal of International Economics*, 108: S23–S41.

Eggertsson, Gauti B., and Michael Woodford. 2003. "The Zero Bound on Interest Rates and Optimal Monetary Policy." *Brookings Papers on Economic Activity*, 2003(1): 139–211.

Eggertsson, Gauti B., Ragnar E. Juelsrud, Lawrence H. Summers, and Ella Getz Wold. 2019. "Negative Nominal Interest Rates and the Bank Lending Channel." *NBER Working Paper No. 25416*.

Egorov, Konstantin, and Dmitry Mukhin. 2019. "Optimal Monetary Policy under Dollar Pricing." *Available at SSRN 3404660*.

Fanelli, Sebastián, and Ludwig Straub. 2019. "A Theory of Foreign Exchange Interventions."

Farhi, Emmanuel, and Ivan Werning. 2016. "A Theory of Macroprudential Policies in the Presence of Nominal Rigidities." *Econometrica*, 84(5): 1645–1704.

Fornaro, Luca. 2015. "Financial crises and exchange rate policy." *Journal of International Economics*, 95(2): 202–215.

Gabaix, Xavier, and Matteo Maggiori. 2015. "International Liquidity and Exchange Rate Dynamics." *Quarterly Journal of Economics*, 130(3): 1369–1420.

Gertler, Mark, and Peter Karadi. 2011. "A model of unconventional monetary policy." *Journal of monetary Economics*, 58(1): 17–34.

Gertler, Mark, Nobuhiro Kiyotaki, and Albert Queralto. 2012. "Financial crises, bank risk exposure and government financial policy." *Journal of Monetary Economics*, 59: 17–34.

Goodhart, Charles, and Ali Kabiri. 2019. "Monetary policy and bank profitability in a low interest rate environment: a follow-up and a rejoinder." *CEPR Discussion Paper No. DP13752*.

Gopinath, Gita, Emine Boz, Camila Casas, Federico J. Díez, Pierre-Olivier Gourinchas, and Mikkel Plagborg-Møller. 2019. "Dominant Currency Paradigm." *Mimeo*.

Gourinchas, Pierre-Olivier. 2018. "Monetary Policy Transmission in Emerging Markets: An Application to Chile." *Central Banking, Analysis, and Economic Policies Book Series*, 25: 279–324.

Han, Xuehui, and Shang-Jin Wei. 2018. "International transmissions of monetary shocks: Between a trilemma and a dilemma." *Journal of International Economics*, 110: 205–219.

Iacoviello, Matteo, and Gaston Navarro. 2019. "Foreign effects of higher US interest rates." *Journal of International Money and Finance*, 95: 232–250.

Ilzetzki, Ethan, Carmen M Reinhart, and Kenneth S Rogoff. 2019. "Exchange Arrangements Entering the Twenty-First Century: Which Anchor will Hold?" *The Quarterly Journal of Economics*, 134(2): 599–646.

Jeanne, Olivier, and Anton Korinek. 2010. "Excessive volatility in capital flows: A pigouvian taxation approach." *American Economic Review*, 100(2): 403–07.

Kalemli-Özcan, Şebnem. 2019. "U.S. Monetary Policy and International Risk Spillovers." *Jackson Hole Economic Policy Symposium*.

Kollmann, Robert, Werner Roeger, and Jan in't Veld. 2012. "Fiscal Policy in a Financial Crisis: Standard Policy versus Bank Rescue Measures." *The American Economic Review*, 102(3): 77–81.

Korinek, Anton, and Alp Simsek. 2016. "Liquidity Trap and Excessive Leverage." *American Economic Review*, 106(3): 699–738.

Korinek, Anton, and Damiano Sandri. 2016. "Capital controls or macroprudential regulation?" *Journal of International Economics*, 99: S27–S42.

Krugman, Paul. 1999. "Balance Sheets, the Transfer Problem, and Financial Crises." In *International Finance and Financial Crises*. , ed. Peter Isard, Assaf Razin and Andrew K. Rose, 31–55. Springer.

Krugman, Paul R., Kathryn M. Dominquez, and Kenneth Rogoff. 1998. "It's baaack: Japan's slump and the return of the liquidity trap." *Brookings Papers on Economic Activity*, 1998(2): 137–205.

Lustig, Hanno, and Adrien Verdelhan. 2007. "The cross section of foreign currency risk premia and consumption growth risk." *American Economic Review*, 97(1): 89–117.

Lustig, Hanno, Nikolai Roussanov, and Adrien Verdelhan. 2011. "Common risk factors in currency markets." *The Review of Financial Studies*, 24(11): 3731–3777.

McCauley, Robert N., Patrick McGuire, and Vladyslav Sushko. 2015. "Global Dollar Credit: Links to US Monetary Policy and Leverage." *Economic Policy*, 30(82): 187–229.

Menkhoff, Lukas, Lucio Sarno, Maik Schmeling, and Andreas Schrimpf. 2012. "Carry trades and global foreign exchange volatility." *The Journal of Finance*, 67(2): 681–718.

Miranda-Agrippino, Silvia, and Hélène Rey. 2019. "Monetary Policy and the Global Financial Cycle."

Mundell, Robert A. 1963. "Capital Mobility and Stabilization Policy under Fixed and Flexible Exchange Rates." *The Canadian Journal of Economics and Political Science*, 29(4): 475–485.

Negro, Marco Del, Gauti Eggertsson, Nubuhiro Kiyotaki, and Andrea Ferrero. 2011. "The Great Escape? A Quantitative Evaluation of the Fed's Non-Standard Policies." *NY FED Staff Report no. 520*.

Obstfeld, Maurice. 2015. “Trilemmas and Trade-offs: Living with Financial Globalization.” In *Global Liquidity, Spillovers to Emerging Markets and Policy Responses*. , ed. Claudio Raddatz, Diego Saravia and Jaume Ventura, Chapter 2, 13–78. Central Bank of Chile.

Obstfeld, Maurice, Jay C. Shambaugh, and Alan M. Taylor. 2005. “The trilemma in history: tradeoffs among exchange rates, monetary policies, and capital mobility.” *Review of Economics and Statistics*, 87(3): 423–438.

Ottonello, Pablo. 2015. “Optimal Exchange-Rate Policy Under Collateral Constraints and Wage Rigidities.” *Manuscript*.

Rey, Hélène. 2013. “Dilemma not Trilemma: The Global Financial Cycle and Monetary Policy Independence.” In *Global Dimensions of Unconventional Monetary Policy*. Jackson Hole Symposium Proceedings. Federal Reserve Bank of Kansas City.

Rey, Hélène. 2016. “International Channels or Transmission of Monetary Policy and the Mundellian Trilemma.” *IMF Economic Review*, 64(1): 6–35.

Sandri, Damiano, and Fabian Valencia. 2013. “Financial Crises and Recapitalizations.” *Journal of Money, Credit and Banking*, 45(s2): 59–86.

Svensson, Lars E.O. 2003. “Escaping from a Liquidity Trap and Deflation: The Foolproof Way and Others.” *Journal of Economic Perspectives*, 17(4): 145–166.

Wu, Jing Cynthia, and Fan Dora Xia. 2016. “Measuring the macroeconomic impact of monetary policy at the zero lower bound.” *Journal of Money, Credit and Banking*, 48(2-3): 253–291.

Appendix

A Generalized model with carry traders

In this appendix, we start by describing the equations of the carry-trade model in their generalized version, introducing the full set of policy instruments analyzed in the paper, allowing monetary policy to affect credit demand (by not forcing the borrowers' aggregate share of income to vary with the policy rate) and without setting the inter-temporal discount factor to 1. We proceed in section A.1 to describe the solution of the simplified model presented in the paper which considers only the role of conventional monetary policy, prevents monetary policy from affecting credit demand, and sets the discount factor to 1. We then consider how the model equilibrium varies under alternative policy tools in section A.2, allowing monetary policy to affect credit demand in section A.3, and without restricting the inter-temporal discount factor to 1 in section A.4. Finally, we show in section A.5 how the elasticity of the exchange rate with respect to the policy rate differs if we depart from the assumption of unitary intra and inter-temporal elasticities of substitution.

The generalized equations of the carry-trade model are as follows. Borrowers and Savers budget constraints are

$$P_t C_t^b - \Pi_t^b = L_t - \mathbb{L}_t$$
$$P_t C_t^s - \Pi_t^s = -D_t + \mathbb{D}_t$$

where $\mathbb{L}_t = L_{t-1} I_{t-1}^L$, $\mathbb{D}_t = D_{t-1} I_{t-1}$. The income of the borrowers and savers is given by how much they earn from the sale of goods to domestic households, foreign households, the government net of taxes, and possible dividend payments by domestic banks. Incomes can thus be expressed in very generic form as

$$\begin{aligned}
\Pi_t^b &= \omega_t^b P_H C_{H,t}^b + \omega_t^s P_H C_{H,t}^s + \omega_t^f e_t P_H^* C_{H,t}^* + \omega_t^g \left(P_H G_{H,t} - T_t\right) + \omega_t^n \left(\mathbb{N}_t - N_t\right) \\
\Pi_t^s &= \left(1-\omega_t^b\right) P_H C_{H,t}^b + \left(1-\omega_t^s\right) P_H C_{H,t}^s + \left(1-\omega_t^f\right) e_t P_H^* C_{H,t}^* \\
&\quad + \left(1-\omega_t^g\right)\left(P_H G_{H,t} - T_t\right) + \left(1-\omega_t^n\right)\left(\mathbb{N}_t - N_t\right)
\end{aligned}$$

where $G_{H,t}$ is government spending, assumed to consist entirely of domestic goods, T_t are lump-sum taxes, and $\mathbb{N}_t$ is beginning-of-period banks networth (i.e. before transfer to/from households). The coefficients $\omega_t^b, \omega_t^s, \omega_t^f, \omega_t^g, \omega_t^n$ are the shares of each income component appropriated by borrowers.

The household Euler equations are

$$1 = \beta I_t^L \mathbb{E}_t \left[P_t C_t^b / \left(P_{t+1} C_{t+1}^b \right) \right]$$
$$1 = \beta I_t \mathbb{E}_t \left[P_t C_t^s / \left(P_{t+1} C_{t+1}^s \right) \right]$$

while their demand for Home goods is given by $P_H C_{H,t}^i = (1-\alpha) P_t C_t^i$. Foreign households Euler equation is

$$1 = \beta^* I_t^* \mathbb{E}_t \left[P_t^* C_t^* / \left(P_{t+1}^* C_{t+1}^* \right) \right]$$

while their demand for Home goods is given by $P_H^* C_{H,t}^* = \alpha P_t^* C_t^*$.

The balance sheet of the domestic banking sector is

$$N_t + D_t = L_t + B_t + R_t$$

therefore $\mathbb{N}_t = \mathbb{L}_t + \mathbb{B}_t + \mathbb{R}_t - \mathbb{D}_t$, where $\mathbb{B}_t = B_{t-1} I_{t-1}^B$, $\mathbb{R}_t = R_{t-1} I_{t-1}$. Banks are subject to the leverage constraint $L_t + \lambda B_t \leq \phi N_t$. Foreign demand for domestic government bonds is

$$B_t^f = \frac{1}{\gamma_t} \mathbb{E}_t \left[\frac{e_t}{e_{t+1}} \frac{(1-\chi_t) I_t^B}{I_t^*} - 1 \right]$$

where χ_t is a tax on capital inflows. The balance sheet of the domestic central bank is

$$N_t^{cb} + R_t = B_t^{cb} + e_t X_t$$

therefore $\mathbb{N}_t^{cb} = \mathbb{B}_t^{cb} + e_{t+1} \mathbb{X}_t - \mathbb{R}_t$, with $\mathbb{X}_t = X_{t-1} I_{t-1}^*$, where X_t are foreign reserves. Finally, the consolidated budget constraint of the public sector is

$$P_H G_{H,t} - T_t = B_t^g - \mathbb{B}_{t-1}^g + \chi_t B_t^f + \mathbb{N}_{t-1}^{cb} - N_t^{cb}$$

where $G_{H,t}$ is government spending, assumed to consist entirely of domestic goods. Market clearings require

$$\begin{aligned} Y_t &= C_{H,t} + C_{H,t}^* + G_{H,t} \\ B_t^g &= B_t + B_t^f + B_t^{cb} \end{aligned}$$

The aggregate budget constraint of the country is

$$\alpha P_t C_t = \alpha e_t P_t^* C_t^* + (1+\chi_t) B_t^f - \mathbb{B}_{t-1}^f + e_t \left(\mathbb{X}_{t-1} - X_t \right)$$

From time 2 onwards the economy is in steady state with $\gamma_t = \chi_t = 0$ and $I_t = 1/\beta$. This implies that $B_t^f = \beta \mathbb{B}_2^f$ and $X_t = \beta \mathbb{X}_2$, for all $t \geq 2$. Thus, at time 2 we have

$$e_2 = \frac{\alpha P_2 C_2 + (1-\beta)\,\mathbb{B}_2^f}{\alpha P_2^* C_2^* + (1-\beta)\,\mathbb{X}_2}$$

and

$$\begin{aligned}
\Pi_2 &= P_2 C_2 + (1-\beta)\,(\mathbb{L}_2 - \mathbb{D}_2) \\
P_2 C_2^b &= \omega_2 P_2 C_2 - (1-\beta)\,[(1-\omega_2)\,\mathbb{L}_2 + \omega_2 \mathbb{D}_2] \\
P_2 C_2^s &= (1-\omega_2)\,P_2 C_2 + (1-\beta)\,[(1-\omega_2)\,\mathbb{L}_2 + \omega_2 \mathbb{D}_2]
\end{aligned}$$

where we set $\omega_2^B = \omega_2^S = \omega_2^F = \omega_2^G = \omega_2^N = \omega_2$. In steady state the law of one price must hold, $P_H^* = P_H/e_2$. Hence, from market clearing we obtain

$$P_H Y = \frac{\alpha P_2^* C_2^* + (1-\alpha)\,(1-\beta)\,\mathbb{X}_2}{\alpha P_2^* C_2^* + (1-\beta)\,\mathbb{X}_2} P_2 C_2 + \frac{\alpha\,(1-\beta)\,\mathbb{B}_2^f P_2^* C_2^*}{\alpha P_2^* C_2^* + (1-\beta)\,\mathbb{X}_2}$$

where Y and is the steady state levels of output and we assumed $G_H = 0$. To fix the nominal level of the economy, we assume that at time 0 the central bank announces steady-state nominal GDP $M = P_H Y$ and then adjusts the supply of money, which in equilibrium must be equal to $P_2 C_2$, to achieve the desired nominal level of GDP. This removes all the nominal uncertainty and allows firms to set steady-state prices at the beginning of time 0.

At time 1, demand and supply for foreign funds are given by

$$\begin{aligned}
B_1^f &= \frac{\mathbb{B}_1^f + \alpha\left(\frac{P_2 C_2^b}{\beta I_1^L} + \frac{P_2 C_2^s}{\beta I_1}\right) + e_1\left(X_1 - \mathbb{X}_0 - \alpha \frac{P_2^* C_2^*}{\beta^* I_1^*}\right)}{1+\chi_1} \\
B_1^f &= \frac{1}{\gamma_1}\mathbb{E}_1\left[\frac{e_1}{e_2}\frac{(1-\chi_1)\,I_1^B}{I_1^*} - 1\right]
\end{aligned}$$

while loan demand and deposit supply are

$$\begin{aligned}
L_1 &= \mathbb{L}_1 + \frac{P_2 C_2^b}{\beta I_1^L} - (1-\alpha)\left(\omega_1^b \frac{P_2 C_2^b}{\beta I_1^L} + \omega_1^s \frac{P_2 C_2^s}{\beta I_1}\right) - \omega_1^f e_1 \frac{\alpha P_2^* C_2^*}{\beta^* I_1^*} - \omega_1^g\,(P_{H,1} G_{H,1} - T_1) \\
D_1 &= \mathbb{D}_1 - \frac{P_2 C_2^s}{\beta I_1} + (1-\alpha)\left[\left(1-\omega_1^b\right)\frac{P_2 C_2^b}{\beta I_1^L} + (1-\omega_1^s)\,\frac{P_2 C_2^s}{\beta I_1}\right] \\
&\quad + \left(1-\omega_1^f\right) e_1 \frac{\alpha M}{\beta I_1^*} + \left(1-\omega_1^g\right)(P_{H,1} G_{H,1} - T_1)
\end{aligned}$$

and the collateral constraint is

$$(1+\chi_1)\,\lambda B_1^f \geq L_1 + \lambda\left(\mathbb{B}_1^g - \mathbb{N}_1^{cb} + P_H G_{H,1} - T_1 - R_1 + e_1 X_1\right) - \phi \mathbb{N}_1$$

where we assumed the no-dividend policies $N_1 = \mathbb{N}_1$ and $N_1^{cb} = \mathbb{N}_1^{cb}$. Output at time 1 is given by

$$Y_1 = (1-\alpha)\frac{P_1 C_1^b + P_1 C_1^s}{P_H} + \alpha \frac{P_1^* C_1^*}{P_H^*}$$

At time 0, demand and supply for foreign funds are given by

$$B_0^f = \frac{\mathbb{B}_0^f + \alpha\left(\frac{1}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1^L}{P_2 C_2^b}\right]} + \frac{1}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1}{P_2 C_2^s}\right]}\right) + e_0\left(X_0 - \mathbb{X}_0 - \frac{\alpha P_2^* C_2^*}{(\beta^*)^2 I_0^* I_1^*}\right)}{1+\chi_0}$$

$$B_0^f = \frac{1}{\gamma_0}\mathbb{E}_0\left[\frac{e_0}{e_1}\frac{(1-\chi_0) I_0^B}{I_0^*} - 1\right]$$

while loan demand and deposit supply are

$$\begin{aligned}
L_0 = \mathbb{L}_0 &+ \frac{1}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1^L}{P_2 C_2^b}\right]} - (1-\alpha)\left(\frac{\omega_0^b}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1^L}{P_2 C_2^b}\right]} + \frac{\omega_0^s}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1}{P_2 C_2^s}\right]}\right) \\
&- \omega_0^f e_0 \frac{\alpha M}{(\beta^*)^2 I_0^* I_1^*} - \omega_0^g \left(P_{H,0} G_{H,0} - T_0\right) \\
D_0 = \mathbb{D}_0 &- \frac{1}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1}{P_2 C_2^s}\right]} + (1-\alpha)\left(\frac{1-\omega_0^b}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1^L}{P_2 C_2^b}\right]} + \frac{1-\omega_0^s}{\beta I_0 \mathbb{E}_0\left[\frac{\beta I_1}{P_2 C_2^s}\right]}\right) \\
&+ \left(1-\omega_0^f\right) e_0 \frac{\alpha M}{\beta^2 I_0^* I_1^*} + \left(1-\omega_0^g\right)\left(P_{H,0} G_{H,0} - T_0\right)
\end{aligned}$$

and the collateral constraint is

$$(1+\chi_0)\lambda B_0^f \geq L_0 + \lambda\left(\mathbb{B}_0^g - \mathbb{N}_0^{cb} + P_{H,0} G_{H,0} - T_0 - R_0 + e_0 X_0\right) - \phi \mathbb{N}_0$$

where, again, we assumed the no-dividend policies $N_0 = \mathbb{N}_0$ and $N_0^{cb} = \mathbb{N}_0^{cb}$. Output at time 0 is given by

$$Y_0 = (1-\alpha)\frac{P_0 C_0^b + P_0 C_0^s}{P_H} + \alpha \frac{P_0^* C_0^*}{P_H^*}$$

A.1 Solution of simplified model

The simplified version of the model, presented in the main body of the paper, is obtained by setting $\beta = \beta^* = 1$, $\omega_1^b = \omega_1^f = \omega_1^g = \omega_0^b = \omega_0^s = \omega_0^f = \omega_0^g = 0$, $\omega_1^s = \frac{1}{1-\alpha}\frac{P_2 C_2^b}{P_2 C_2^s}$, and $G_{H,t} = T_t = \chi_t = R_t = N_t^{cb} = X_t = 0$ for all $t \geq 0$. We also normalize $M = M^* = 1$. Then, we obtain $P_2 C_2 = P_2^* C_2^* = 1$ and $e_2 = 1$.

By equating demand and supply of foreign funds at time 1 we obtain

$$e_1 = I_1^* \frac{1+\alpha\gamma_1\left(\frac{\omega_2}{I_1^L}+\frac{1-\omega_2}{I_1}\right)+\gamma_1\mathbb{B}_1^F}{I_1^B+\alpha\gamma_1}$$
$$B_1^f = I_1^B \frac{\mathbb{B}_1^f+\alpha\left(\frac{\omega_2}{I_1^L}+\frac{1-\omega_2}{I_1}-\frac{1}{I_1^B}\right)}{I_1^B+\alpha\gamma_1}$$

while output is given by

$$Y_1 = \frac{1-\alpha}{P_H}\left(\frac{\omega_2}{I_1^L}+\frac{1-\omega_2}{I_1}\right)+\frac{\alpha}{P_H I^*}$$
$$= Y\left[(1-\alpha)\left(\frac{\omega_2}{I_1^L}+\frac{1-\omega_2}{I_1}\right)+\frac{\alpha}{I^*}\right]$$

If the banks leverage constraint does not bind, then $I_1^L = I_1$ and

$$e_1 = \frac{I_1^*}{I_1}\left(1+\frac{\gamma_1 I_1\mathbb{B}_1^f}{I_1+\alpha\gamma_1}\right)$$
$$B_1^f = \frac{I_1\mathbb{B}_1^f}{I_1+\alpha\gamma_1}$$

If the constraint binds, then $L_1 = \mathbb{L}_0+\omega_2\left(\frac{1}{I_1^L}-\frac{1}{I_1}\right)$ and I_1^L is given by

$$\frac{\mathbb{B}_1^f\left[\lambda I_1^L+(1-\lambda)I_1\right]+\alpha\left[\lambda(1-\omega_2)\frac{1}{I_1}-\omega_2(1-\lambda)\frac{1}{I_1^L}\right]\left(I_1^L-I_1\right)}{\lambda I_1^L+(1-\lambda)I_1+\alpha\gamma_1}+\frac{\omega_2}{\lambda}\left(\frac{1}{I_1}-\frac{1}{I_1^L}\right)-\underline{B}_1^f = 0$$

which yields

$$\frac{I_1^L}{I_1} = 1-\frac{\frac{(1+\lambda)I_1-\bar{I}_1}{\bar{I}_1}\alpha\gamma_1\underline{B}_1^f+\frac{\omega_2}{\lambda}\left(1+\frac{\alpha\gamma_1}{I_1}\right)-\alpha(\omega_2-\lambda)}{2\left[\alpha\lambda\left(1-\omega_2+\gamma_1\underline{B}_1^f\frac{I_1}{\bar{I}_1}\right)+\omega_2\right]}$$
$$+\frac{\sqrt{\left[\frac{(1+\lambda)I_1-\bar{I}_1}{\bar{I}_1}\alpha\gamma_1\underline{B}_1^f+\frac{\omega_2}{\lambda}\left(1+\frac{\alpha\gamma_1}{I_1}\right)-\alpha(\omega_2-\lambda)\right]^2+4\alpha\gamma_1\underline{B}_1^f\frac{\bar{I}_1-I_1}{\bar{I}_1}\left[\alpha\lambda\left(1-\omega_2+\gamma_1\underline{B}_1^f\frac{I_1}{\bar{I}_1}\right)+\omega_2\right]}}{2\left[\alpha\lambda\left(1-\omega_2+\gamma_1\underline{B}_1^f\frac{I_1}{\bar{I}_1}\right)+\omega_2\right]}$$

where $\bar{I}_1 = \frac{\alpha\gamma_1}{\frac{\mathbb{B}_1^f}{\underline{B}_1^f}-1}$ is the level of the interest rate below which the constraint binds, $\underline{B}_1^f \equiv \mathbb{B}_1^g - (\phi N_1-\mathbb{L}_1)/\lambda$, and we used $I_1^B = \lambda I_1^L+(1-\lambda)I_1$. We can compute the left derivative of I_1^L with respect to I_1 around $\bar{I}_1$ to obtain

$$\left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-} = 1 - \frac{\gamma_1 \underline{B}_1^f}{\lambda\left(1+\gamma_1 \underline{B}_1^f\right) + \omega_2\left[\mathbb{B}_1^f / \left(\alpha\lambda \underline{B}_1^f\right) - 1\right]}$$

Notice that $\partial I_1^L / \partial I_1$ eventually turns positive for values of I_1 well below $\bar{I}_1$. The reason is that eventually the expansionary effect on borrowers' income outweighs the credit crunch effect and I_1^L starts falling and eventually will stop binding. This of course does not happen if borrowers have no income at time 1, or if their income is not sufficiently elastic with respect to the domestic interest rate. Output at $\bar{I}_1$ is equal to $Y_1 = Y\left[(1-\alpha)/\bar{I}_1 + \alpha/I_1^*\right]$ and its response to a reduction in the interest rate below $\bar{I}_1$ is

$$\left.\frac{\partial Y_1}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-} = -\frac{1-\alpha}{I_1^2} Y \left(\omega_2 \left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-} + 1 - \omega_2\right)$$

Therefore, monetary easing is contractionary if $\omega_2 \left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1=\bar{I}_1}^{-} + 1 - \omega_2 < 0$, or

$$\gamma_1 \underline{B}_1^f (\omega_2 - \lambda) > \lambda + \omega_2\left[\mathbb{B}_1^f / \left(\alpha\lambda \underline{B}_1^f\right) - 1\right]$$

Assume that, with probability ρ, $\gamma_1 = \overline{\gamma}_1$ where $\overline{\gamma}_1$ is high enough such that the ELB is a binding constraint for the central bank and the monetary authority is forced to set $I_1 = \bar{I}_1 \equiv I_1^{ELB}$. With the remaining probability the realization of γ_1 is zero. By equating demand and supply of foreign funds at time 1 we obtain

$$e_0 = I_0^* I_1^* \frac{1 + \gamma_0 \mathbb{B}_0^f + \frac{\alpha\gamma_0}{I_0 \mathbb{E}_0[I_1]}}{I_0 I_1^* \mathbb{E}_0\left[\frac{1}{e_1}\right] + \alpha\gamma_0}$$

$$B_0^f = \mathbb{E}_0\left[\frac{1}{e_1}\right] \frac{\mathbb{B}_0^f - \frac{\alpha}{I_0}\left(\frac{1}{I_1^* \mathbb{E}_0\left[\frac{1}{e_1}\right]} - \frac{1}{\mathbb{E}_0[I_1]}\right)}{\mathbb{E}_0\left[\frac{1}{e_1}\right] + \frac{\alpha\gamma_0}{I_0 I_1^*}}$$

where

$$\mathbb{E}_0[I_1] = (1-\rho) I_1 + \rho I_1^{ELB}$$

$$\mathbb{E}_0\left[\frac{1}{e_1}\right] = (1-\rho)\frac{I_1}{I_1^*} + \frac{\rho I_1^{ELB}}{I_1^*\left(1 + \overline{\gamma}_1 \underline{B}_1^f\right)}$$

while loan demand is

$$L_0 = \mathbb{L}_0 + \frac{\omega_2}{I_0 \mathbb{E}_0[I_1]}$$

To simplify the algebra, assume $\mathbb{L}_0 = 0$ and $\lambda \mathbb{B}_0^g = \phi \mathbb{N}_0$ (that is the country enters time 0 with no capital shortfall). Then $\underline{B}_1^f = \frac{\omega_2}{\lambda \mathbb{E}_0[I_1]}$ and the state variable that determines the ELB is $\mathbb{B}_1^f / \underline{B}_1^f = \lambda B_0^f / L_0$. We can use the implicit function theorem to show

$$\frac{\partial I_1^{ELB}}{\partial I_0} = -\frac{\frac{\overline{\gamma}_1 \alpha \lambda}{\left(\lambda B_0^f - L_0\right)^2} \left(L_0 \frac{\partial B_0^f}{\partial I_0} - B_0^f \frac{\partial L_0}{\partial I_0} \right)}{1 + \frac{\overline{\gamma}_1 \lambda}{\left(\lambda B_0^f - L_0\right)^2} \left(L_0 \frac{\partial B_0^f}{\partial I_1^{ELB}} - B_0^f \frac{\partial L_0}{\partial I_1^{ELB}} \right)}$$

It is easy to check that the denominator is weakly larger than one and equal to one if $\rho = 0$.

The objective of the central bank is to stabilize output around its steady state. This is achieved at time zero and one if

$$\begin{aligned} I_0^{FB} &= \frac{1}{\mathbb{E}_0\left[I_1\right]} \frac{1-\alpha}{1-\alpha / I_0^* I_1^*} \\ I_1^{FB} &= \frac{1-\alpha}{1-\alpha / I_1^*} \end{aligned}$$

Now assume the following loss function: $\mathscr{L} = \left(I_0 - I_0^{FB}\right)^2 + \mathbb{E}_0\left[\left(I_1 - I_1^{FB}\right)^2\right]$. Without commitment the loss function can be simplified to

$$\mathscr{L} = \left(I_0 - I_0^{FB}\right)^2 + \rho \left(I_1^{ELB} - I_1^{FB}\right)^2$$

The first order condition is

$$\left(I_0^{SB} - I_0^{FB}\right) \left(1 + \frac{\rho I_0^{FB}}{\mathbb{E}_0\left[I_1\right]} \frac{\partial I_1^{ELB}}{\partial I_0}\right) + \rho \left(I_1^{ELB} - I_1^{FB}\right) \frac{\partial I_1^{ELB}}{\partial I_0} = 0$$

Since the second derivative must be positive, then the implicit function theorem applied to the first order condition yield

$$\begin{aligned} \frac{\partial I_0^{SB}}{\partial z} \propto \frac{\partial I_0^{FB}}{\partial z} \left(1 + \frac{\rho I_0^{FB}}{\mathbb{E}_0\left[I_1\right]} \frac{\partial I_1^{ELB}}{\partial I_0}\right) - \rho \left(\frac{\partial I_1^{ELB}}{\partial z} - \frac{\partial I_1^{FB}}{\partial z}\right) \frac{\partial I_1^{ELB}}{\partial I_0} - \rho \left(I_1^{ELB} - I_1^{FB}\right) \frac{\partial^2 I_1^{ELB}}{\partial I_0 \partial z} \\ - \left(I_0^{SB} - I_0^{FB}\right) \left(\frac{\rho \frac{\partial I_0^{FB}}{\partial z} \mathbb{E}_0\left[I_1\right] - \rho I_0^{FB} \frac{\partial \mathbb{E}_0\left[I_1\right]}{\partial z}}{\mathbb{E}_0\left[I_1\right]^2} \frac{\partial I_1^{ELB}}{\partial I_0} + \frac{\rho I_0^{FB}}{\mathbb{E}_0\left[I_1\right]} \frac{\partial^2 I_1^{ELB}}{\partial I_0 \partial z} \right) \end{aligned}$$

Consider a shock to γ_0. Then

$$\frac{\partial I_0^{SB}}{\partial \gamma_0} \propto -\rho \left[\left(1 - \rho \frac{I_0^{SB} - 1}{\mathbb{E}_0\left[I_1\right]^2}\right) \frac{\partial I_1^{ELB}}{\partial \gamma_0} \frac{\partial I_1^{ELB}}{\partial I_0} + \left(I_1^{ELB} - 1 + \frac{I_0^{SB} - 1}{\mathbb{E}_0\left[I_1\right]}\right) \frac{\partial^2 I_1^{ELB}}{\partial I_0 \partial \gamma_0} \right]$$

Now take the limit of the term in square brakets for $\rho \downarrow 0$ to obtain

$$\frac{\partial I_0^{SB}}{\partial \gamma_0} \propto \rho \left[-\frac{\partial I_1^{ELB}}{\partial \gamma_0} \frac{\partial I_1^{ELB}}{\partial I_0} - \left(I_1^{ELB} - 1 \right) \frac{\partial^2 I_1^{ELB}}{\partial I_0 \partial \gamma_0} \right]$$

with

$$\frac{\partial I_1^{ELB}}{\partial \gamma_0} = -\frac{\overline{\gamma}_1 \alpha \lambda}{\left(\lambda B_0^f - L_0 \right)^2} L_0 \frac{\partial B_0^f}{\partial \gamma_0}$$

$$\frac{\partial^2 I_1^{ELB}}{\partial I_0 \partial \gamma_0} = -\frac{\partial I_1^{ELB}}{\partial \gamma_0} \left(\frac{B_0^f}{\mathbb{B}_0^f} - \frac{\partial I_1^{ELB}}{\partial I_0} \frac{L_0}{\lambda B_0^f} \frac{1 + \frac{\lambda B_0^f}{L_0}}{I_1^{ELB}} \right)$$

Therefore

$$\frac{\partial I_0^{SB}}{\partial \gamma_0} \propto \rho \left[-\frac{\partial I_1^{ELB}}{\partial I_0} \left(2 + \frac{I_1^{ELB}}{I_1^{ELB} - 1} + \frac{\alpha \overline{\gamma}_1}{I_1^{ELB}} \right) + \frac{I_1^{ELB}}{1 + \alpha \gamma_0} \right]$$

Consider a shock to I_0^* that has some persistency. That is $I_1^* = 1 + \rho \left(I_0^* - 1 \right)$. Then

$$\begin{aligned} \frac{\partial I_0^{SB}}{\partial I_0^*} &= \frac{\partial I_0^{FB}}{\partial z} - \rho \frac{\partial I_1^{ELB}}{\partial I_0} \frac{\partial I_0^{FB}}{\partial z} \frac{\left(I_0^{SB} - 2 \right)}{\mathbb{E}_0 \left[I_1 \right]} + \left[\frac{(1-\rho)}{\mathbb{E}_0 \left[I_1 \right]^2} \left(I_0^{SB} - 1 \right) + 1 \right] \rho \frac{\partial I_1^{FB}}{\partial z} \frac{\partial I_1^{ELB}}{\partial I_0} \\ &= -\frac{1+\rho}{\mathbb{E}_0 \left[I_1 \right]} - \rho \frac{\partial I_1^{ELB}}{\partial I_0} \left[\frac{1 + \rho - (1 + \rho\rho) \left(I_0^{SB} - 1 \right)}{\mathbb{E}_0 \left[I_1 \right]^2} + \rho \right] \end{aligned}$$

A.2 Model solution with full set of policy tools

Assume $\beta = \beta^* = 1$, $\omega_1^b = \omega_1^f = \omega_0^b = \omega_0^s = \omega_0^f = 0$, $\omega_1^s = \frac{1}{1-\alpha} \frac{P_2 C_2^b}{P_2 C_2^s}$, and normalize $M^* = 1$. To study the effect of forward guidance, we assume that the central bank credibly announces $M = 1$ at time 0 but then is allowed to change it at time 1. To avoid confusion we denote the time-1 announcement with M_1. Then, we obtain $P_2 C_2 = P_2^* C_2^* = M_1$ and $e_2 = M_1$.At time 1 we have

$$e_1 = e_2 \frac{I_1^*}{I_1^B} \frac{1 + \chi_1 + \alpha \gamma_1 \left[\frac{\omega_2 M_1}{I_1^L} + \frac{(1-\omega_2) M_1}{I_1} \right] + \gamma_1 \mathbb{B}_1^F}{1 - \chi_1^2 - \gamma_1 M_1 \frac{I_1^*}{I_1^B} \left(X_1 - \mathbb{X}_1 - \frac{\alpha}{I_1^*} \right)}$$

$$B_1^f = (1 - \chi_1) \frac{\mathbb{B}_1^f + \alpha \left[\omega_2 \frac{M_1}{I_1^L} + (1 - \omega_2) \frac{M_1}{I_1} \right] + \frac{1+\chi_1}{\gamma_1}}{1 - \chi_1^2 - \gamma_1 M_1 \frac{I_1^*}{I_1^B} \left(X_1 - \mathbb{X}_0 - \frac{\alpha}{I_1^*} \right)} - \frac{1}{\gamma_1}$$

$$L_1 = \mathbb{L}_0 + \omega_2 M_1 \left(\frac{1}{I_1^L} - \frac{1}{I_1} \right) - \omega_1^g \left(P_{H,1} G_{H,1} - T_1 \right)$$

The ELB is given by

$$\left(1-\chi_1^2\right)\mathbb{B}_1^f-(1+\chi_1)\frac{M_1}{I_1^{ELB}}\left(\alpha\chi_1+\mathbb{X}_0I_1^*\right)-\gamma_1X_1M_1\frac{I_1^*}{I_1^{ELB}}\left(\mathbb{B}_1^f+\frac{\alpha M_1}{I_1^{ELB}}\right)+$$
$$+\left[1-\chi_1^2-\gamma_1M_1\frac{I_1^*}{I_1^{ELB}}\left(X_1-\mathbb{X}_0-\frac{\alpha}{I_1^*}\right)\right]\left[\left(1-\frac{\omega_1^G}{\lambda}\right)(T_1-P_{H,1}G_{H,1})+R_1-\underline{B}_1^f\right]=0$$

The ELB cannot be derived analytically, but we can use the implicit function theorem to prove the following comparative static results

$$\begin{aligned}
\frac{\partial I_1^{ELB}}{\partial T_1} &= \left(\frac{1}{\underline{B}_1^f I_1^{ELB}}\right)^2\frac{\mathbb{B}_1^f}{\alpha\gamma_1}\frac{\omega_1^G-\lambda}{\lambda}\\
\frac{\partial I_1^{ELB}}{\partial \chi_1} &= \left(\frac{1}{I_1^{ELB}}\right)^3\frac{1}{\gamma_1\underline{B}_1^f}\\
\frac{\partial I_1^{ELB}}{\partial X_1^{Ster}} &= \left(\frac{1}{I_1^{ELB}}\right)^4\frac{1+\gamma_1\underline{B}_1^f}{\underline{B}_1^f}\\
\frac{\partial I_1^{ELB}}{\partial X_1^{Unster}} &= -\left(\frac{1}{I_1^{ELB}}\right)^3\frac{1+\gamma_1\underline{B}_1^f}{\alpha\gamma_1\underline{B}_1^f}\\
\frac{\partial I_1^{ELB}}{\partial R_1} &= -\left(\frac{1}{I_1^{ELB}}\right)^4\frac{\alpha\gamma_1\mathbb{B}_1^f}{\left(\mathbb{B}_1^f-\underline{B}_1^f\right)^2}\\
\frac{\partial I_1^{ELB}}{\partial M_1} &= \frac{I_1^{ELB}}{M_1}
\end{aligned}$$

Output at the ELB is given by $Y_1^{ELB}=Y\left[(1-\alpha)\frac{M_1}{I_1^{ELB}}+\frac{\alpha}{I_1^*}\right]$, where we used the fact that prices are set at time 0 under the assumption $M=1$.Thus, it's easy to see that

$$\frac{\partial Y_1^{ELB}}{\partial M_1}=Y\frac{1-\alpha}{I_1^{ELB}}\left[1-\frac{M_1}{I_1^{ELB}}\frac{\partial I_1^{ELB}}{\partial M_1}\right]=0$$

Now assume that all unconventional tools are set to zero at time 1 and $M_1=1$, such that $I_1^{ELB}=\alpha\bar{\gamma}_1/\left(\frac{\lambda B_0^f}{L_0+\lambda B_0^g-\phi N_0}-1\right)$. At time 0 we have

$$\begin{aligned}
L_0 &= \mathbb{L}_0+\frac{\omega_2}{I_0\mathbb{E}_0\left[I_1\right]}+\omega_0^gPB_0\\
B_0^f &= \frac{\mathbb{E}_0\left[\frac{1}{e_1}\right](1-\chi_0)I_0\mathbb{B}_0^f+\frac{\alpha}{I_1^*}\left(\frac{1-\chi_0}{I_0^*}\frac{I_1^*\mathbb{E}_0\left[\frac{1}{e_1}\right]}{\mathbb{E}_0[I_1]}-1\right)+X_0-\mathbb{X}_0}{\mathbb{E}_0\left[\frac{1}{e_1}\right]\left(1-\chi_0^2\right)I_0+\frac{\alpha\gamma_0}{I_1^*}-\gamma_0\left(X_0-\mathbb{X}_0\right)I_0^*}\\
B_0^g &= \mathbb{B}_0^g-\chi_0B_0^f-PB_0
\end{aligned}$$

$$B_0^f = \frac{\mathbb{E}_0\left[\frac{1}{e_1}\right](1-\chi_0) I_0 \mathbb{B}_0^f + \frac{\alpha}{I_1^*}\left(\frac{1-\chi_0}{I_0^*}\frac{I_1^* \mathbb{E}_0\left[\frac{1}{e_1}\right]}{\mathbb{E}_0[I_1]} - 1\right) + X_0 - \mathbb{X}_0}{\mathbb{E}_0\left[\frac{1}{e_1}\right]\left(1-\chi_0^2\right) I_0}$$

with $\mathbb{E}_0\left[\frac{1}{e_1}\right] = 1-\rho+\rho\frac{I_1^{ELB}}{1+\gamma_1 \underline{B}_1^f}$, $\underline{B}_1^f = I_0 \frac{L_0+\lambda B_0^g - \phi N_0}{\lambda}$, and PB_0 is the government's primary balance. We can use the implicit function theorem to show that, for any policy variable z we have

$$\frac{\partial I_1^{ELB}}{\partial z} = \frac{\left[\rho\left(\frac{I_1^{ELB}}{1+\bar{\gamma}_1 \underline{B}_1^f}\right)^2 \frac{\mathbb{B}_0^f - \underline{B}^f}{\mathbb{E}_0\left[\frac{1}{e_1}\right]^2} + \mathbb{B}_0^f\right]\left(\frac{\partial L_0}{\partial z} + \lambda \frac{\partial B_0^g}{\partial z}\right) - \lambda \underline{B}_1^f \frac{\partial B_0^f}{\partial z}}{\lambda \frac{\left(\mathbb{B}_0^f - \underline{B}_1^f\right)^2}{\alpha \bar{\gamma}_1 I_0} + \lambda \underline{B}_1^f\left(\mathbb{B}_0^f + \frac{\alpha}{I_0 \mathbb{E}_0\left[\frac{1}{e_1}\right]^2}\frac{\rho}{1+\bar{\gamma}_1 \underline{B}_1^f}\right) + \rho \frac{\mathbb{B}_0^f \omega_2 - \alpha \lambda \underline{B}_1^f}{I_0 \mathbb{E}_0[I_1]^2}}$$

A sufficient condition for the denominator to be positive is $\omega_2 > \lambda$. Therefore we obtain

$$\frac{\partial I_1^{ELB}}{\partial T_0} \propto \left[\left(\frac{I_1^{ELB}}{1+\bar{\gamma}_1 \underline{B}_1^f}\right)^2 \frac{\rho\left(\mathbb{B}_0^f - \underline{B}_1^f\right)}{\mathbb{E}_0\left[\frac{1}{e_1}\right]^2} + \mathbb{B}_0^f\right]\left(\omega_0^G - \lambda\right)$$

$$\frac{\partial I_1^{ELB}}{\partial \chi_0} \propto -\lambda B_0^f\left[\left(\frac{I_1^{ELB}}{1+\bar{\gamma}_1 \underline{B}_1^f}\right)^2 \frac{\rho\left(\mathbb{B}_0^f - \underline{B}_1^f\right)}{\mathbb{E}_0\left[\frac{1}{e_1}\right]^2} + \mathbb{B}_0^f\right] + \lambda \underline{B}_1^f\left(\mathbb{B}_0^f + \frac{\alpha}{I_0 \mathbb{E}_0[I_1]}\right)$$

$$\frac{\partial I_1^{ELB}}{\partial X_0} \propto -\frac{\lambda \underline{B}_1^f}{I_0 \mathbb{E}_0\left[\frac{1}{e_1}\right]}$$

A.3 Model solution with monetary policy affecting credit demand

Assume $\omega_1^b = \omega_1^s = \omega_1^f = \omega_1$ and set all the alternative policy tools to zero, with $M = M^* = \beta = \beta^* = 1$. Then

$$e_1 = \frac{I_1^*}{I_1^B}\frac{1+\alpha\gamma_1\left(\frac{\omega_2}{I_1^L}+\frac{1-\omega_2}{I_1}\right)+\gamma_1\mathbb{B}_1^f}{1+\frac{\alpha\gamma_1}{I_1^B}}$$

$$B_1^F = \frac{\mathbb{B}_1^F + \alpha\left(\frac{\omega_2}{I_1^L}+\frac{1-\omega_2}{I_1}-\frac{1}{I_1^B}\right)}{1+\frac{\alpha\gamma_1}{I_1^B}}$$

$$L_1 = \mathbb{L}_1 + \frac{\omega_2}{I_1^L} - \omega_1\left[(1-\alpha)\left(\frac{\omega_2}{I_1^L}+\frac{1-\omega_2}{I_1}\right)+\frac{\alpha e_1}{I_1^*}\right]$$

while the banks' leverage constraint is $\lambda B_1^f - L_1 - \lambda \mathbb{B}_1^g + \phi \mathbb{N}_1 \geq 0$. In the unconstrained region we have

$$\frac{\partial \left(\lambda B_1^f - L_1\right)}{\partial I_1} = \alpha \gamma_1 \mathbb{B}_1^f \frac{\lambda - \omega_1}{\left(I_1 + \alpha \gamma_1\right)^2} + \frac{\omega_2 - \omega_1}{I_1^2}$$

which is positive if ω_1 is small relative to λ and ω_2, i.e. if borrowers face positive income growth. When the constraint binds, the lending rate solves

$$\left[\left(\omega_1 (1-\alpha) - 1 + \alpha\lambda\right) I_1^B - \alpha\gamma_1 (1-\omega_1)\right] \frac{\omega_2}{I_1^L} + \left[\left(\omega_1 (1-\alpha) + \alpha\lambda\right) I_1^B + \omega_1 \alpha\gamma_1\right] \frac{1-\omega_2}{I_1} + \\ + \lambda I_1^B \left(\mathbb{B}_1^f - \underline{B}_1^f\right) - \alpha (\lambda - \omega_1) + \left(\omega_1 \mathbb{B}_1^f - \lambda \underline{B}_1^f\right) \alpha\gamma_1 = 0$$

with $I_1^B = \lambda I_1^L + (1-\lambda) I_1$. Thus

$$\left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1 = I_1^{ELB}} = -\frac{\left(\omega_1 (1-\alpha) + \alpha\lambda\right) \frac{\omega_2 - \lambda}{I_1} + (1-\lambda)(\omega_2 - \omega_1) \frac{\alpha\gamma_1}{I_1^2} + \lambda (1-\lambda) \underline{B}_1^f \frac{\alpha\gamma_1}{I_1}}{\left(1 - \alpha\lambda - \omega_1 (1-\alpha)\right) \frac{\omega_2 - \lambda}{I_1} + \lambda \frac{1-\omega_2}{I_1} + \alpha\gamma_1 (1-\omega_1) \frac{\omega_2}{I_1^2} + \lambda^2 \left(\mathbb{B}_1^f - \underline{B}_1^f\right)} + \\ + \frac{\frac{\omega_1}{I_1}\left[(1-\omega_2) \frac{\alpha\gamma_1}{I_1} + (1-\lambda)\left(1 + \alpha\gamma_1 \mathbb{B}_1^f\right)\right]}{\left(1 - \alpha\lambda - \omega_1 (1-\alpha)\right) \frac{\omega_2 - \lambda}{I_1} + \lambda \frac{1-\omega_2}{I_1} + \alpha\gamma_1 (1-\omega_1) \frac{\omega_2}{I_1^2} + \lambda^2 \left(\mathbb{B}_1^f - \underline{B}_1^f\right)}$$

which is negative if γ_1 is large and ω_1 is small relative to ω_2.

A.4 Model solution with unrestricted discount factors

Assume $\omega_1^b = \omega_1^f = \omega_1^g = 0$, $\omega_1^s = \frac{1}{1-\alpha} \frac{P_2 C_2^b}{P_2 C_2^s}$, and set all the alternative policy tools to zero, with $M = M^* = 1$. Then

$$P_2 C_2 = 1 - (1-\beta) \mathbb{B}_2^f$$

At time 1 we have

$$e_1 = \frac{I_1^*}{\alpha} \left(1 + \gamma_1 B_1^f\right) \left[\frac{\alpha}{I_1^B} + (1-\beta) B_1^f\right]$$

$$B_1^f = \mathbb{B}_1^f + \alpha \frac{P_2 C_2^b}{\beta} \left(\frac{1}{I_1^L} - \frac{1}{I_1}\right) + \frac{\alpha}{\beta I_1} - \left(1 + \gamma_1 B_1^f\right) \left(\frac{\alpha}{\beta I_1^B} + \frac{1-\beta}{\beta} B_1^f\right)$$

while loan demand and deposit supply are

$$
\begin{aligned}
L_1 &= \mathbb{L}_1 + \frac{P_2C_2^b}{\beta}\left(\frac{1}{I_1^L} - \frac{1}{I_1}\right) \\
D_1 &= \mathbb{D}_1 + (1-\alpha)\frac{P_2C_2^b}{\beta}\left(\frac{1}{I_1^L} - \frac{1}{I_1}\right) - \frac{\alpha}{\beta I_1} + \left(1+\gamma_1 B_1^f\right)\left[\frac{\alpha}{\beta I_1^B} + \frac{1-\beta}{\beta}B_1^f\right]
\end{aligned}
$$

with

$$
\begin{aligned}
P_2C_2^b &= \omega_2 - (1-\beta)\left[(1-\omega_2)\mathbb{L}_2 + \omega_2\left(\mathbb{D}_2 + \mathbb{B}_2^f\right)\right] \\
P_2C_2^s &= 1-\omega_2 + (1-\beta)\left[(1-\omega_2)\left(\mathbb{L}_2 - \mathbb{B}_2^f\right) + \omega_2\mathbb{D}_2\right]
\end{aligned}
$$

When the constraint does not bind we have

$$
B_1^f - \mathbb{B}_1^f + \gamma_1 B_1^f \frac{\alpha}{\beta I_1} + \left(1+\gamma_1 B_1^f\right)\frac{1-\beta}{\beta}B_1^f = 0
$$

and $L_1 = \mathbb{L}_1$. Using the implicit function theorem we obtain

$$
\frac{\partial B_1^f}{\partial I_1} = \frac{\alpha\gamma_1 B_1^f/I_1^2}{\beta + \frac{\alpha\gamma_1}{I_1} + \left(1+2\gamma_1 B_1^f\right)(1-\beta)} > 0
$$

When the constraint binds, I_1^L and B_1^f jointly solve the following system of equations

$$
\begin{aligned}
0 =& \lambda B_1^F - \frac{P_2C_2^B}{\beta}\left(\frac{1}{I_1^L} - \frac{1}{I_1}\right) - \lambda \underline{B}_1^F \\
0 =& B_1^F - \mathbb{B}_1^F - \alpha\frac{P_2C_2^B}{\beta}\left(\frac{1}{I_1^L} - \frac{1}{I_1}\right) - \frac{\alpha}{\beta I_1} + \left(1+\gamma_1 B_1^F\right)\left(\frac{\alpha}{\beta I_1^B} + \frac{1-\beta}{\beta}B_1^F\right)
\end{aligned}
$$

where $I_1^B = \lambda I_1^L + (1-\lambda)I_1$ and

$$
P_2C_2^b = \frac{\omega_2 - (1-\beta)\left\{(1-\omega_2)\mathbb{L}_1 I_1^L + \omega_2\left[\mathbb{D}_1 I_1 - \frac{\alpha}{\beta} + I_1\left(1+\gamma_1 B_1^f\right)\left(\frac{\alpha}{\beta I_1^B} + \frac{1-\beta}{\beta}B_1^f\right)\right] + \omega_2 B_1^f I_1^B\right\}}{1 - \left(I_1^L - I_1\right)\frac{1-\beta}{\beta}\left(\frac{1-\omega_2}{I_1} + \omega_2\frac{1-\alpha}{I_1^L}\right)}
$$

Thus, the ELB is given by

$$
I_1^{ELB} = \frac{\alpha\gamma_1}{\beta\left(\frac{\mathbb{B}_1^f}{\underline{B}_1^f} - 1\right) - (1-\beta)\left(1+\gamma_1 \underline{B}_1^f\right)}
$$

Thus

$$\left.\frac{\partial B_1^F}{\partial I_1}\right|_{I_1=\bar{I}_1} = -\frac{1}{I_1}\frac{1}{I_1}\alpha\frac{-P_2C_2^B+\lambda-(1-\lambda)\gamma_1 B_1^F}{1+\gamma_1\left(\frac{\alpha}{I_1}+2(1-\beta)B_1^F\right)} - \frac{1}{I_1}\frac{1}{I_1}\alpha\frac{P_2C_2^B-\lambda-\lambda\gamma_1 B_1^F}{1+\gamma_1\left(\frac{\alpha}{I_1}+2(1-\beta)B_1^F\right)}\left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1=\bar{I}_1}$$

and we obtain

$$\left.\frac{\partial I_1^L}{\partial I_1}\right|_{I_1=I_1^{ELB}} = 1-\frac{\gamma_1\underline{B}_1^f}{\frac{P_2C_2^b}{\lambda\beta\alpha}\left[\frac{\alpha}{I_1^{ELB}}+1-\alpha\lambda\beta+2\gamma_1(1-\beta)\underline{B}_1^f\right]+\lambda\left(1+\gamma_1\underline{B}_1^f\right)}$$

which is negative if γ_1 is large.

A.5 Non-unitary elasticities of substitution

As discussed in the paper, domestic monetary easing generates capital outflows if the elasticity of the exchange rate with respect to the policy rate is less than one. Under the model assumption of unitary elasticity of intra and inter-temporal substitution, equation (6) shows that the exchange rate elasticity is less than one if the country has a current account surplus. We now show that if we depart from the assumption of unitary elasticity of substitution, the elasticity of the exchange rate can be less than one even if the current account is in deficit, provided that γ_1 is sufficiently high.

Consider the role of global global financial conditions, γ_1, in determining carry-trade capital flows. Let the equilibrium in the foreign funds market be described by the equation $B^f(eI/I^*) - \mathbb{B}^f = \iota(e,I) - \xi(e,I^*)$, where B^f is the foreign investors supply function, which depends positively on the foreign-currency excess return of the domestic bond, proxied by eI/I^*, $\mathbb{B}^f$ the beginning-of-period debt of the country, ι the value of imports, and ξ the value of exports, both measured in domestic currency. Then we can use the implicit function theorem to show that

$$\varepsilon_I^e = -1+\frac{\iota\left(\varepsilon_I^\iota-\varepsilon_e^\iota\right)+\xi\varepsilon_e^\xi}{\xi\varepsilon_e^\xi-\iota\varepsilon_e^\iota+B^f\varepsilon_e^{B^f}}$$

where ε_z^x is the elasticity of x with respect to z. Assume that all elasticities are constant with $\varepsilon_I^\iota<0$, $\varepsilon_{I^*}^\xi<0$, $\varepsilon_e^\iota\leq 0$, and $\varepsilon_e^\xi>0$. Since the denominator is positive, we can conclude that $\partial B^f/\partial I \propto \iota\left(\varepsilon_I^\iota-\varepsilon_e^\iota\right)+\xi\varepsilon_e^\xi$, where the first term is negative if $\varepsilon_I^\iota<\varepsilon_e^\iota$, while the second term is positive. This implies that, if $\varepsilon_e^\xi>\varepsilon_e^\iota-\varepsilon_I^\xi$, the elasticity of the exchange rate with respect to the domestic policy rate is greater than -1 even if the country is running a trade deficit, that is $\xi<\iota$. Furthermore, if the country is a net debtor the lower the willingness of foreign investors to hold domestic assets, i.e. the higher γ , the more depreciated the exchange rate. This, in turn, tend to increase the country's trade balance, raising ξ and reducing ι. Both forces increase $\partial B^f/\partial I$ and can change its sign from negative to positive. In our model, where the elasticities of substitution across goods and across time are equal to one, we have $\varepsilon_I^\iota=-1$, $\varepsilon_e^\iota=0$, and $\varepsilon_e^\xi=1$. Therefore, $\partial B^f/\partial I\propto\xi-\iota$. In a similar fashion, we can show that $\partial B^f/\partial I^* \propto -\iota\varepsilon_e^\iota + \xi\left(\varepsilon_e^\xi + \varepsilon_{I^*}^\xi\right)$,where the first term is positive if $\varepsilon_e^\iota > 0$, while the second term is positive if $\varepsilon_e^\xi > \varepsilon_{I^*}^\xi$. Hence, a high γ tends to generate a positive correlation between B^f and I^* if export revenues are more sensitive to the exchange rate than to the foreign policy rate. In our calibration $\varepsilon_e^\iota = 0$, $\varepsilon_e^\xi = 1$, and $\varepsilon_{I^*}^\xi = -1$. Therefore we obtain $\partial B^f/\partial I^* = 0$.

B Generalized model with currency mismatches

In this appendix, we first describe the equations of the model with currency mismatches in their generalized version, introducing the full set of policy instruments analyzed in the paper and without setting the inter-temporal discount factor to 1. We then present in B.1 the solution of the model setting the the discount factor to 1, while including all policy instruments. Finally, in section B.2 we solve the model allowing the discount factor to differ from 1, focusing on interest rate policy only.

The generalized equations of the carry trade model are as follows. The budget constraint of the representative agent is

$$P_t C_t - \Pi_t = L_t - \mathbb{L}_t$$

where $\mathbb{L}_t = L_{t-1} I_{t-1}^L$ and net income is

$$\Pi_t = P_{H,t} C_{H,t} + e_t P_{H,t}^* C_{H,t}^* - T_t + \mathbb{N}_t - N_t$$

Its Euler equation is

$$1 = \beta_t I_t \mathbb{E}_t\left[P_t C_t / \left(P_{t+1} C_{t+1}\right)\right]$$

while its demand for Home goods is given by $P_{H,t} C_{H,t} = (1-\alpha) P_t C_t$. The balance sheet of the domestic banking sector is

$$N_t + e_t D_t^* = L_t + R_t$$

therefore $\mathbb{N}_t = \mathbb{L}_t + \mathbb{R}_t - e_t \mathbb{D}_t^*$, where the exchange rate satisfies the modified UIP condition

$$\mathbb{E}_t\left[\left(e_t I_t - e_{t+1} I_t^* \left(1-\chi_t\right)\right)\left(I_{t+1} + \phi\mu_{t+1}\right)\right] = 0$$

and μ_{t+1} is the shadow cost of the collateral constraints. Banks are subject to the leverage constraint $L_t \leq \phi N_t$. The balance sheet of the domestic central bank is

$$N_t^{cb} + R_t = e_t X_t$$

therefore $\mathbb{N}_t^{cb} = e_t \mathbb{X}_t - \mathbb{R}_t$, where X_t are foreign reserves. Finally, the consolidated budget constraint of the public sector is

$$T_t = N_t^{cb} - \mathbb{N}_t^{cb} + \chi_t e_t D_t^*$$

Market clearing requires $Y_t = C_{H,t} + C_{H,t}^*$. The aggregate budget constraint of the country is

$$\alpha P_t C_t = e_t \left[\alpha P_t^* C_t^* + (1-\chi_t) D_t^* - \mathbb{D}_t^* + \mathbb{X}_t - X_t\right]$$

In a steady state with $\chi_t = 0$, we have

$$e_t = \frac{\alpha \beta_1 P_t C_t}{\alpha \beta_1^* P_t^* C_t^* + (1-\beta)(X_t - D_t^*)}$$

with $D_t^* = \beta \mathbb{D}_2^*$ and $X_t = \beta \mathbb{X}_2$. Therefore, at time 2 we have

$$e_2 = \frac{\alpha M}{\alpha M^* + (1-\beta)(\mathbb{X}_2 - \mathbb{D}_2^*)}$$

and $\Pi_2 = M + (1-\beta)\mathbb{L}_2$.

At time 1, loand demand is

$$L_1 = \frac{1}{1-\chi_1}\frac{\alpha M}{\beta_1 I_1^L} - \frac{e_1}{1-\chi_1}\left(\frac{\alpha M^*}{\beta_1^* I_1^*} - \chi_1 \mathbb{D}_1^*\right) + \mathbb{L}_1 + (N_1 - \mathbb{N}_1) + \frac{\chi_1}{1-\chi_1}(R_1 - \mathbb{R}_1)$$

while the collateral constraint is $L_1 \leq \phi\left(\mathbb{L}_1 + \mathbb{R}_1 - e_1 \mathbb{D}_1^*\right)$, with

$$e_1 = (1-\chi_1)\frac{I_1^*}{I_1}\frac{\alpha M}{\alpha M_2^* + (1-\beta)(\mathbb{X}_2 - \mathbb{D}_2^*)}$$

At time 0, loand demand is

$$L_0 = \frac{1}{1-\chi_0}\frac{1}{\beta_0 I_0}\frac{\alpha M}{\beta_1 \mathbb{E}_0\left[I_1^L\right]} - \frac{e_0}{1-\chi_0}\frac{1}{\beta_0^* I_0^*}\frac{\alpha M^*}{\beta_1^* \mathbb{E}_0\left[I_1^*\right]} + N_0 - \mathbb{N}_0$$

with

$$e_0 = (1-\chi_0)\frac{I_0^*}{I_0}\frac{\mathbb{E}_0\left[e_1\left(I_1 + \phi \mu_1\right)\right]}{\mathbb{E}_0\left[I_1 + \phi \mu_1\right]}$$

B.1 Model solution under full set of policy tools

The simplified version of the model, presented in the main body of the paper, is recovered by setting $\beta_1 = \beta_2 = \beta_0^* = \beta_1^* = \beta_2^* = 1$. Then, we obtain $e_2 = M/M^*$. At time 1 we have

$$e_1 = (1-\chi_1)\frac{I_1^*}{I_1}\frac{M}{M^*}$$

Thus, the ELB is given by

$$I_1^{ELB} = \frac{M}{M^*} \frac{\frac{\alpha M^*}{1-\chi_1} - \alpha M^* + [\phi - \chi_1 (\phi - 1)] \mathbb{D}_1^* \bar{I}_1^*}{(\phi - 1)(\mathbb{L}_1 + N_1 - \mathbb{N}_1) - \frac{\chi_1}{1-\chi_1} R_1 + \frac{\phi(1-\chi_1)+\chi_1}{1-\chi_1} \mathbb{R}_1}$$

and

$$\begin{aligned}
\frac{\partial I_1^{ELB}}{\partial \chi_1} &= -\frac{(\phi - 1)\mathbb{D}_1^* \bar{I}_1^* - \alpha}{(\phi - 1)\mathbb{L}_1} \\
\frac{\partial I_1^{ELB}}{\partial M} &= \frac{I_1^{ELB}}{M} \\
\frac{\partial I_1^{ELB}}{\partial N_1} &= -\frac{I_1^{ELB}}{\mathbb{L}_1}
\end{aligned}$$

Now assume that all unconventional tools are set to zero at time 1 and $M = M^* = 1$, such that $I_1^{ELB} = \frac{\phi \mathbb{D}_1^* I_1^*}{(\phi-1)\mathbb{L}_1}$. At time 0 we have

$$\begin{aligned}
\mathbb{L}_1 &= \frac{\frac{1-\beta_0}{\beta_0} + \chi_0}{1 - \chi_0} \frac{\alpha}{\mathbb{E}_0 [I_1]} + N_0 I_0 \\
\mathbb{D}_1^* &= \frac{\frac{1-\beta_0}{\beta_0} + \chi_0}{(1 - \chi_0)^2} \frac{\alpha}{\mathbb{E}_0 [I_1^*]}
\end{aligned}$$

with $\mathbb{E}_0 [I_1] = \rho I_1^{ELB} + (1 - \rho) \tilde{I}_1$. We can use the implicit function theorem to show that, for any policy variable z we have

$$\frac{\partial I_1^{ELB}}{\partial z} \propto \frac{\phi}{\phi - 1} \frac{\partial \mathbb{D}_1^*}{\partial z} \bar{I}_1^* - \frac{\partial \mathbb{L}_1}{\partial z} I_1^{ELB}$$

Therefore we obtain

$$\begin{aligned}
\frac{\partial I_1^{ELB}}{\partial I_0} &\propto -(\mathbb{L}_0 + N_0) I_1^{ELB} \\
\frac{\partial I_1^{ELB}}{\partial \chi_0} &\propto \frac{\phi \alpha \bar{I}_1^*}{\phi - 1} \frac{1}{\mathbb{E}_0 [I_1^*]} \left[\frac{1 - \beta_0}{\beta_0} + \frac{(1 + \delta) N_0 \mathbb{E}_0 [I_1] I_0}{\alpha \delta + N_0 I_0 \mathbb{E}_0 [I_1]} \right] \\
\frac{\partial I_1^{ELB}}{\partial \bar{I}_1^*} &\propto \frac{\phi \mathbb{D}_1^*}{(\phi - 1)\mathbb{L}_1} - \frac{\phi}{\phi - 1} \frac{\mathbb{D}_1^* \bar{I}_1^*}{\alpha \delta} \rho \mathbb{D}_1^* \\
\frac{\partial I_1^{ELB}}{\partial \mathbb{E}_0 [I_1^*]} &\propto -\frac{\phi}{\phi - 1} \frac{1 - \beta_0}{\beta_0} \frac{\alpha}{\mathbb{E}_0 [I_1^*]^2} \bar{I}_1^*
\end{aligned}$$

B.2 Model solution with unrestricted discount factors

Set all the alternative policy tools to zero. Then at time 1 we have

$$
\begin{aligned}
e_1 &= \frac{\alpha \beta_1^* I_1^* \left(\frac{1-\beta}{\beta_1 I_1^L} + \frac{1}{I_1}\right)}{\alpha\left(1-\beta+\beta_1^*\right) - (1-\beta)\,\beta_1^* \mathbb{D}_1^* I_1^*} \\
L_1 &= \mathbb{L}_1 - \alpha \frac{(1-\beta)\frac{\beta_1^*}{\beta_1}\frac{\mathbb{D}_1^* I_1^*}{I_1^L} + \alpha\left(\frac{1}{I_1} - \frac{1}{I_1^L}\frac{\beta_1^*}{\beta_1}\right)}{\alpha\left(1-\beta+\beta_1^*\right) - (1-\beta)\,\beta_1^* \mathbb{D}_1^* I_1^*} \\
D_1^* &= \frac{\frac{\alpha}{I_1^*}\left(I_1 - \frac{\beta_1 I_1^L}{\beta_1^*}\right) + \beta_1 I_1^L \mathbb{D}_1^*}{\beta_1 I_1^L + (1-\beta)\, I_1}
\end{aligned}
$$

When the constraint binds, the lending rate is

$$
\frac{1}{I_1^L} = \frac{(\phi-1)\,\mathbb{L}_1\left[\alpha\left(1-\beta+\beta_1^*\right) - (1-\beta)\,\beta_1^* \mathbb{D}_1^* I_1^*\right] - \frac{\alpha}{I_1}\left(\phi \beta_1^* \mathbb{D}_1^* I_1^* - \alpha\right)}{\alpha\left[\alpha\frac{\beta_1^*}{\beta_1} + (\phi-1)\,\frac{1-\beta}{\beta_1}\beta_1^* \mathbb{D}_1^* I_1^*\right]}
$$

which is decreasing in I_1 iff $\phi \mathbb{D}_1^* > \alpha / \left(\beta_1^* I_1^*\right)$. The ELB is given by

$$
I_1^{ELB} = \frac{\alpha}{\beta_1} \frac{\alpha\left(\beta_1^* - \beta_1\right) + \left[(\phi-1)(1-\beta) + \phi\beta_1\right]\beta_1^* \mathbb{D}_1^* I_1^*}{(\phi-1)\,\mathbb{L}_1\left[\alpha\left(1-\beta+\beta_1^*\right) - (1-\beta)\,\beta_1^* \mathbb{D}_1^* I_1^*\right]}
$$

The effect of monetary policy around the ELB is

$$
\begin{aligned}
\left.\frac{\partial Y_1}{\partial I_1}\right|^{-}_{I_1 = I_1^{ELB}} = &-\left(\frac{1}{I_1^{ELB}}\right)^2 \left[1 - \alpha + \frac{\alpha^2 \beta_1^* \frac{1-\beta}{\beta_1}}{\alpha\left(1-\beta+\beta_1^*\right) - (1-\beta)\,\beta_1^* \mathbb{D}_1^* I_1^*}\right] \left.\frac{\partial I_1^L}{\partial I_1}\right|^{-}_{I_1 = I_1^{ELB}} \\
&-\left(\frac{1}{I_1^{ELB}}\right)^2 \frac{\alpha^2 \beta_1^*}{\alpha\left(1-\beta+\beta_1^*\right) - (1-\beta)\,\beta_1^* \mathbb{D}_1^* I_1^*}
\end{aligned}
$$

Therefore output contracts in the constrained region iff

$$
\left(\mathbb{D}_1^* I_1^*\right)^2 - \frac{\alpha}{\phi}\left(\frac{1+\phi}{\beta_1^*} + \frac{\phi}{1-\beta} + \frac{\alpha}{1-\alpha}\frac{1-\beta}{\beta_1}\right)\mathbb{D}_1^* I_1^* + \frac{\alpha^2}{\phi}\left(\frac{1}{\beta_1^*} + \frac{1}{1-\beta}\right)\left(\frac{1}{\beta_1^*} + \frac{\alpha}{1-\alpha}\frac{1}{\beta_1}\right) < 0
$$

That is, if $\mathbb{D}_1^* I_1^*$ is high enough, but not too high.