Sterilized Interventions May Not Be So Sterilized*

Shalva Mkhatrishvili, Giorgi Tsutskiridze, and Lasha Arevadze
National Bank of Georgia

It is widely believed that sterilized FX interventions do not affect domestic currency interest rates. The reason is the word "sterilized." Yet we show in this paper that when a collateral base for central bank operations isn't big enough, sterilized interventions may still affect interest rates, loan extension, and, hence, real economy (beyond the effects of altered exchange rate). The mechanism is simple and works through the liquidity risk premium. We demonstrate the importance of this channel through theoretical as well as empirical perspectives. Our modeling framework also provides interesting insights about a relationship between a liquidity risk and reserve requirements, among other results.

JEL Codes: E43, E58, F31.

1. Introduction

While theoretical contributions on a topic of foreign exchange (FX) interventions are still relatively scarce, many emerging market economies (EMEs) have been casually intervening on FX markets for quite a while, sometimes even heavily. As Bank for International Settlements (BIS) (2019) puts it, "practice has moved ahead of

*We would like to thank Archil Imnaishvili, Zviad Zedginidze, Gaston Gelos, Umang Rawat, Altynai Aidarova, Selim Cakir, Tobias Adrian, and the three anonymous referees for their useful comments and feedback. The views expressed here are the authors' own and not necessarily those of their affiliation. All errors and omissions remain with the authors. Corresponding author e-mail: shalva.mkhatrishvili@ngb.gov.ge.

theory" in this sense. To make sure that practice does its job the right way, it is a responsibility of the economics profession to study macro-financial interlinkages related to FX interventions. The recent work of the International Monetary Fund on the Integrated Policy Framework is along these lines; it studies if and when central banks should use FX interventions in addition to other tools like a policy rate and macroprudential instruments (see Adrian et al. 2020 or Basu et al. 2020). This topic is especially important during episodes of large capital flows when central banks conduct large amounts of FX interventions. The COVID-19 crisis is an example of such an episode (International Monetary Fund 2020).

In this work of studying all the important effects of FX interventions (FXIs), we contribute to the lending side, i.e., we explore how FXIs influence domestic currency lending rates, even when the interventions are sterilized. A widely accepted view is that sterilized FXIs, in principle, have no impact on domestic currency (DC) interest rates. The reason is that when central banks sterilize their FX interventions, they essentially undo any effect that those interventions may have on a monetary base. With demand for domestic currency liquidity being unchanged, if its supply remains unchanged as well, it is natural to expect that the price (money market interest rates) will remain the same. Indeed, having no impact on DC interest rates is the way sterilized interventions are usually defined as such (e.g., Abildgren 2005 or Benes et al. 2013). Some even argued that a sterilized FXI does not have any effect on any real variable and, hence, is not an independent instrument at all (e.g., Backus and Kehoe 1989).

To be sure, the literature has identified mechanisms through which the above claim can be countered. For instance, Kumhof and van Nieuwerburgh (2002) developed a general equilibrium model that shows how sterilized FX interventions may affect a real economy. What they (and other related papers) claim is that sterilized FXIs influence uncovered interest rate parity (UIP) risk premium and that is the channel through which they affect exchange rates. A theory that we develop below, and provide some empirical support for, argues that there is another channel at work—the *FXI liquidity risk channel*—that may affect DC loan interest rates and, hence, other variables as well, including deposit (money) creation and the exchange rate.

This domestic currency liquidity risk channel of sterilized FXIs works in the following way: when banks make decisions about loan extension and, hence, deposit (money) creation, they take liquidity risk into account. The risk is that these newly created deposits may be withdrawn by those depositors that prefer cash instead. The risk is present because, in general, loans have longer maturity than deposits (i.e., maturity mismatch), so that deposits may leave a bank much faster than loans are paid off. These deposit withdrawals, in turn, necessitate central bank money (reserves). Banks may have some (precautionary) reserves above reserve requirements but, more importantly, a banking system as a whole relies on an ability to get liquidity from a central bank (e.g., central bank refinancing operations). The latter requires eligible collateral though, which may be a scarce resource in some countries. Namely, even if collateral constraint is not currently binding, when collateral base for central bank operations is not big enough, banks may *still* fear (massive) deposit withdrawals that, in principle, can make the constraint start binding in the future, until (sufficient amount of) loans are paid off. This is especially true in countries that have fragile inflation expectations and large amounts of foreign currency borrowing, where central banks may not be able to do massive liquidity injections (see Mishkin 2001). Banks internalizing this feature will set high-enough interest rates on DC loans to reflect the liquidity risk premium.

However, this fear is reduced when banks get permanent liquidity from a central bank that buys FX as opposed to getting the same amount of liquidity by borrowing from the central bank (that uses up a scarce collateral). The reduction in this fear will result in lower DC loan interest rates and/or easier terms for loans. The lower loan rates will increase demand for loans and, hence, loan extension. Newly extended loans create new purchasing power (deposits) that then puts some pressure on an exchange rate (among other prices). Hence, this novel channel, working through loan interest rates, may as well explain exchange rate effects of sterilized interventions, and this may work on top of a traditional portfolio balance channel (see, e.g., Branson and Henderson 1985). This also implies that having sufficiently large collateral base not only minimizes interest rate effects of sterilized FXIs, but also leads to low liquidity risk on average. However, achieving this is difficult unless the amount of near risk-free securities is abundant enough.[1] This means that, as a liquidity management tool, FX interventions could be considered as an independent policy instrument. Or put differently, sterilized FXIs can also be thought of as a quantitative easing (QE) tool in the presence of collateral constraints.

In addition to the conclusion that sterilized FX interventions may affect liquidity risk premium and, therefore, loan interest rates, we arrive at a number of other interesting results. Namely, our modeling framework shows that the level of reserve requirements may still matter for loan interest rates even in financial systems that operate under an interest-rate-targeting framework. Also, the public's propensity to use cash instead of bank deposits affects loan interest rate setting as well (both through a direct impact from a policy rate as well as an indirect impact on a liquidity risk premium). On the other hand, the size of government bond portfolio (or other near risk-free and liquid assets) also affects interest rates. Namely, while there are channels that result in a crowding-out effect, in our modeling framework more government bonds may put a downward pressure on loan interest rates (through a lower liquidity risk premium)—an opposite to the crowding-out channel. Finally, our framework shows that in 100 percent reserve banking, liquidity risk would either be zero (when collateral constraint for central bank operations isn't binding) or infinite (when it is binding). This shows how switching from fractional banking to full reserve banking would turn commercial banks into traditional intermediaries (as described by loanable funds theory) instead of being the major creators of (deposit) money.

Section 2 discusses the related literature, while Section 3 develops an argument for our new channel linking sterilized FXIs and domestic credit conditions. Namely, Subsection 3.1 develops a theoretical model that shows how profit-maximizing banks set interest rates and react to central bank interventions, while the following subsection shows empirically how important this channel has been for interest rate setting in Georgia and quantifies the effects. Section 4 concludes.

[1] In other words, taking risky assets as a collateral for central bank operations is a tricky task (possibly, unless a very big haircut is applied), as it is a quasi-fiscal step.

2. Literature Review

Our paper is related to two different domains of economic literature: one that examines macroeconomic implications of sterilized FXIs mainly through their impact on lending rates, loan extensions, and aggregate demand; and one that investigates the effects of financial frictions (i.e., constraints on the amount/value of safe assets that can be used as a collateral in interbank markets) on bank lending and output. The first part of the literature, while containing only a small number of papers, displays mixed results, some claiming that sterilized FXIs (buying FX) have expansionary effects on an economy through stimulating domestic currency credit to the private sector, while others strongly doubt the existence of such a relationship.

For example, Hofmann and Shin (2019) propose a model similar to the banking model of Bruno and Shin (2015) which implies that a purchase of U.S. dollars by a central bank sterilized through a corresponding sale of domestic bonds slows down domestic currency credit supply. The model arrives at this conclusion through two different but mutually enforcing channels. The first one is a “risk-taking channel” of the exchange rate, as the authors name it, and the second one is the widely known “crowding-out” channel. The risk-taking channel arises from the fact that borrowers have a legacy debt in a foreign currency (in this case, in U.S. dollars) and hence are subject to balance sheet effects of the exchange rate. When the central bank intervenes by purchasing USD, given that local currency depreciates, borrowing firms bearing USD-denominated debts on their balance sheets become more vulnerable as a result of higher debt service burden. This increased vulnerability of borrowers directly translates into a higher tail risk for banks with a diversified loan portfolio. And, given that banks follow a value-at-risk (VaR) rule, a higher tail risk dampens domestic credit growth. The crowding-out channel, on the other hand, works through reducing banks’ lending capacity due to the absorption of the increased supply of domestic bonds coming from the sterilization leg of the FX intervention. The authors then test these two channels against a high-frequency micro data set and confirm that sterilized FX purchases have a significant and persistent dampening effect on new domestic bank credit. Qualitatively similar results are found by some other authors such as Céspedes, Chang, and Velasco (2017) and Chang (2018), though mechanisms at play for the crowding-out channel to work are completely different.

Contrary to the results above, Gadanecz, Mehrotra, and Mohanty (2014) conduct an empirical investigation of effects of sterilized FX purchases on bank lending and find the expansionary effects of such FXIs, which they believe to be stemming from the resulting shift in the composition of the banking system's balance sheets. In this work, the authors consider two competing hypotheses through the country-level panel data from emerging market economies (EMEs). One is that liquid government and central bank securities may act as a substitute for bank credit and, hence, crowd out lending to the private sector—an idea in line with Bernanke and Blinder (1988) and others discussed above. The alternative hypothesis, however, states that those government and central bank securities are considered by banks as an equivalent to central bank reserves and, hence, they reduce liquidity constraints which, in turn, leads to increased lending to the real economy (Kashyap and Stein 1997, 2000). The empirical results support the alternative hypothesis and conclude that an increase in government bonds and central bank securities, as a result of the sterilization leg of large-scale and persistent FX purchases in EMEs, leads to an expansion in credit to the private non-banking sector. Furthermore, as the authors argue, this result is economically as well as statistically significant. Similar results are presented by Vargas, González, and Rodríguez (2013) using a small open-economy dynamic stochastic general equilibrium (DSGE) model with financial sector.

As for the second strand of the literature, Gorton and Laarits (2018) emphasize the role of safe assets (i.e., high-quality collateral) for the well-functioning of the modern banking system and its resilience in times of distress. Caballero and Farhi (2018) point to the devastating effects of the shortage of safe assets for the overall economy. In a more tractable and insightful general equilibrium model with interbank money markets, central bank, and collateralizable assets, De Fiore, Hoerova, and Uhlig (2019) show that when interbank money markets suffer from large and abrupt private haircut increases, liquidity constraints for banks turn binding, and lending and, consequently, output drop significantly. In such cases, the presence of a central bank by providing collateralized loans at noticeably lower haircuts can alleviate banks' liquidity shortage and push lending activity back on track.

Linking the two strands, we employ this role of high-quality collateral in banks' liquidity management and formulate the theoretical model accompanied with empirical investigation to contribute to the first domain of the literature, claiming that sterilized interventions (FX purchases) can have a positive real effect on the economy through their impact on collateral sufficiency, lending rates, and credit extension. In particular, we recognize the importance of possible liquidity constraints that private banks may face and take into account when deciding their optimal portfolio allocations. Furthermore, under our setup sterilization does not necessarily require any deliberate issuance or purchase of government securities. Instead, as is the case for inflation-targeting central banks operating under interest-rate-targeting framework and structural liquidity deficit, sterilization happens automatically through central bank borrowing instruments (e.g., refinancing loans or, if not directly provided, some kind of standing facilities of the central bank). Building on this, in the next section we provide a theoretical model followed by an empirical investigation.

3. Interventions and Interest Rates

In this section we develop a theory of the *FXI liquidity risk channel* and provide some empirical support for it for the case of Georgia. Namely, first, we obtain an analytic representation of the dependence of loan interest rates on FXI, i.e., develop a theoretical model that shows how profit-maximizing banks would take a collateral constraint for central bank operations into account when setting interest rates on loans and deposits. Then, we bring the key testable implications of the model to data. In particular, we estimate a distributed lag model with Georgian data, which shows the significance of our channel, both economically as well as statistically.

3.1 Theoretical View

The discussion of the theoretical side is split into two parts: describing the key assumptions of our model setup/framework and enumerating its key implications, which, in addition to our main result on

FXI, also shows other interesting takeaways—underlying the usefulness/realism of the model.

3.1.1 Modeling Framework

A partial equilibrium model is introduced to describe how (infinitely many) banks (each of them represented by an index i), operating in a monopolistic competitive market,[2] make decisions on financial variables, such as an amount of loans ($L_t(i)$), reserve holdings ($Q_t(i)$), deposits ($D_t(i)$), holdings of government securities ($S_t(i)$), refinancing loans from a central bank ($R_t(i)$), and all the respective interest rates, to maximize their profit. While we are keeping banks' balance sheets as simple as possible, this degree of detail is still sufficient to realistically arrive at novel results regarding FXI (and not only). Our banks are distributed on a $[0, 1]$ interval. Commercial bank i's balance sheet[3] is summarized below:

Commercial Bank i

Assets	Liabilities
($L_t(i)$) Loans	Deposits ($D_t(i)$)
($Q_t(i)$) Reserve Balances	Refinancing Loans ($R_t(i)$)
($S_t(i)$) Securities	

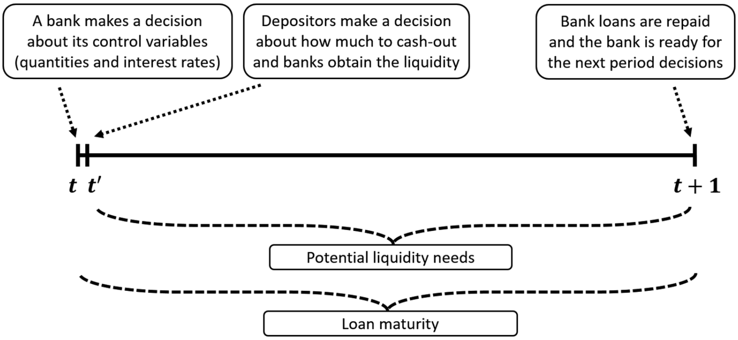
Each individual bank's decision is subject to a risk of liquidity shortfall, a situation when a bank is short of eligible collateral (government securities) to obtain liquidity from the central bank for settling transactions with other banks, satisfying reserve requirements, or satisfying cash withdrawals.

Before discussing how banks are making decisions on various markets, we explain the timing convention built into our model. Here we emphasize three possible time instants during each period: time instant t, when banks have to make their decisions to plan their business (the monetary amount of loans to extend and at what

[2]All the assumptions of our model are summarized in Appendix C.

[3]We abstract from capital adequacy issues, since this is a different (credit risk) topic and, while introducing more complexity, would not alter our qualitative results (on liquidity risk). We also abstract from interbank market borrowings, because we tried modeling it in our framework and the key model implications remained the same.

Figure 1. Timing of the Model



Source: Authors' construction.

interest rate, etc.); time instant t', when depositors decide how much cash to withdraw and when banks will need to obtain a sufficient amount of liquidity (to satisfy withdrawals); and time instant $t+1$, when the period is finalized (loans are repaid, etc.) and the bank is ready for the next period. This process is summarized in Figure 1.

Given these time instants, we can define the maturity of loans and banks' borrowings for obtaining liquidity. Namely, loan maturity is the period between t and $t+1$, while the maturity of a bank's borrowing from the central bank is the period between t' and $t+1$. Because t and t' are assumed to be very close, those two maturities are practically the same. Hence, in the optimization problem all interest rates are assumed to be for the same maturity: a period from time instant t to that of $t+1$. Banks maximize their profit (net interest margin) subject to several constraints, which we discuss now one by one.

In the case of loans, each bank is making decisions about the monetary amount of loans ($L_t(i)$) to extend and what interest rate to charge ($i^l_t(i)$); however, they face a demand constraint—the monetary amount of loans each bank can extend depends on overall loan demand ($\bar{L}_t$),[4] how different the bank's loan interest rate is relative

[4]Variables with bars over them indicate that they are not modeled here endogenously—their values are determined outside of our framework (something that could be relaxed while applying the approach to a general equilibrium model).

to a market average ($\bar{i_t^l}$), and how high an elasticity of substitution (ε^l) there is between different bank loans (i.e., measure of bank competition)—standard result of constant elasticity of substitution (CES) aggregation:

$$L_t(i) \leq \left(\frac{i_t^l(i)}{\bar{i_t^l}}\right)^{-\varepsilon^l} \bar{L_t}. \tag{1}$$

Each bank must maintain reserve balances that at least satisfy minimum reserve requirements (rr). For this, banks may have to take out refinancing loans ($R_t(i)$) from the central bank to manage liquidity. An interest rate paid on those loans equals the policy rate ($\bar{i_t}$). As in many countries (with a corridor system for interest rates), we also assume that the central bank remunerates reserve balances with the policy rate only if those reserves are required, while excess reserves are remunerated at zero. This incentivizes the banks to not hoard reserves.

Monopolistic competitive banks are the only primary dealers on government securities' market in our model. They are bidding their own preferred yields $i_t^s(i)$ when the government issues securities and the amount of securities each bank obtains through the auction is constrained with an interest-elastic demand schedule. This downward-sloping demand schedule, linking the yield bid by each bank and the share of securities obtained by this bank, also depends on the aggregate amount of securities $\bar{S_t}$ supplied by the government (or aggregate amount of borrowing demanded by it) and average yield on those securities—again, standard CES aggregation[5]:

[5]We acknowledge that government bonds are more like a homogeneous asset, and a competitive threat in such a market means everyone would bid the same interest rate on the auction (since below that would make no economic sense and above that a buyer will be left without any bond whatsoever). However, this argument presumes each bank has an ability to buy the whole bond portfolio, which may not be realistic. Instead, we assume that each bank, e.g., due to a leverage ratio cap, can at most buy a certain (relatively small) portion of the whole portfolio, even if it bids the lowest interest rate. This means that even if one bank knows that its competitor will bid a very low interest rate, this bank will still not have an incentive to follow suit and can instead bid a bit higher rate (if it's not too desperate for bonds), but still be able to get at least some portion of bonds. When the number of banks becomes large (infinity, in the limit), this assumption results in a downward-sloping demand curve for bonds.

$$S_t(i) \leq \left(\frac{i_t^s(i)}{\bar{i}_t^s}\right)^{-\varepsilon^s} \bar{S}_t. \tag{2}$$

Then, deposit demand also restricts the banks from setting deposit interest rates below the policy rate by more than a mark-down $\frac{\varepsilon^d-1}{\varepsilon^d}$, which measures a competition in the deposit market:

$$i_t^d(i) \geq \frac{\varepsilon^d - 1}{\varepsilon^d}\bar{i}_t. \tag{3}$$

Next, each bank also internalizes the presence of its balance sheet identity $(L_t(i)+Q_t(i)+S_t(i) = D_t(i)+R_t(i))$ as well as the way permanent liquidity is provided in the system.[6] The latter is reflected in the fact that a bank needs smaller refinancing loans the higher is the amount of FX reserves the central bank accumulates:

$$R_t(i) = Q_t(i) + cD_t(i) + \hat{E}_t(i) - \bar{R}_t^{fx}. \tag{4}$$

This equation incorporates the fact that the public (non-bank sector) has cash demand consisting of two parts: average demand for cash (constant c fraction of deposits), $cD_t(i)$, and stochastic demand for it,[7] $\hat{E}_t(i)$. This cash demand may be satisfied by the central bank accumulating FX reserves $\bar{R}_t^{fx}$ (against which it provides liquidity to the non-bank sector, even if through banks). But whatever cash demand is left needs to be satisfied by banks. Banks, on the other hand, need to obtain liquidity to (i) satisfy this (net) cash demand as well as (ii) hold it (in the form of $Q_t(i)$) to satisfy reserve requirements. Hence, they have to obtain this needed liquidity from the

[6] The only way for the central bank to provide permanent liquidity to our model economy is through FX interventions. We could have easily included a central bank's open-market operations with government bonds, but it would not have changed the final results. Buying government bonds does not relax the collateral constraint, as the bond owner becomes the central bank instead of a commercial bank, which is a (major) bondholder here. On the other hand, whenever the central bank conducts an FX intervention, even if through commercial banks, it eventually buys (sells) FX from (to) non-banks, since our assumption is that the banks have a closed FX position. This is how most financial systems work worldwide. But even if we relax this assumption, results wouldn't change much. And when FX reserves increase on the asset side of the central bank balance sheet, so does the liquidity (which is a liability of the central bank).

[7] This shock can be interpreted as an idiosyncratic liquidity shock to a particular bank.

central bank (by refinancing loans, $R_t(i)$). The above equation simply uses this information to express demand for refinancing loans as a function of all the above (of which FXI is the most relevant here). In turn, the amount of permanent liquidity provided (or withdrawn) through FX interventions is exogenous to each bank. We assume that distribution of (non-bank) clients who get to adjust their balances at commercial banks after the central bank's FXI is also exogenous and symmetric[8] to banks. If we were to integrate this demand for refinancing loans over all the banks, we would nicely arrive at the central bank balance sheet identity, which states that demand for central bank money (coming from reserve requirements and cash demand) will be satisfied by either the central bank's net foreign assets (FX reserves here) or net domestic assets (refinancing loans here).

Last but not least, there's one key constraint each bank also faces, in addition to more standard ones listed above: if there are massive-enough deposit withdrawals so that the bank reaches its collateral constraint (with a collateral base in this case being equal to $S_t(i)$ for each bank), then it incurs an additional cost (say cost of a bank run) equal to $\Delta_t(i)$.[9] Given these constraints and decisions in our model, each monopolistic competitive commercial bank's profit reads (given there are no excess reserves[10]):

$$\Pi_t(i) = \begin{cases} (i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)) & \\ \quad - (i_t^d(i)D_t(i) + \bar{\imath}_t R_t(i)), & \text{if } R_t(i) \leq S_t(i) \\ (i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)) & \\ \quad - (i_t^d(i)D_t(i) + \bar{\imath}_t R_t(i)) - \Delta_t(i), & \text{otherwise.} \end{cases} \tag{5}$$

[8]That's why $\bar{R}_t^{fx}$ has no i index. But even if we had an asymmetric distribution of clients, what's important for our (qualitative) result is for $\bar{R}_t^{fx}(i)$ to have been an increasing function of $\bar{R}_t^{fx}$, which is a very reasonable assumption.

[9]What this cost is proportional to will be discussed below.

[10]The question can be, why do we rule out the possibility of excess reserves? The answer is a combination of two points: (i) in our model, as in corridor systems, excess reserves pay no interest (aren't remunerated), while securities pay positive interest; and (ii) excess reserves and securities provide the same degree of liquidity risk insurance because securities are 100 percent eligible as collateral (i.e., no haircut) and can always be easily liquidated. In other words, while the bank is indifferent from the benefit (liquidity) side, it strictly prefers securities from the (opportunity) cost side, meaning that if the bank has some excess liquidity, it would rather buy securities with it than hold it as excess reserves.

If we assume that these banks are risk neutral,[11] then the banks try to maximize the following expected (probability-weighted) profit:

$$\Pi_t(i) = (i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)) - (i_t^d(i)D_t(i) + \bar{\imath}_t R_t(i)) \\ - \Delta_t(i)Prob(R_t(i) > S_t(i)). \tag{6}$$

Here all interest rate parts are standard interest revenues and costs. The crucial new term, as discussed above, is $\Delta_t(i)$ which, in our model, will be non-zero. This would mean that each commercial bank, to some extent (depending on the value of $\Delta_t(i)$), fears the possibility of refinancing needs ($R_t(i)$) exceeding the available collateral for central bank operations ($S_t(i)$). The interpretation of $\Delta_t(i)$ can be from both market as well as regulatory perspective. In terms of the former, the bank may fear a bank run (liquidity crisis) and, hence, bankruptcy excluding this particular bank from future profits (given re-entry into a banking sector would, as in the real world, be costly—e.g., attracting a customer base once again is difficult). In terms of the regulatory perspective, the bank may fear a liquidity crisis, because the supervisory authority may impose large regulatory burden in that case (also reducing profits). Even if the central bank widens the collateral base and accepts other assets (like loans), the terms would still be more costly (even Bagehot's dictum instructs us to require a good collateral and a penalty rate). In any case, running out of liquidity (obtaining which requires collateral) is costly and the higher $\Delta_t(i)$, the higher is this cost in our model. Given that in the real world bank runs are something that everybody in the banking system fears and tries to protect themselves from, it only makes sense to assume non-zero (or, more precisely, positive) $\Delta_t(i)$.

Hence, a bank's profit-maximization problem[12] reads as follows:

$$\max_{\substack{i_t^l(i),L_t(i),Q_t(i),i_t^s(i),\\ S_t(i),i_t^d(i),D_t(i),R_t(i)}} \left[i_t^l(i)L_t(i) + \bar{\imath}_t Q_t(i) + i_t^s(i)S_t(i)\right] - \left[i_t^d(i)D_t(i) \right. \\ \left. + \bar{\imath}_t R_t(i)\right] - \Delta_t(i)Prob[R_t(i) > S_t(i)]$$

[11]Our final results seem to only get magnified with the assumption of risk aversion, as risk-averse banks would fear the collateral constraint even more.

[12]Here profit means the next-period profit, since banks decide on interest rates and profits realize afterwards. Hence, given the stochastic component $\hat{E}_t(i)$, there is some uncertainty surrounding profits that the banks are trying to maximize. This is the reason why we have $Prob(\cdot)$ in the model.

$$\text{subject to} \qquad (i) \quad L_t(i) \leq \left(\frac{i_t^l(i)}{\bar{\imath}_t^l}\right)^{-\varepsilon^l} \bar{L}_t$$

$$(ii) \quad Q_t(i) = rr \cdot D_t(i)$$

$$(iii) \quad S_t(i) \leq \left(\frac{i_t^s(i)}{\bar{\imath}_t^s}\right)^{-\varepsilon^s} \bar{S}_t$$

$$(iv) \quad i_t^d(i) \geq \frac{\varepsilon^d - 1}{\varepsilon^d} \bar{\imath}_t$$

$$(v) \quad L_t(i) + Q_t(i) + S_t(i) = D_t(i) + R_t(i)$$

$$(vi) \quad R_t(i) = Q_t(i) + cD_t(i) + \hat{E}_t(i) - \bar{R}_t^{fx}.$$

Before completing the model description, let's have a look at the growth rates (e.g., credit growth) incorporated into the model. We assume that the system follows a balanced-growth path (BGP), implying that in the steady state, growth rates of all quantities (like, loans, deposits, reserves, etc.) are the same. In general, this shared factor that drives growth rates can be interpreted as, for instance, a labor-augmenting technology which drives the output growth in the long term and, hence, credit given that in the very long-run credit-to-GDP is stable. Linking steady-state growth rates to a single exogenous technology is an already standard feature of many DSGE models (e.g., see Christiano, Motto, and Rostagno 2010). With this shared factor, which we denote as $z_t > 0$ (growth rate of which, $\frac{z_t - z_{t-1}}{z_{t-1}} = g$, is constant along the balanced-growth path), we can now stationarize our model by dividing all quantity variables (like loans, deposits, reserves, etc.) with that shared factor z_t, and denote those stationarized variables with the same letters as non-stationary ones but with a lowercase. That is, we have

$$l_t(i) \equiv \frac{L_t(i)}{z_t} \qquad q_t(i) \equiv \frac{Q_t(i)}{z_t} \qquad s_t(i) \equiv \frac{S_t(i)}{z_t} \qquad d_t(i) \equiv \frac{D_t(i)}{z_t}$$

$$r_t(i) \equiv \frac{R_t(i)}{z_t} \qquad \delta_t(i) \equiv \frac{\Delta_t(i)}{z_t} \qquad \bar{r}_t^{fx} \equiv \frac{\bar{R}_t^{fx}}{z_t} \qquad \hat{e}_t(i) \equiv \frac{\hat{E}_t(i)}{z_t}.$$

Because z_t is an exogenous process (and takes strictly positive values), we can safely write that $Prob\big(R_t(i) > S_t(i)\big) = Prob\Big(\frac{R_t(i)}{z_t} > \frac{S_t(i)}{z_t}\Big) = Prob\big(r_t(i) > s_t(i)\big)$.

First-order conditions of this optimization problem described above, after some manipulations (see a detailed derivation in Appendix A), yield the following equation for the loan interest rate setting (in a symmetric equilibrium)[13]:

$$\boldsymbol{i_t^l} = \frac{\varepsilon^l}{\varepsilon^l - 1}\left[\frac{1}{1+c}\boldsymbol{i_t^d} + \frac{c}{1+c}\bar{\boldsymbol{i}}_{\boldsymbol{t}} + \delta_t \frac{rr+c}{1-rr}\boldsymbol{f}\left(\bar{r}_t^{fx} + s_t - \frac{rr+c}{1-rr}\cdot l_t\right)\right], \tag{7}$$

while almost exactly the same procedure results in the following equation for the equilibrium yield on securities:

$$\boldsymbol{i_t^s} = \frac{\varepsilon^s}{\varepsilon^s - 1}\left[\frac{1}{1+c}\boldsymbol{i_t^d} + \frac{c}{1+c}\bar{\boldsymbol{i}}_{\boldsymbol{t}} - \delta_t \boldsymbol{f}\left(\bar{r}_t^{fx} + s_t - \frac{rr+c}{1-rr}\cdot l_t\right)\right]. \tag{8}$$

All other variables can be extracted from the constraints above (e.g., loans and securities demand schedules give the quantities of l_t and s_t), while f (a probability density function of $\hat{e}_t(i)$[14]) represents liquidity risk premium. The intuition is that the bank takes a distance between the maximum possible supply of liquidity $(\bar{r}_t^{fx} + s_t)$[15] and an average demand for liquidity $(\frac{rr+c}{1-rr}l_t)$[16] into account. The bigger this distance, the less concerned the bank is (about liquidity risk), which means charging less premium. This risk premium,

[13] The assumption here is that $0 \leq rr < 1$. The case when $rr = 1$ is discussed below. Also, in a symmetric equilibrium index i does not matter, since all banks face the same problem and make the same decisions. Hence, in equilibrium conditions we can get rid of it, making the equation easier to read.

[14] As $\hat{e}_t(i) \equiv \frac{\hat{E}_t(i)}{z_t}$ is stationarized, the actual size of the liquidity shock in our model $\hat{E}_t(i)$ is gradually increasing as the financial system and, hence, the amount of deposits increase over time. In other words, while the size of the liquidity shock doesn't depend on the short-term dynamics of deposits, it depends on the long-term dynamics of it. One can argue that this seems plausible. But even if it doesn't, relaxing this assumption doesn't change the qualitative results, while it complicates the derivations.

[15] Maximum possible supply of liquidity is what central banks supply through FXI plus the collateral base (i.e., sum of all security holdings here).

[16] Average demand for liquidity is the amount of deposits each dollar of loan generates $(\frac{1}{1-rr})$ times how much liquidity each dollar of deposits necessitates on average (to satisfy reserve requirements and average cash withdrawals). The same is true for loans as well as for securities.

usually absent in DSGE models that feature banking systems, is the central part in our analysis. The implications of that premium are provided in the next subsection. Namely, we describe how optimal choices made by banks (dictated by equilibrium conditions) are affected after a change of exogenous variables or model parameters.

Equilibrium. In a symmetric equilibrium, loans and securities markets clear, so that $\int_0^1 L_t(i)di = \bar{L}_t$ and $\int_0^1 S_t(i)di = \bar{S}_t$. As for the deposit market, we are not showing it explicitly here. Instead, it is assumed to clear implicitly, since that would be the result of applying Walras's law.

Possibility for General Equilibrium Extension. Up to this point, we have discussed only the bank's optimization problem (i.e., taking demand schedules as given—something that should come out of households' or other agents' optimization problems). However, the model we consider here can (most probably) easily be made part of a general equilibrium framework. We do not argue that *any* general equilibrium model can easily incorporate our channel, but that *some* can do so. For instance, an otherwise-standard DSGE model where the collateral constraint for central bank operations is either the only financial friction or is linearly independent from other financial frictions can easily be built. In that model all equilibrium conditions will be derived independently of the derivations shown here. For example, we could have firms in our model that have standard pay-in-advance constraints and are dependent on loans. In standard DSGE models an interest rate on that loan would be based on a policy rate. But, if our channel is incorporated, then that loan rate would now also depend on FX interventions per the equation we derived above. Hence, looking at the banks' problem should be sufficient for our purposes, to see how interest rates would depend on the collateral base and central bank liquidity injections or withdrawals (e.g., through FX interventions).

3.1.2 Implications of the Model

Even though the modeling framework is quite simple, it results in many interesting implications—some of them new results, while others are already well established (underlying the model's realism). The most important result here, for the purposes of this paper, is the dependence of a liquidity risk premium on central bank FX interventions. That's what we discuss first.

FX Interventions and Loan Interest Rates. Whenever the central bank buys FX reserves, it swaps borrowed reserves into non-borrowed reserves. Hence, even if the total amount of reserve money is unchanged (i.e., intervention is sterilized), the refinancing needs decline. The latter in turn increases the amount of free (unused) collateral and, hence, lowers the probability of reaching the collateral constraint in the event of a bank run or big liquidity needs in the future. This, in turn, reduces the liquidity risk premium and, therefore, loan interest rates. This can be shown by differentiating i_t^l with respect to $\bar{r}_t^{fx}$, which would depend on the probability density function $f(\cdot)$. Here, we remain agnostic about the functional form of $f(\cdot)$. We just do not consider cases when refinancing needs are already above the collateral base, in which case the liquidity risk premium would be infinite (banks will just have to de-leverage right away or default). In addition, for positive values of its argument x, $f(x)$ is assumed to be a decreasing function (i.e., $f'(\cdot) < 0$[17]), so that it is less likely for a depositor to cash out large sums than smaller sums. Then we have

$$\frac{\partial i_t^l}{\partial \bar{r}_t^{fx}} = \frac{\varepsilon^l}{\varepsilon^l - 1} \delta_t \frac{rr + c}{1 - rr} f'(\cdot) < 0. \tag{9}$$

Hence, a higher level of FX reserves (i.e., intervention on the buying side), results in a reduction of loan interest rates. Lower loan rates induce more borrowing (through loan demand schedule), which, on its own, creates new purchasing power or deposits (through balance sheet identity). This new money, at least under sticky prices or monetary non-neutrality in general, will then temporarily stimulate the real economy, including through exchange rate depreciation (which we discuss in the next part). Clearly, the channel works in the opposite direction when the central bank sells FX reserves. What's crucial for the quantitative importance of this non-linear channel is the distance between the amount of borrowing needed from the central bank and the available collateral ($f(\cdot)$ is

[17] Otherwise, we could still have the dependence of loan rates on FX interventions but with a different direction.

non-linear). The smaller this distance, the more elastic the liquidity risk premium could be to changes in FX reserves. That's why the process is non-linear: if the need for borrowing from the central bank declines from a large value, liquidity risk also declines significantly, but if this need declines by the same amount from a small value, liquidity risk may not change much (and remain close to zero). This means that buying FX and selling FX, under certain conditions, may result in asymmetric effects on interest rates.

Therefore, because of the fear of not being able to obtain liquidity in the future, this channel is mostly visible when a central bank has a net creditor position (structural liquidity deficit). If there were structural liquidity surplus in the financial system, then this liquidity risk premium channel would probably be negligible. The examples of this could be floor systems where central banks flood the system with liquidity (because assets they can buy are abundant enough), or central banks try hard to stem off exchange rate appreciation and have accumulated too much of FX reserves. But for other countries that are less developed (so that risk-free assets aren't abundant enough) and have current account deficits (so that FX reserves aren't over-accumulated), this liquidity risk premium channel is probably going to show up, as the system would be in a structural liquidity deficit.

FX Interventions and Yields on Securities. Another important aspect (or flip side) of our channel is that FX interventions also affect securities yields but with a different direction than loan rates. Analytically, this can be seen by differentiating i_t^s with respect to $\bar{r}_t^{fx}$, which results in

$$\frac{\partial i_t^s}{\partial \bar{r}_t^{fx}} = -\frac{\varepsilon^s}{\varepsilon^s - 1}\delta_t f'(\cdot) > 0. \tag{10}$$

Intuitively, contrary to the result above with i_t^l, yield on securities i_t^s increases as central banks accumulate FX reserves. The reason is that when FX reserves increase, so do non-borrowed reserves. This reduces the need for central bank borrowing and, hence, the probability of reaching the collateral constraint in the future. This means that a security that can be used as collateral becomes less valuable—meaning its price declines, which by definition means higher yields. Clearly, the opposite happens when central banks sell FX reserves—now the amount of non-borrowed reserves decrease, which requires more collateral and an increase in its price. This explains how securities included in collateral base may incorporate a collateral service premium into their prices. This premium, when the collateral base is quite small, can get so big that the yields on those securities may even drift below the policy rate or result in a much more flat (risk-free) yield curve. This is important, because an inverted yield curve is usually thought to be a sign of an imminent recession, while we show that in developing economies described above this may also be a sign of collateral scarcity.

Reserve Requirements and Interest Rates. In addition to the main results above, other interesting insights (some of them trivial and some of them usually overlooked) can also be extracted from the above optimization problem. First, according to our loan interest-rate-setting and securities yield equations, liquidity risk premium, in addition to FX reserves, depends on the reserve requirements. For loan interest rates, given $f(\cdot)$ is a probability density function and takes on positive values:

$$\frac{\partial i_t^l}{\partial rr} = \frac{\varepsilon^l}{\varepsilon^l - 1}\delta_t \frac{1+c}{(1-rr)^2}\left(f(\cdot) - \frac{rr+c}{1-rr}f'(\cdot)l_t\right) > 0. \tag{11}$$

This may be a surprise result to standard analysis of interest-rate-targeting frameworks. Whenever short-term interest rate is an operational target of a central bank, the level of a reserve requirement, the argument goes, should not matter, because if it is high or low the required reserves will always be provided by the central bank so that short-term interest rates do not change. This argument, however, misses the point we described above: the distance between central bank refinancing needs and collateral base. Indeed, whenever reserve requirements increase, for instance, banks would need to borrow more, on average, from the central bank (given non-borrowed reserves aren't changed). This would reduce the amount of free collateral and, hence, increase the probability of reaching the collateral constraint in the future. The result would be a higher liquidity risk premium and loan interest rate. Therefore, when the collateral base isn't big enough, reserve requirements still matter, even in interest-rate-targeting frameworks. Yields on securities respond to reserve requirements similarly but with a different sign—when reserve requirements increase, yields on securities decline (as collateral service becomes more valuable).

FX Interventions and Exchange Rates. As discussed from the very beginning of this section, our model is a partial equilibrium one. The aim was to show how FX interventions affect domestic currency interest rates. But we can go one step further and discuss how the latter, in turn, can affect the exchange rate. For this we would need to introduce some other economic agent into our model, which determines the exchange rate. Following Cesa-Bianchi et al. (2019), just for the sake of exposition, we can assume that there are households that can hold both domestic currency as well as foreign currency deposits (the latter are issued by foreign banks). These households would then arbitrage and result in a certain form of a uncovered interest rate parity (UIP) condition. Cesa-Bianchi et al. (2019) assume that these two domestic and foreign currency deposits are imperfect substitutes—leading to a deviation from a textbook UIP. With this assumption we can arrive at what they call a monetary UIP condition[18] of the following form:

$$i_t - i_t^* = (E_t x_{t+1} - x_t) + m_t, \tag{12}$$

where i_t and i_t^* are domestic and foreign interest rates, while x_t and m_t are the exchange rate[19] and monetary spread, respectively, at time t. What's important is that in Cesa-Bianchi et al. (2019) the monetary spread is a function of deposits. Hence, in our case it means that $m_t = m(d_t)$ with $\frac{\partial m}{\partial d_t} > 0$. This implies that whenever more domestic currency deposits are created, the monetary spread increases and depreciates the exchange rate. The reasoning is that more domestic currency money means less relative convenience of it (relative to a foreign currency). Hence, domestic currency deposit holders should be compensated by higher interest rates or otherwise exchange rate would depreciate.

Now, the question is, how do we link FX interventions in our model and the exchange rate? This channel starts from the loan rate. For instance, when the central bank buys FX, it reduces the liquidity

[18]The main part of the equation is fairly standard: interest rate differential compensating for expected depreciation.

[19]Here increase means depreciation.

risk premium (as described above)—lowering the loan rate. Lower loan rate means more loan extension, which, in turn, means more deposit creation through the balance sheet identity. More deposits then increase the monetary spread m_t—putting depreciationary pressure on the exchange rate.[20]

Collateral Base and Financial-Sector Efficiency. As also mentioned above, making sure that the collateral base for central bank operations is sufficiently large not only minimizes interest rate effects of sterilized FX interventions, but it also leads to low liquidity risk on average. This may, in principle, be related to increased efficiency in the financial sector. However, this (widening the collateral base) is a difficult task unless the amount of near risk-free (e.g., government) securities is abundant enough or excessively high haircuts are applied on risky assets. Put differently, taking risky assets as a collateral for central bank operations, even if it reduces liquidity risk, is difficult for central banks, as it is a quasi-fiscal step.

Loan Rates and Deposit Rates. As would have been expected, the weighted average of the deposit rate and the policy rate is the major component of the loan rate. The weights depend on the public's demand for cash relative to deposits (i.e., deposit cash-out ratio c). The higher this ratio, the more the commercial banks need to borrow from the central bank (to satisfy deposit withdrawals) and, hence, the more their costs depend on the policy rate. On the other hand, in cashless societies, banks would no longer need central bank borrowing[21] after loan extension and, hence, the sole determinant of the loan rate (possibly in addition to liquidity risk premium) becomes the deposit rate.[22]

[20] It may seem like the effect on the exchange rate is solely inherited from the Cesa-Bianchi et al. (2019) model, but this is not the case. While they show how more domestic currency deposits (private money) may depreciate the exchange rate, they are completely silent on how more FX reserves may result in more domestic currency deposits. The latter is what we show in this paper.

[21] Banks may still need to borrow from the central bank to satisfy reserve requirements, but this is a neutral operation in terms of banks' profit, as long as required reserves are fully remunerated.

[22] Deposit rate could still depend on the policy rate (due to competition from government bonds, money market mutual funds, or alike). Hence, while a higher cash ratio implies the direct impact of the policy rate on the loan rate, in cashless societies, all central banks can hope for is to affect loan interest rates mainly through deposit rates.

Cash-to-Deposit Ratio and Liquidity Risk Premium. A bit more unexpectedly though, deposit withdrawal rate also affects the liquidity risk premium. A higher cash ratio would mean higher need for central bank liquidity and, hence, may exacerbate the problem of collateral constraint. Therefore, the higher c, the higher is the liquidity risk premium (clearly, holding other factors constant). This can easily be seen by differentiating i_t^l with respect to c (not shown here).

Government Debt: Crowding In vs. Crowding Out. If, in the model equilibrium conditions, we explicitly impose a symmetry between banks and then aggregate, we would get a result where the liquidity risk premium depends on an aggregate amount of securities ($\bar{s}_t$). Increasing the amount of this kind of (near) risk-free securities, like government bonds, would reduce the liquidity risk premium, per the mechanism described above. But what's striking is that this means that a bigger government bond portfolio may support lower loan interest rates and, hence, more private borrowing (crowding in). This is in contrast to the classic crowding-out argument. To be sure, we do not rule out the possibility of crowding out. Instead, what we argue is that the bigger size of the government bond portfolio may lower the liquidity risk premium, even if crowding out may still happen as a result of a deliberate central bank reaction to fiscal expansion (i.e., central banks increasing policy rates in response to higher government deficits) or higher sovereign default risk premium.

Liquidity Risk Premium and Monetary Transmission. Here we assumed that $\bar{s}_t$ is exogenous. But if this problem were to be incorporated into a general equilibrium model, one could easily see that monetary policy transmission would also be working through the liquidity risk premium channel, on top of more traditional channels. For instance, an increase in the policy rate would reduce prices of securities and, hence, the size of their portfolio (marked to market). Lower size of portfolio $\bar{s}_t$ would then mean less distance until the collateral constraint and, therefore, a higher liquidity risk premium—reducing loan extension and aggregate demand.

Money Market: Demand vs. Supply. In our model we haven't emphasized banks' borrowings from each other on the money market, in addition to central bank borrowing. Can our model say more about the equilibrium money market rate that balances money demand and supply? In fact, collateralized borrowing on the money market is essentially the same in our model as accessing the central bank facility, because both have the same maturity and both are free of risk (because of collateral). Indeed, one can assume that each bank's borrowing r_t includes the liquidity from the other banks on the money market. This means that collateralized borrowing on the money market has the same interest rate as the central bank facility—that is, the policy rate.

But, in the case of uncollateralized borrowing from other banks, that's what our model does not incorporate. If it did, what could be the resulting equilibrium interest rate on that market that makes sure the demand and supply are equal? Comparing our loans l_t and that kind of borrowing on the money market makes it clear that interest rate on uncollateralized money market borrowing will be directly dependent on liquidity risk premium we discussed above, like i_t^l does. For instance, when a central bank sells FX and reduces non-borrowed reserves, this makes the collateral constraint more probable to become binding in the future and makes the existing liquidity more valuable, resulting in an increase of interest rates on loans whether it's to non-financial clients or financial clients. Of course, this is in line with the situation when liquidity fears shoot uncollateralized interest rates on the money market up while corresponding collateralized ones remain stable and close to the central bank's policy rate.[23]

Hence, one of the reasons why we didn't explicitly incorporate this additional layer was that the implications would be similar. Also, we can assume a symmetry in the model, where banks have similar optimization problems and if there's a flight to liquidity all banks experience this and it's the central bank that has to satisfy this demand. Therefore, one way or another we end up with the problem of how much the central bank can satisfy this demand, which depends on the collateral base.

[23]Think of the liquidity fears during the global financial crisis—yields on securities no longer deemed a good collateral shot up significantly, even as policy rates and risk-free yields dropped down.

Fractional vs. Full Reserve Banking. Last but not least, the bank optimization problem above was for fractional reserve banking. If we had assumed that $rr = 1$, the model would have shown that in this case the stochastic component in our model vanishes and liquidity risk premium becomes zero when collateral constraint isn't binding and infinity when it is binding. In other words, the bank would no longer include any liquidity risk premium in its loan rate if it already has enough liquidity (including securities) to cover 100 percent of a newly created deposit, or if it doesn't it will just not extend the credit (which, in principle, is equivalent to imposing an infinitely high loan rate). As expected, switching from fractional banking to full reserve banking would seem to turn commercial banks into traditional intermediaries (as described by the loanable funds theory) instead of being the major creators of (deposit) money. For a related discussion, see Jakab and Kumhof (2019).

To sum up, the model, while simple, seems rich enough. Incorporating this liquidity risk channel into general equilibrium (e.g., DSGE) models shouldn't be difficult, as discussed above. What's more challenging is the solution of the resulting model, since the liquidity risk premium in our model is non-linear. Yet there is some work, including our own, that tries to deal with the issue of solving non-linear dynamic models (see Fernández-Villaverde, Rubio-Ramírez, and Schorfheide 2016 or Mkhatrishvili et al. 2019).

3.2 Empirical View

The empirical literature, as discussed above, is somewhat limited on the effects of FX interventions on lending rates. According to our theoretical discussions, FX interventions on the purchase side, for example, could relax a collateral constraint and reduce liquidity risks along with lending rates. A few empirical papers do suggest that sterilized interventions could affect credit markets through heightening a risk-taking behavior on the side of a financial system. This could drive credit expansion, something related to lower interest rates (e.g., see Gadanecz, Mehrotra, and Mohanty 2014) as in our model. However, as shown in our analytic exercise, the channel through which FX interventions affect interest rates is different from those discussed in other papers. We show that this channel depends on the size of a central bank's collateral base. The question is, do we see this in the data?

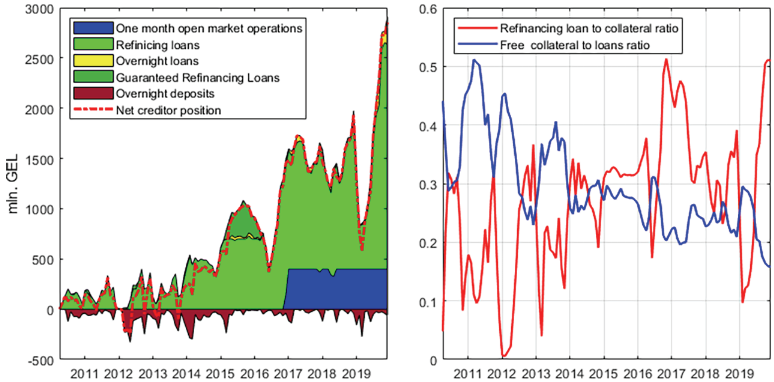
With this question in mind, we estimate a possible link between lending rates and freely available collateral (i.e., distance until the collateral constraint) in the banking system of the country of Georgia. The estimated transmission from the collateral constraint to lending rates, in turn, would be suggestive of the presence of FXI's effects on lending conditions, given that when the central bank conducts FX purchase (sell) operations it usually relaxes (tightens) the collateral constraint. To identify the above channel, our empirical strategy is somewhat similar to the literature on estimating determinants of lending rates (e.g., Almarzoqi and Ben Naceur 2015), but we further extend those empirical models by introducing freely available collateral (total amount of collateral minus borrowings from the central bank) in banks' balance sheets as an additional determinant of lending rates. To the best of our knowledge, this channel is not quantified in other empirical studies yet. Hence, we try to assess whether the amount of freely available collateral makes financial institutions more or less anxious about future liquidity risks, consequently changing rates on their loans. In other words, in case of an FX purchase by the central bank, for instance, we test "leveraging-up" effects of FX interventions.

To estimate the empirical relationship between the collateral base and loan interest rates, as mentioned, we include other standard control variables as well which could also contribute to the variation in loan interest rates of local currency loans in Georgia. In that sense, the equation estimated here is quite close to empirical models on interest rate determinants (see also Ho and Saunders 1981 or Saunders and Schumacher 2000). The estimated equation has the following form:

$$\lambda(a)i_t = \lambda(p)col_t + \lambda(q)x_t + \epsilon_t, \tag{13}$$

where i_t is the interest rate on domestic currency loans (that includes all types of loans), while col_t is a measure of the distance until the collateral constraint (available securities in the collateral base minus borrowings from the central bank). $\lambda(a)$, $\lambda(p)$, and $\lambda(q)$ are

Figure 2. Monetary Policy Operations and Net Creditor Position of the NBG (left panel); Refinancing-Loans-to-Collateral and Free-Collateral-to-Loans Ratios (right panel)



Source: National Bank of Georgia.

lag polynomials, while x_t represents a set of control variables.[24] ϵ_t is a residual. We estimate two specifications of Equation (13): in the first specification we test whether the log of the ratio of freely available collateral (difference between collateral base and borrowings from the central bank) to loans in the local currency affects lending rates. Hence, we estimate constant elasticity of interest rate with respect to free collateral in the first specification. In the second one, we included the inverse of that ratio to estimate non-linear effects of the free-collateral-to-loan ratio on interest rates. All variables in our empirical exercise are expressed in percentage points, except the free-collateral-to-loan ratio (with the effect interpreted as a change in terms of basis points).

As mentioned above, our channel would most probably be more visible in a structural liquidity deficit scenario. This is indeed so in our case. Georgia moved to an inflation-targeting framework in 2009. Since then, as Figure 2 also shows, the net creditor position of and liquidity provision by the National Bank of Georgia (NBG) has

[24]Variable descriptions are provided below in the main text as well as in Appendix B.

been widening over time. Alongside this, freely available collateral has declined as measured either by the ratio of refinancing loans to collateral (which increased) or by the free-collateral-to-loans ratio (which decreased). The amount of collateral used in the calculation of the free collateral ratio includes all financial instruments eligible for monetary operations except loan assets. Given the fact that loan assets pledged as collateral must not be more than a certain fraction of debt securities (and have very high haircuts), their exclusion only effects the level of the collateral base but not its variation. In terms of the evolution of dependent as well as independent variables, their time-series graphs are provided in Appendix B. Worth noting is that a declining trend of loan interest rates (see Figure B.2 in Appendix B) could be related to the improved liquidity provision framework, among other factors.

As regards the control variables, to account for the *cost of funding and liquidity* we included (domestic currency) deposit and monetary policy rates in the equation. In addition, loan loss provisions (from the consolidated financial reports of commercial banks) are applied to control for *credit risk*.[25] Also, the ratio of non-interest income over assets in the banking system is used as a proxy for diversification of banks' activities. Theoretically, this may contribute to lower lending rates. To control for *macroeconomic risks* in our model, GDP growth, sovereign spread (the difference between yields on Georgia's government bonds issued in FX and U.S. government bonds with the same maturity), and CPI inflation were considered. Share of non-interest expenses is applied to account for the contribution of *overheads* in interest rates. To account for the effect of *market structure* on interest rate margins, proxies of competition are used such as Herfindahl-Hirschman (HH) and Lerner indices.[26] The ratio of equity to assets as well as the index of risk appetite from the survey on lending conditions are used to measure banks' *risk aversion* and its effects.[27] The average maturity of local currency loans,

[25]The ratio of non-performing loans to total loans was also tried, but the shortcoming of the indicator is its backward-lookingness in representing the credit risk.

[26]Based on our own calculations using financial reports of the commercial banks.

[27]However, it is questionable whether this index measures changes in banks' risk preference or reflects a variation in perceived risks. But even if we fail to

also included in the estimation, has an increasing trend in our case (see Figure B.1 in Appendix B), which, all else equal, could have an upward pressure on interest rates due to higher term premium. Despite the formal test of a unit root on lending rate suggesting the variable is trend stationary, we still include a time dummy to account for an accelerated decline of a spread between lending rates and the monetary policy rate after 2014. It seems reasonable to assume that all those controls would be sufficient to capture the net effect of collateral on interest rates.[28]

We estimate Equation (13) with a distributed lag model. Most of the variables are stationary processes, at least around a deterministic trend. We fail to show that the lending rate and free collateral are co-integrated—those variables are stationary processes around a deterministic trend. Hence, we include the trend in the estimated equation, while the variables which failed to be stationary around a deterministic trend are included in the equation in the form of first-order differences. Lag orders are selected based on Schwarz information criteria.[29] Heteroskedasticity and autocorrelation consistent (HAC) standard errors are applied for testing significance of the estimated coefficients.

Both of the estimated specifications suggest largely the same fit of the models to the data, but Specification 1 (constant elasticity of lending rates to free collateral ratio) implies a higher test statistic (for example, F statistics) to reject no relationship between the variables. However, significance levels are only marginally different from each other. An approximately same empirical fit of both of the specifications seems intuitive as long as we do not observe large shocks to the free collateral ratio when the non-linearities would be expected to kick in.

---

account for the change in risk appetite (that moves interest rates and the amount of riskless assets in the same direction), the results would only underestimate the linkage we hope to prove, making our claim even more convincing.

[28] As a control, in the estimation we also tried accounting for the active dedollarization policy in Georgia that started in 2017; however, it didn't significantly change the results.

[29] The Akaike information criterion (AIC) suggested longer lag structure, but we ended up with the problem of autocorrelation in this case (probably, due to model misspecification).

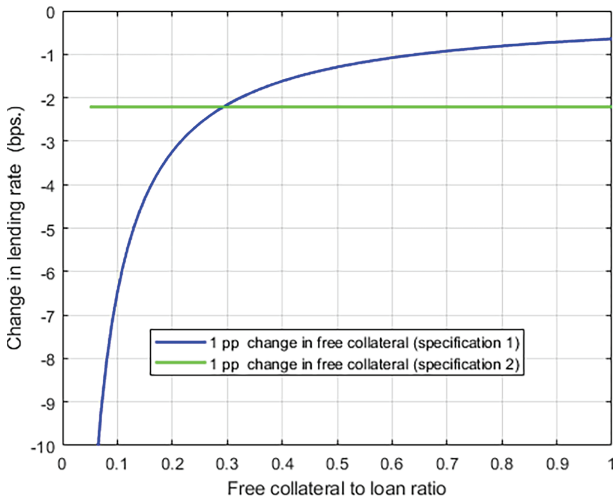
Table 1. Results of the Estimated Distributed Lag Models

	Specification 1	Specification 2
Lending Rate(–1)	0.288***	0.305***
Lending Rate(–2)	0.130*	0.145*
Lending Rate(–3)	−0.110	−0.114
Lending Rate(–4)	0.230***	0.245***
Lending Rate(–12)	−0.158***	−0.147***
Free-Collateral-to-Loan Ratio(–1)	−1.367***	
Inverse Free Collateral Ratio(–1)		0.366***
Policy Rate	0.154*	0.201***
Deposit Rate	0.103	
Reserve Requirement	0.146	0.171*
d(maturity)	2.549	2.914
d(maturity(–1))	−4.317*	−4.149*
Loan Loss Provision Ratio	−0.136	−0.157
Diversification	−2.718*	−2.834*
Non-interest Expense Ratio	0.960	0.840
d(HH Index)	0.205**	0.207**
GDP Growth	−0.130***	−0.121***
Sovereign Risk Premium	0.393***	0.390***
Time Dummy	−1.427***	−1.396***
Trend	−0.024**	−0.024**
Constant	10.438***	10.324***
F statistic	150.5	128.5

Note: *≡ $0.05 \leq$ P-value < 0.1; **≡ $0.01 \leq$ P-value < 0.05; ***≡ P-value < 0.01. Definitions: Lending rate is a weighted average interest rate on Georgian lari (GEL) loans. Free-collateral-to-loan ratio is the total amount of collateral adjusted with refinancing loans divided by the total amount of lending in GEL by commercial banks; policy rate is the monetary policy (refinancing) rate, while deposit rate is an interest rate on deposits in GEL; reserve requirement is the minimum reserve ratio set by the NBG for GEL funding; maturity measures average maturity of loans in GEL; loan loss provision is the ratio of loan loss provisions to gross loans; diversification is the ratio of non-interest income to total assets, while non-interest expense ratio is a measure of non-interest expenses to total assets; HH index is the Herfindahl-Hirschman index calculated based on loan portfolios; GDP growth is year-on-year percentage change in GDP; sovereign risk premium is in bps.

The estimation results are shown in Table 1. As it shows, 1 percentage point (pp) change in free collateral ratio decreases the lending rate by 1.4 basis points (bps) on impact and by 2.2 bps in the long run, in the case of Specification 1. In Specification 2, the marginal effect of a 1 pp change in free collateral depends on the size of this ratio at the moment of the change (see Figure 3). For example,

Figure 3. Change in Lending Rates Due to 1 pp Change in Free Collateral (as a function of the level of free collateral)



Source: Authors' estimates.

if the ratio is 0.22 (as it was in Georgia at the end of 2019), then the lending rate decreases by 1.6 bps on impact and by 2.9 bps in the long run. These estimates are non-negligible and in line with our theory. As mentioned, since the impact of FX interventions on lending rates depends on the amount of free collateral in the second specification, we plot this relationship, between the effect (of FXIs) on lending rate, on the one hand, and the amount of free collateral, on the other, in Figure 3.

To put these numbers in perspective, we can consider the overall (partial-equilibrium) impact of this channel on lending rates in Georgia in 2015. Namely, FX interventions done by the NBG in 2015 contributed to higher lending rates—in a partial equilibrium sense the size of this effect, based on our empirical exercise, was close to 90 basis points, which is a significant effect,[30] in principle similar to

[30]The ratio of net FX sales to free collateral was about 40 percent at that time.

a sizable tightening in the monetary policy rate. Of course, in a general equilibrium sense it's difficult to directly infer what would have happened if our channel was absent, but this number just underlines the economic significance of our channel in Georgia, in addition to statistical significance.

Apart from the main result, in some cases the estimated coefficients of the banking-system-related variables are intuitive, but others seem against our prior beliefs: loan loss provisioning ratio, for example, is estimated to have a negative contribution to interest rates, while overheads have a positive but insignificant effect. On the other hand, the index of industry concentration has a positive impact on interest rates, as expected. The proxies of macroeconomic risks play an important role in the determination of interest rates as well. For instance, an increase in GDP growth by 1 pp reduces lending rates by 13 bps on impact, while a 1 pp shock to sovereign risk premium pushes lending rates up by 0.38 pp on impact and 0.62 pp in the long run.

As mentioned above, endogeneity problems may arise in the estimated equation if risk aversion is not properly treated—higher risk aversion pushes both lending rates as well as investments in risk-free assets up (Gadanecz, Mehrotra, and Mohanty 2014). We have applied several alternative proxies of risk aversion to fix the problem. First, we included equity-to-assets ratio (capital adequacy) and deviation of capital adequacy ratio from regulatory requirements. However, both of them were highly insignificant and made statistical properties of the estimated equation worse, while the estimates of the rest of the coefficients were not affected at all. Also, we applied a risk appetite indicator from the survey of lending conditions conducted by the NBG, but the results are not much different than in the former case. In addition, the sample size shrank further. Therefore, those proxies of risk aversion are not included in the final stage of the estimation. If those proxy variables are appropriate measures of unobserved risk aversion, then we can conclude that it doesn't have a significant simultaneous effect on lending rates and the amount of risk-free asset holdings. However, even if the above-mentioned indicators fail to adequately measure unobserved risk aversion, we can show that it could be a source of underestimation (not overestimation) of the linkage we try to prove, which is a negative impact of free collateral on lending rates.

Liquidity shocks, other than those related to collateral constraint, could be a source of a biased estimation too. For example, a run to liquidity could dry up freely available collateral and also increase lending rates at the same time. To control for liquidity shocks which are not directly driven by collateral constraint, we have included the cash-to-M3 ratio in the empirical model. However, the inclusion of the variable did not significantly change the effect of the collateral constraint. The sign of the effect was still in line with our theoretical predictions and remained significant (see Table B.1 in Appendix B). Also, instead of the free-collateral-to-loans ratio, we have applied the ratio of refinancing loans to collateral, to exclude a possible effect of an outstanding amount of loans on the magnitude of the channel in question (as loans are in the denominator in the regressor). Here as well, we still came up with the result that tightening of the collateral constraint implies higher lending rates and the effect is significant.

As an additional robustness check, we have estimated the same regression models (by applying the free-collateral-to-loans ratio as a proxy of the collateral constraint) by using interbank and government securities (T-bills and notes) interest rates as the regressand. The results are qualitatively the same. Namely, if the collateral constraint eases (free collateral increases), then interbank market rates decline. On the other hand, according to our theoretical discussion, the free-collateral-to-loans ratio is expected to have a positive effect on T-bills and notes yields. That is, when the collateral base is less binding, yields should go up. However, at first we failed to show this effect contemporaneously. The reason could be that maybe contemporaneous effects show movements along the supply curve of securities as a result of demand shocks—showing how quantities and prices (which are inversely related to yields) move together. To isolate the demand effects on yields, we have applied lagged values of the free-collateral-to-loans ratio (i.e., if the collateral has been binding, then it would be an indicator of high demand on securities in the next periods). With this we found that the third lag of the free-collateral-to-loans ratio has a positive impact on security yields.

We also tried to include the central bank's net FX purchases in our empirical models. The estimated coefficient of that additional variable was negative and significant, implying a negative effect of

FX purchases on lending rates, as expected by our theory. At the same time, the magnitude of the effect of the free collateral ratio to lending rates has decreased after the inclusion of that new variable (FXIs), which further encourages us to argue that FX interventions' effect on lending rates indeed works through tightening/relaxing the central bank collateral constraint.

As a final remark, the effects quantified in the empirical exercise seem robust across changes in model specifications as well as the definition of collateral constraint. However, more research is needed to explicitly identify episodes of shocks related to collateral constraint, given that our estimation strategy depends on the assumption that control variables are an exhaustive set of determinants of lending rates. Panel estimation seems to be a particularly fruitful area.

4. Conclusion

The literature has identified mechanisms through which sterilized FX interventions may affect exchange rates and a real economy. Yet, what it usually claims is that sterilized interventions work through currency or country risk premiums. The theory that we developed above, and provided some empirical support for, demonstrates an additional mechanism at work—a liquidity risk channel. This is tightly related to the available collateral that can be used for central bank operations: even when the collateral constraint isn't currently binding, if the collateral isn't sufficiently abundant banks may still fear (massive) deposit withdrawals that, in principle, can make the constraint start binding in the future. This fear, however, is reduced when banks get permanent liquidity from the central bank that buys FX as opposed to getting the same amount of liquidity by borrowing from the central bank (that uses up scarce collateral). Reduction in this fear will then result in loan interest rate reduction and, hence, more loan extension. This novel channel, working through loan interest rates, may also explain exchange rate effects of sterilized interventions. In addition, the theory above arrives at a number of other interesting results, e.g., related to reserve requirements. For future research it would be very interesting to see how important this channel would be if estimated based on a cross-country panel data.

Finally, despite a theoretical rigor and significant empirical evidence, there is one important caveat. It is very difficult to estimate a true size of the amount of unused collateral. Namely, sometimes FX of banks itself is part of a collateral base (but not always). In those cases our channel may shut down. Also, whenever commercial banks know that their central bank will find ways to expand a collateral base if needed, the banks may not have much liquidity risk fear even if the current collateral base is small. However, it is politically difficult for a central bank to take risky assets as collateral (since in that case it will essentially be conducting a quasi-fiscal operation). That's why we still think that our approach of calculating liquidity risk premium based only on near risk-less securities should be a good-enough approximation, at least in normal times.

Appendix A. Deriving Loan Interest Rate Equation

First, let's reiterate the optimization problem with stationarized variables:

$$\begin{aligned}\max_{i_t^l(i),l_t(i),q_t(i),i_t^s(i),s_t(i),i_t^d(i),d_t(i),r_t(i)} \quad & \left(i_t^l(i)l_t(i)+\bar{\imath}_t q_t(i)+i_t^s(i)s_t(i)\right)\\ & -\left(i_t^d(i)d_t(i)+\bar{\imath}_t r_t(i)\right)\\ & -\delta_t(i)Prob(r_t(i)>s_t(i))\end{aligned}$$

$$\begin{aligned}\text{subject to} \qquad & (i) \quad l_t(i)\leq\left(\frac{i_t^l(i)}{\bar{\imath}_t^l}\right)^{-\varepsilon^l}\bar{l}_t\\ & (ii) \quad q_t(i)=rr\cdot d_t(i)\\ & (iii) \quad s_t(i)\leq\left(\frac{i_t^s(i)}{\bar{\imath}_t^s}\right)^{-\varepsilon^s}\bar{s}_t\\ & (iv) \quad i_t^d(i)\geq\frac{\varepsilon^d-1}{\varepsilon^d}\bar{\imath}_t\\ & (v) \quad l_t(i)+q_t(i)+s_t(i)=d_t(i)+r_t(i)\\ & (vi) \quad r_t(i)=q_t(i)+c\cdot d_t(i)+\hat{e}_t-\bar{r}_t^{fx}\end{aligned}$$

with all the variables as defined in the main text. We next form the Lagrangian function[31] in the following way[32]:

$$\begin{aligned}
\mathcal{L} = & \left(i_t^l(i)l_t(i) + \bar{i}_t q_t(i) + i_t^s(i)s_t(i)\right) - \left(i_t^d(i)d_t(i) + \bar{i}_t r_t(i)\right) \\
& - \delta_t(i)\left(1 - \Phi\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}\cdot l_t(i)\right)\right) \\
& - \lambda_1\left(l_t(i) - \left(\frac{i_t^l(i)}{\bar{i}_t^l}\right)^{-\varepsilon^l}\bar{l}_t\right) - \lambda_2(q_t(i) - rr\cdot d_t(i)) \\
& - \lambda_3\left(s_t(i) - \left(\frac{i_t^s(i)}{\bar{i}_t^s}\right)^{-\varepsilon^s}\bar{s}_t\right) + \lambda_4\left(i_t^d(i) - \frac{\varepsilon^d - 1}{\varepsilon^d}\bar{i}_t\right) \\
& - \lambda_5(l_t(i) + q_t(i) + s_t(i) - d_t(i) - r_t(i)) \\
& - \lambda_6\left(r_t(i) - q_t(i) - c\cdot d_t(i) - \hat{e}_t + \bar{r}_t^{fx}\right) \qquad \text{(A.1)}
\end{aligned}$$

$$\left[i_t^l(i)\right]: \quad l_t(i) - \lambda_1\varepsilon^l\left(\frac{i_t^l(i)}{\bar{i}_t^l}\right)^{-\varepsilon^l}\bar{l}_t\frac{1}{i_t^l(i)} = 0 \qquad \text{(A.2)}$$

$$\begin{aligned}
[l_t(i)]: \quad & i_t^l(i) - \delta_t(i)\frac{rr+c}{1-rr}f\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}\cdot l_t(i)\right) \\
& - \lambda_1 - \lambda_5 = 0 \qquad \text{(A.3)}
\end{aligned}$$

$$[q_t(i)]: \quad \bar{i}_t - \lambda_2 - \lambda_5 + \lambda_6 = 0 \qquad \text{(A.4)}$$

$$[i_t^s(i)]: \quad s_t(i) - \lambda_3\varepsilon^s\left(\frac{i_t^s(i)}{\bar{i}_t^s}\right)^{-\varepsilon^s}\bar{s}_t\frac{1}{i_t^s(i)} = 0 \qquad \text{(A.5)}$$

$$\begin{aligned}
[s_t(i)]: \quad & i_t^s(i) + \delta_t(i)f\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}\cdot l_t(i)\right) \\
& - \lambda_3 - \lambda_5 = 0 \qquad \text{(A.6)}
\end{aligned}$$

$$\left[i_t^d(i)\right]: \quad -d_t(i) + \lambda_4 = 0 \qquad \text{(A.7)}$$

[31] To make notation easier, each Lagrange multiplier λ means a multiplier at time t.

[32] By combining the constraints (ii), (v), and (vi) and using the definition of cumulative distribution function (CDF), we can write $Prob(r_t(i) > s_t(i)) = Prob\left(\hat{e}_t > \bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}l_t(i)\right) = 1 - \Phi\left(\bar{r_t}^{fx} + s_t(i) - \frac{rr+c}{1-rr}l_t(i)\right)$.

$$[d_t(i)]: \quad -i_t^d(i) + \lambda_2 rr + \lambda_5 + \lambda_6 \cdot c = 0 \tag{A.8}$$

$$[r_t(i)]: \quad -\bar{i_t} + \lambda_5 - \lambda_6 = 0 \tag{A.9}$$

$$\lambda_1 \left(l_t(i) - \left(\frac{i_t^l(i)}{\bar{i}_t^{\,l}} \right)^{-\varepsilon^l} \bar{l_t} \right) = 0 \tag{A.10}$$

$$\lambda_3 \left(s_t(i) - \left(\frac{i_t^s(i)}{\bar{i}_t^s} \right)^{-\varepsilon^s} \bar{s_t} \right) = 0 \tag{A.11}$$

$$\lambda_4 \left(i_t^d(i) - \frac{\varepsilon^d - 1}{\varepsilon^d} \bar{i_t} \right) = 0. \tag{A.12}$$

And, $\lambda_1 \geq 0$, $\lambda_3 \geq 0$, $\lambda_4 \geq 0$.

Note that constraints (i), (iii), and (iv) should be binding; otherwise, $\lambda_1 = 0$, $\lambda_3 = 0$, and $\lambda_4 = 0$ to satisfy first-order conditions. With that, (A.2), (A.5), and (A.7) imply $l_t(i) = 0$, $s_t(i) = 0$, and $d_t(i) = 0$, which we exclude as possibilities in our model and set $\lambda_1 > 0$, $\lambda_3 > 0$, and $\lambda_4 > 0$. Therefore, constraints (i), (iii), and (iv) become automatically binding.

From Equation (A.2):

$$\lambda_1 = \frac{1}{\varepsilon^l} i_t^l(i). \tag{A.13}$$

Equation (A.13) together with (A.3) implies

$$i_t^l(i) = \frac{\varepsilon^l}{\varepsilon^l - 1} \left(\lambda_5 + \frac{rr + c}{1 - rr} \delta_t(i) f \left(\bar{r_t}^{fx} + s_t(i) - \frac{rr + c}{1 - rr} \cdot l_t(i) \right) \right). \tag{A.14}$$

By combining (A.4) and (A.8) we get

$$\lambda_5 = \frac{1}{1 + c} i_t{}^d(i) + \frac{c}{1 + c} \bar{i_t} - \frac{c + rr}{1 + c} \lambda_2 \tag{A.15}$$

and

$$\lambda_6 = \frac{1}{1 + c} (i_t{}^d(i) - \bar{i_t}) + \frac{1 - rr}{1 + c} \lambda_2. \tag{A.16}$$

Putting (A.15) and (A.16) in Equation (A.9) implies that $\lambda_2 = 0$. Then by combining Equations (A.14) and (A.15), we get the optimality condition for the lending rate given by the equation shown in the main text. The same steps can be applied to derive the equilibrium yield on bonds.

Appendix B. Data and Robustness Checks

Figure B.1. Control Variables

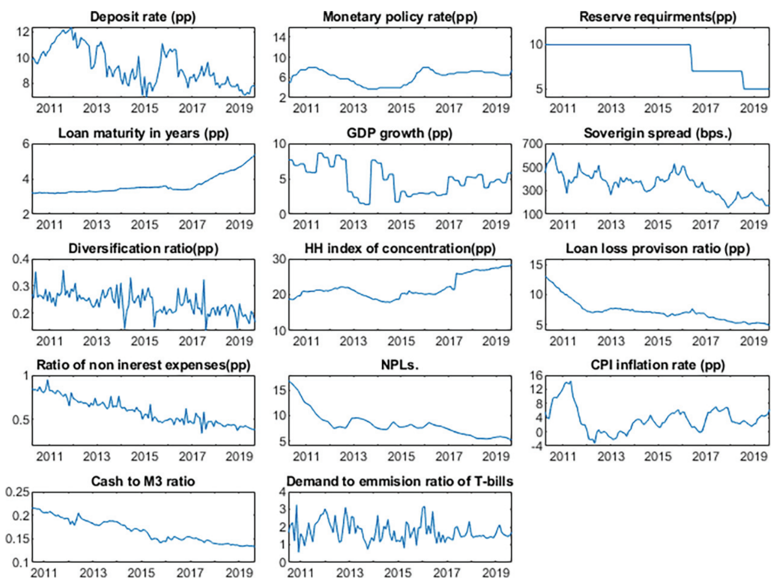


Figure B.2. Lending, T-bill, and Interbank Rates

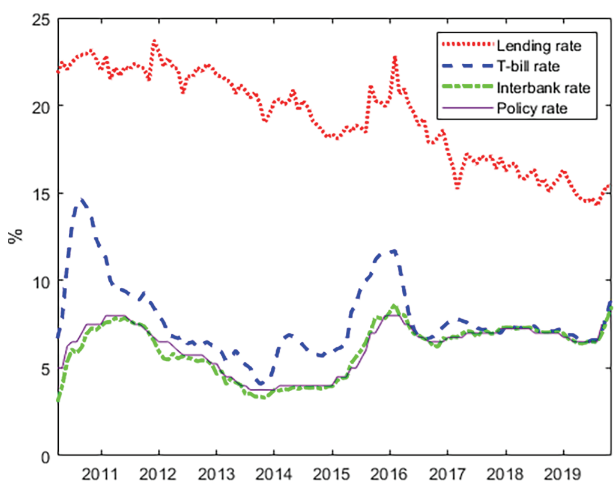
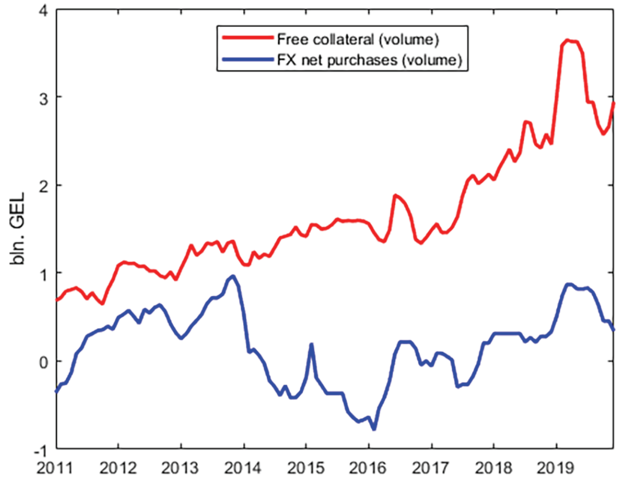


Figure B.3. Amount of Free Collateral and FX Net Purchases[33]



[33]The volume of net FX purchases over a 12-month rolling window, as interventions would have a cumulative effect on the amount of free collateral.

Table B.1. Alternative Specifications and Extensions

	Specification 1A	Specification 1B	Specification 3	Specification 4
Lending Rate(–1)	0.402***	0.456***		
Lending Rate(–2)	0.158**			
Lending Rate(–3)	−0.098			
Lending Rate(–4)	0.257***			
Lending Rate(–12)	−0.258***	−0.197***		
Interbank Rate(–1)			0.525***	
T-bills Rate(–1)				1.080***
T-bills Rate(–2)				−0.313***
Refinancing-Loans-to-Collateral Ratio(–1)		0.155**		
Free-Collateral-to-Loan Ratio(–1)	−1.274***		−0.36**	
Free-Collateral-to-Loan Ratio(–3)				0.441**
Policy Rate(–1)	0.033	0.069	0.522***	0.540***
Policy Rate(–2)			0.308*	0.249
Policy Rate(–3)			−0.354***	−0.489*
Policy Rate(–4)				0.211
Deposit Rate	0.154**	0.203***		−0.310
Reserve Requirement			0.017	
d(maturity)	2.809	0.803		
d(maturity(–1))	−4.901*	−4.151*		
Loan Loss Provision Ratio	−0.344***	−0.155*		
Diversification	−4.171***	−2.559*		
Non-interest Expense Ratio	1.873			
d(HH Index)	0.143	0.206***		
GDP Growth	−0.111***	−0.118***	−0.007	−0.063**
GDP Growth(–1)				0.041
Sovereign Risk Premium	0.356***	0.432***	0.014	0.140**
Cash-to-M3 Ratio	0.266**	−0.043	−1.418	
Cash-to-M3 Ratio(–1)		0.119		
T-bills Demand				−0.142
Inflation				0.042
Inflation(–1)				−0.044
Time Dummy		−1.971***	0.034	
Trend	−0.022	−0.026**	−0.001	
Constant	5.072	13.494***	−0.361	1.305***

Note: *≡ 0.05 ≤ P-value < 0.1; **≡ 0.01 ≤ P-value < 0.05; ***≡ P-value < 0.01. Definitions: Specification 1A is Specification 1 extended with cash-to-M3 ratio as an additional control variable; Specification 1B applies refinancing loans to collateral as a measure of the collateral constraint. Specification 3 is the model where dependent variable is interbank rate, and Specification 4 estimates an effect of collateral constraint on T-bills rates. In addition to control variables defined in the main text, here are some additional variables to mention: Cash to M3 is the ratio of the cash outside of banks to M3 money aggregate; also, T-bills demand is the ratio of demand on T-bills and notes to the issuance volume (sum of the issuance volume and demand in a given month is used in the calculation of the ratio).

Appendix C. Key Model Assumptions

Here we summarize all key modeling assumptions.

General Assumptions of the Model:

- Monopolistic competitive market structure of banking sector with (infinitely) many banks.
- Banks are making decisions on the allocation of resources at the beginning of the period to maximize profits at the end of that period.
- Three possible time instances: t, t', and $t+1$. In time instant t, banks are making decisions on how to plan their business while in t' depositors are deciding how much cash to withdraw from banks and, therefore, banks have to decide how much refinance loans they need from the central bank. We assume that time instances t and t' are practically the same.
- No term premium, as we discuss only one time period.
- Banks are risk neutral.
- Model variables follow a balanced-growth path (trend).
- Liquidity shock is assumed to be (trend) stationary.

Loan Market and Central Bank Framework:

- CES-type demand schedule for loans, where aggregate demand on loans is exogenously given.
- Interest rate accrued on refinancing loans equals the policy rate $(\bar{i_t})$.
- Reserve balances, which are required, are remunerated with the policy rate $(\bar{i_t})$ by the central bank.
- Excess reserves are remunerated at zero.
- Reserve requirements are assumed to be in the interval $0 \leq rr < 1$.

FXI and Bond/Deposit Markets:

- Each FX intervention is equally distributed across banks over the interval [0,1].
- Monopolistic competitive banks are the only primary dealers on the government securities market.

- CES-type demand schedule for bonds, where aggregate demand for bonds is exogenously given. For further discussion, see footnote 5 in Section 3.1.1.
- Banks have closed FX position.
- Deposit demand restricts banks from setting interest rates below the policy rate by more than a markdown $\frac{\varepsilon^d - 1}{\varepsilon^d}$.

References

Abildgren, K. 2005. "Sterilised and Non-Sterilised Intervention in the Foreign-Exchange Market." *Monetary Review* (Danmarks Nationalbank) (1st Quarter): 61–71.

Adrian, T., C. Erceg, J. Lindé, P. Zabczyk, and J. Zhou. 2020. "A Quantitative Model for the Integrated Policy Framework." Working Paper No. 20/122, International Monetary Fund.

Almarzoqi, R., and S. Ben Naceur. 2015. "Determinants of Bank Interest Margins in the Caucasus and Central Asia." Working Paper No. 15/87, International Monetary Fund.

Backus, D. K., and P. J. Kehoe. 1989. "On the Denomination of Government Debt: A Critique of the Portfolio Balance Approach." *Journal of Monetary Economics* 23 (3): 359–76.

Bank for International Settlements. 2019. "Annual Economic Report 2019."

Basu, S. S., E. Boz, G. Gopinath, F. Roch, and F. D. Unsal. 2020. "A Conceptual Model for the Integrated Policy Framework." Working Paper No. 20/121, International Monetary Fund.

Benes, J., A. Berg, R. A. Portillo, and D. Vavra. 2013. "Modeling Sterilized Interventions and Balance Sheet Effects of Monetary Policy in a New-Keynesian Framework." Working Paper No. 13/11, International Monetary Fund.

Bernanke, B. S., and A. S. Blinder. 1988. "Credit, Money, and Aggregate Demand." *American Economic Review* 78 (2): 435–39.

Branson, W. H., and D. W. Henderson. 1985. "The Specification and Influence of Asset Markets." In *Handbook of International Economics*, Vol. 2, ed. R. W. Jones and P. B. Kenen, 749–805. North-Holland.

Bruno, V., and H. S. Shin. 2015. "Capital Flows and the Risk-taking Channel of Monetary Policy." *Journal of Monetary Economics* 71 (April): 119–32.

Caballero, R., and E. Farhi. 2018. "The Safety Trap." *Review of Economic Studies* 85 (1): 223–74.

Cesa-Bianchi, A., M. Kumhof, A. Sokol, and G. Thwaites. 2019. "Towards a New Monetary Theory of Exchange Rate Determination." Staff Working Paper No. 817, Bank of England.

Céspedes, L. F., R. Chang, and A. Velasco. 2017. "Financial Intermediation, Real Exchange Rates, and Unconventional Policies in an Open Economy." *Journal of International Economics* 108 (Supplement 1): S76–S86.

Chang, R. 2018. "Foreign Exchange Intervention Redux." Working Paper No. 24463, National Bureau of Economic Research.

Christiano, L., R. Motto, and M. Rostagno. 2010. "Financial Factors in Economic Fluctuations." Working Paper No. 1192, European Central Bank.

De Fiore, F., M. Hoerova, and H. Uhlig. 2019. "Money Markets, Collateral and Monetary Policy." Working Paper No. 2239, European Central Bank.

Fernández-Villaverde, J., J. F. Rubio-Ramírez, and F. Schorfheide. 2016. "Solution and Estimation Methods for DSGE Models." In *Handbook of Macroeconomics*, Vol. 2, ed. J. B. Taylor and H. Uhlig, 527–724 (Chapter 9). Elsevier.

Gadanecz, B., A. Mehrotra, and M. S. Mohanty. 2014. "Foreign Exchange Intervention and the Banking System Balance Sheet in Emerging Market Economies." Working Paper No. 445, Bank for International Settlements.

Gorton, G. B., and T. Laarits. 2018. "Collateral Damage." Working Paper No. 24298, National Bureau of Economic Research.

Ho, T. S., and A. Saunders. 1981. "The Determinants of Bank Interest Margins: Theory and Empirical Evidence." *Journal of Financial and Quantitative Analysis* 16 (4): 581–600.

Hofmann, B., and H. S. Shin. 2019. "FX Intervention and Domestic Credit: Evidence from High-frequency Micro Data." Working Paper No. 774, Bank for International Settlements.

International Monetary Fund. 2020. "Global Financial Stability Report Update 2020."

Jakab, Z., and M. Kumhof. 2019. "Banks are Not Intermediaries of Loanable Funds—Facts, Theory and Evidence." Staff Working Paper No. 761, Bank of England.

Kashyap, A. K., and J. C. Stein. 1997. "The Role of Banks in Monetary Policy: A Survey with Implications for the European Monetary Union." *Economic Perspectives* (Federal Reserve Bank of Chicago) 21 (3): 2–18.

———. 2000. "What Do a Million Observations on Banks Say about the Transmission of Monetary Policy?" *American Economic Review* 90 (3): 407–28.

Kumhof, M. M., and S. van Nieuwerburgh. 2002. "A Fiscal Theory of the Currency Risk Premium and of Sterilized Intervention." Working Paper No. 02/29, International Monetary Fund.

Mishkin, F. 2001. "Financial Policies and the Prevention of Financial Crises in Emerging Market Countries." Working Paper No. 8087, National Bureau of Economic Research.

Mkhatrishvili, S., D. Laxton, D. Tutberidze, T. Sopromadze, S. Metreveli, L. Arevadze, T. Mdivnishvili, and G. Tsutskiridze. 2019. "Solving Non-linear Dynamic Models (More) Efficiently: Application to a Simple Monetary Policy Model." Working Paper No. 01/2019, National Bank of Georgia.

Saunders, A., and L. Schumacher. 2000. "The Determinants of Bank Interest Rate Margins: An International Study." *Journal of International Money and Finance* 19 (6): 813–32.

Vargas, H., A. González, and D. Rodríguez. 2013. "Foreign Exchange Intervention in Colombia." BIS Papers No. 73.