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FX intervention and domestic credit: evidence from high-frequency micro data*

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Abstract

We employ a rarely available high-frequency micro dataset to study the impact of foreign exchange intervention on domestic credit growth. We find that sterilised purchases of dollars by the central bank dampens the flow of new domestic corporate loans in Colombia. Slowing the pace of currency appreciation plays a key role in dampening credit expansion. Our analysis sheds light on the role of FX intervention as part of the financial stability-oriented policy response to credit booms associated with capital inflow surges.

JEL codes: E58, F31, F33, F41, G20

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1 Introduction

There is something of a divide between the theory and practice on the role of exchange rate intervention in the central bank's toolkit. Workhorse open economy macro models used at central banks tend to downplay the role of the exchange rate. The maxim is that central banks should pay attention to exchange rates only to the extent that they bear on inflation and output developments. This stance accords with the long-standing view that sterilised foreign exchange (FX) intervention, i.e. official purchases or sales of foreign currency that leave the money supply unaffected, has little effect on the exchange rate (see, for instance, the survey in Sarno and Taylor (2001)).

However, the doctrine of "benign neglect" of the exchange rate has been honoured more in its breach than in its observance (see Frankel (2017)). Many central banks around the world have engaged in FX intervention, especially those in emerging market economies (EMEs) who have experienced rapid domestic credit growth that has accompanied surges in capital inflows (Ghosh et al (2018)). While individual country studies report mixed results on the effectiveness of sterilised FX intervention, cross-country studies generally find some effectiveness in curbing financial conditions and exchange rate dynamics (Ghosh et al (2018), Villamizar-Villegas and Perez-Reyna (2017), Fratzscher et al (2018)). Recent empirical findings have shed some light on how FX intervention shapes the impact of capital flows on domestic financial conditions. Blanchard et al. (2015) show that capital flow shocks have significantly smaller repercussions on exchange rates and capital accounts in countries that regularly intervene in FX markets.

Our paper aims to deepen our understanding of how FX intervention affects credit growth, and to shed light on the possible mechanisms at play. Conceptually, an important element of our analysis is the role of financial intermediaries in a setting where risk constraints interact with market outcomes, thereby tying together prices and balance sheet quantities. Gabaix and Maggiori (2015) popularised an approach to exchange rate determination in this vein with risk-constrained intermediaries, and we build on their insights here. Additionally, recent contributions have shed light on the role of the exchange rate in credit developments. Diamond, Hu and Rajan (2018) build on corporate finance models on how collateral values and liquidity interact in influencing leverage, and show how currency appreciation elicits similar effects in an open economy setting. They argue that FX intervention has attributes of a prudential tool that leans against credit booms.

Bruno and Shin (2015) focus on the lending capacity of banks that are subject to risk constraints. Currency appreciation reduces tail risks when banks have diversified loan portfolios, thereby increasing loan supply. FX intervention can lean against this process.

We employ a rarely available high-frequency central bank database of FX operations by the Bank of the Republic (BoR), Colombia, and combine it with detailed bank-by-bank daily flow data on new loans to corporates covering the entire Colombian banking system. Our sample covers the period 2002 to 2015. The high frequency nature of the data coupled with the panel structure of the entire credit registry facilitates a rigorous study of the effects of FX intervention on domestic credit. To our knowledge, our paper is the first to draw on such a database for the analysis of the financial stability implications of sterilised FX intervention.

We hone intuition through a model with a banking sector where the exchange rate affects the supply of local currency domestic credit to corporate borrowers. The key prediction of the model is that the purchase of dollars by the central bank financed by the sale of domestic bonds dampens bank credit supply in domestic currency. The channel is through the interaction of balance sheet effects on corporates and the banking sector. When borrowing firms have dollar debts, an appreciation of the currency reduces tail risk for a bank with a diversified loan portfolio. When lending follows a Value-at-Risk (VaR) rule, currency appreciation results in increased loan supply.[1]

Sterilised FX intervention then has two mutually reinforcing effects. The first is to lean against the increase in bank lending capacity due to the effects of currency appreciation operating through the risk-taking channel of the exchange rate. The second effect is the "crowding out" of bank lending capacity by increasing the supply of domestic bonds to be absorbed by banks. The overall quantitative impact of the central bank's FX intervention results from the combination of these two effects.

The core of our paper is the empirical investigation, where we test the key predictions of the model. We report four key findings, obtained based on high-frequency panel local linear projection (LLP) regressions in the spirit of Jordà (2005).

First, we find that sterilised FX purchases have a significant and persistent dampening effect on new domestic bank lending. This is the core result of our analysis.

Second, sterilised FX purchases depreciate the domestic currency and reduce capi-

[1]For a review of the early literature on exchange rate effects working through liability dollarisation of borrower balance sheets, see Frankel (2005).

tal inflows in a significant and persistent manner. This result supports the idea that intervention is transmitted through an exchange rate risk-taking channel.

Third, central bank open market operations (OMOs), even those unrelated to FX intervention, also reduce domestic lending. This finding is consistent with a "crowding out" channel being at work. However, the estimated effect is much smaller than that of the sterilised FX intervention operation, highlighting the importance of the exchange rate channel in the transmission of intervention. Moreover, closer inspection reveals that only OMOs in bonds have a significant impact on lending, not short-term repos.

Fourth, we find that, in the cross-section of banks, the credit-dampening effects of sterilised FX purchases are stronger for banks whose balance sheet constraints bind harder, e.g. due to low capitalisation or high leverage. Weaker banks therefore appear to be more sensitive to the tightening effect on financial conditions of the intervention, a result that echoes the findings established in the literature on the bank lending channel of monetary transmission.

Taken together, our results lend support to the proposition that sterilised intervention can lean against credit growth during periods of sustained capital inflows accompanied by currency appreciation.

The "crowding out" channel of FX intervention has been much discussed in policy circles. When the balance sheet capacity of banks is limited due to capital or leverage constraints, an increase in the supply of bonds to banks through the sterilisation leg of an FX intervention reduces their capacity to extend loans. Céspedes et al. (2017) and Chang (2018) have developed models in this spirit, although the economic impact of crowding out will depend on how far banks can offset the balance sheet constraints.[2] Ghosh et al (2018) explain that "by undertaking sterilized intervention the central bank can absorb... [capital] inflow[s] (parking it in FX reserves)". Cook and Yetman (2012) report similar evidence based on individual bank data for emerging Asian banks. They find that an increase in FX reserves is associated with significantly lower bank loan growth, which they interpret as reflecting a crowding out of loans through reserve accumulation.[3]

In contrast, our paper places at the centre of the analysis the exchange rate itself. FX intervention moderates the appreciation of the domestic currency and thereby leans against the relaxation of the Value-at-Risk constraint and hence the expansion of the

[2]See Benes et al. (2013), Vargas Herrera (2013) and Garcia (2016).

[3]Gadanecs et al (2014), by contrast, find that increases in banks' holdings of liquid central bank securities increases lending of well capitalised banks in a panel of EMEs, with a lag of two years.

lending capacity of the banking sector.

Our paper adds to the literature on financial frictions and capital flows (see, for instance, Cavallino (2018), Amador et al ((2017), and Fanelli and Straub (2017)) and engages with the debate on the co-movement of financial conditions across markets and the associated policy challenges. Rey (2013) argued that economies may not face a trilemma (incompatibility of fixed exchange rate, open capital account and independent monetary policy), but instead may face a dilemma between free capital flows and independent monetary policy. This discussion bears on the design of monetary policy frameworks in emerging market economies (Ghosh et al (2018), Agénor and Pereira da Silva (2019)). Our contribution to this debate is to highlight the link between exchange rates and credit conditions, so that FX intervention takes on attributes of a financial stability tool that can complement monetary policy in macro stabilisation. The building of buffers also bear on the question of central bank liquidity provision during stressed periods. Barbone Gonzales et al (2018), find that the Central Bank of Brazil's intervention in FX derivatives markets during the 2013 taper tantrum mitigated the impact of currency depreciation on domestic credit supply in Brazil.

The remainder of the paper is organised as follows. Section 2 develops the theoretical model and derives its main predictions for the impact of sterilised FX intervention on domestic lending. Section 3 describes the data and the Colombian institutional background. Section 4 presents evidence on the dynamic impact of FX intervention and the channels through which it operates. Finally, section 5 concludes.

2 Model

The model builds on the banking model of Bruno and Shin (2015) to incorporate the portfolio allocation problem between loans and sovereign bonds, so as to study the impact of sterilised FX intervention that has both exchange rate and bond supply effects. We begin with the determination of the loan book.

2.1 Loan demand

There is a continuum of risk-neutral borrowers ("entrepreneurs") with access to a project that needs one unit of fixed capital and one unit of labour input. Entrepreneurs borrow 1 unit of the domestic currency ("peso") from banks to finance the initial fixed investment.

Loans are granted at date 0, and the project realisation and repayment is due at date 1. The loan interest rate is r, so that borrowers need to repay $1 + r$. The disutility of the entrepreneur's labour input is distributed in the population according to cumulative distribution function $H(.)$ with support on $[0, \infty)$.

We assume that borrowers have a legacy debt of 1 dollar, and experience valuation effects of exchange rate movements. Denote by θ the dollar value of the peso at date 0, so that a higher θ indicates a stronger peso. If the borrower takes on the project, the notional value of debt in pesos is thus $1 + 1/\theta$.

The realisation of the borrower's project follows the Merton (1974) model of credit risk, and is assumed to be the random variable V_1, defined as:

$$V_1 = \exp\left\{1 - \frac{s^2}{2} + sW_j\right\} \tag{1}$$

where W_j is a standard normal and s is a constant. Borrowers are risk-neutral and have limited liability. Hence, borrower j with effort cost e_j undertakes the project if:

$$E\left(\max\{0, V_1 - (1 + r)\}\right) - e_j \geq 0 \tag{2}$$

Denote by $e^*(r)$ the threshold cost level where (2) holds with equality when the loan rate is r. Loan demand is the mass of entrepreneurs with effort cost below $e^*(r)$. Denoting by $C_d(r)$ the loan demand at loan interest rate r, we have:

$$C_d(r) = H(e^*(r)) \tag{3}$$

Since $H(\cdot)$ has full support on $[0, \infty)$, $C_d(r) > 0$ for all $r > 0$ and is strictly decreasing in r.

2.2 Banks

There is a continuum of competitive banks. Each bank has two units - a loan unit which lends in pesos to corporate borrowers, and a bond unit which holds risk-free peso sovereign bonds. The bank allocates equity capital to the two units so as to maximise total bank profit subject to constraints on the portfolio choice of the two units, as described below.

For the loan book, the bank lends to many borrowers and can diversify away idiosyncratic risk. Credit risk follows the Vasicek (2002) model, a many borrower generalisation of Merton (1974). The standard normal W_j in (1) is given by the linear combination:

$$W_j = \sqrt{\rho}Y + \sqrt{1-\rho}X_j \tag{4}$$

where Y and X_j are mutually independent standard normals. Y is the common risk factor while each X_j is the idiosyncratic risk facing borrower j. The parameter $\rho \in (0, 1)$ determines the weight given to the common factor Y.

The borrower defaults when $V_1 < 1 + r + 1/\theta$, which can be written as:

$$\sqrt{\rho}Y + \sqrt{1-\rho}X_j < -d_j \tag{5}$$

where d_j is *distance to default:*

$$d_j = \frac{-\ln\left(1 + r + 1/\theta\right) + 1 - \frac{s^2}{2}}{s} \tag{6}$$

Denote by $F_\theta\left(z\right)$ the cumulative distribution function (c.d.f.) of the realised value of one peso face value of loans when the exchange rate is given by θ. We have the following key feature of our model.

Lemma 1 $F_\theta\left(z\right) < F_{\theta'}\left(z\right)$ *if and only if* $\theta > \theta'$.

In other words, the c.d.f. of the bank's loan portfolio is lower when the peso is stronger. In this sense, the tail risk of the bank's loan portfolio from default declines as the peso appreciates in the sense of first-degree stochastic dominance. The proof of Lemma 1 follows Bruno and Shin (2015) and is given in the appendix.

The intuition behind Lemma 1 is that the bank can diversify away idiosyncratic default risk for individual borrowers, but cannot fully diversify away the tail risk due to the common component Y in the project outcomes. However, peso appreciation reduces individual borrower default, and has the effect of reducing tail risk. For a bank that is subject to a Value-at-Risk constraint, the smaller tail risk translates to higher lending.

2.3 Bank portfolio choice

Each bank has two units - a loan unit and a bond unit. The total capital of the bank i (its book equity) in pesos is denoted by E_i. The bond unit is allocated capital of E_i^B, while the loan unit is allocated capital of E_i^C, where "C" stands for "credit". The capital allocation satisfies:

$$E_i^B + E_i^C = E_i \tag{7}$$

The loan unit is subject to the Value-at-Risk (VaR) rule whereby the probability that loan losses exceed the capital of the unit is no higher than constant probability

$\alpha > 0$. Denote by f the funding rate of the loan unit and by L_i the total non-equity funding amount of the loan unit. We assume for simplicity that f is constant.[4] The VaR constraint is that the realised value of the loan portfolio is sufficient to cover the repayment owed by the loan unit with probability at least $1 - \alpha$. Formally, the VaR constraint is given by:

$$F\left(\left(1+f\right)L_i\right) \leq \alpha \tag{8}$$

where $F\left(.\right)$ is the c.d.f. of the loan portfolio value. We then have the following feature of our model.

Lemma 2 *Total lending C_i by bank i satisfies $C_i = \lambda E_i^C$ where λ is an increasing function of θ, and is identical across all i.*

In other words, the leverage of the loan unit increases when the peso appreciates. For any given level of capital E_i^C, an appreciation of the peso translates into an increase in total lending C_i. The proof of Lemma 2 is in the appendix.

The intuition for this result follows from the link between tail risk and the exchange rate described in Lemma 1. First, risk-neutrality implies that (8) binds, and holds as an equality. When the peso appreciates, the tail risk of the loan portfolio shrinks. For the loan unit which is subject only to the VaR constraint, peso appreciation relaxes the constraint and allows it to expand lending.

We now turn to the bank's bond unit. Denote by B_i the peso bond holding of bank i. Further, denote by q the bond interest rate and g the (constant) funding cost of the bond unit. We assume that the bond holding of the bank is determined as a constant leverage multiple μ of the capital allocated to the bond unit of the bank. From the adding up constraint (7), the capital of the bond unit is given by $E_i^B = E_i - E_i^C$, so that the bond holding is:

$$B_i = \mu\left(E_i - E_i^C\right) \tag{9}$$

The aggregate supply of peso lending is obtained by summing C_i across all banks i. Denoting by C the aggregate peso loan supply, we have:

$$C = E^C \cdot \lambda\left(\theta\right) \tag{10}$$

[4]Bruno and Shin (2015) solve for the general case where f is endogenously determined by market clearing of wholesale bank funding.

where E^C is the sum of E_i^C across the banking sector, and where we have indicated that leverage λ is a function of the peso exchange rate.

Aggregate bond holding by all banks i is denoted as B, and is obtained by summing (9) across all banks:

$$B = \mu \left(E - E^C \right) \tag{11}$$

From (10) and (11), the supply of credit for loans and bond holdings satisfies constant returns to scale. Therefore, it is without loss of generality to suppose that there is a single price-taking bank with capital E that is allocated across the two activities.

Let $\bar{B}$ denote the stock of outstanding peso bonds, and assume that the total stock is held by the banking sector, as is often the case in practice for central bank sterilisation bonds. The market clearing condition is that $B = \bar{B}$.

2.4 Impact of currency appreciation

One key result of our model is that peso appreciation increases the supply of peso lending by banks.

Proposition 3 *Bank lending to domestic borrowers in pesos expands when the peso appreciates against the dollar.*

Proof. From (25), we have:

$$\begin{aligned} C &= E^C \cdot \lambda(\theta) \\ &= \left(E - E^B \right) \cdot \lambda(\theta) \\ &= \left(E - \bar{B}/\mu \right) \cdot \lambda(\theta) \end{aligned} \tag{12}$$

Since leverage $\lambda(\theta)$ is an increasing function of θ, equation (12) implies that a peso appreciation increases the overall bank lending to local borrowers. ■

Sterilised FX intervention that weakens the peso dampens domestic credit by lowering $\lambda(\theta)$. Equation (12) further implies that when the outstanding amount of peso bonds $\bar{B}$ increases, there is a "crowding out" effect on domestic loans. Other things equal, an increase in $\bar{B}$ is associated with a decline in lending to domestic corporates. The increased supply of bonds entails a greater amount of bank capital devoted to the bond portfolio, with less bank capital devoted to the loan portfolio. Thus, the sterilisation leg of the FX intervention has an additional and independent negative effect on domestic credit.

Another feature of our model is on the complementarity of peso depreciation and increased bond supply in dampening domestic lending. From (12), when the peso depreciates against the dollar, the leverage of the loan unit decreases. Hence, when the increase in $\bar{B}$ is accompanied by a peso depreciation, the crowding out effect on domestic lending is magnified by the exchange rate change.

Formally, from (12), we have:

$$\frac{dC}{d\theta} = \left(E - \bar{B}/\mu\right)\lambda'(\theta)$$

Hence the cross derivative is:

$$\frac{dC^2}{d\theta d\bar{B}} = -\frac{\bar{B}\lambda'(\theta)}{\mu} < 0 \tag{13}$$

We summarise our findings as follows.

Proposition 4 *An increase in the stock of peso bonds reduces lending. This reduction is larger if the increased stock of peso bonds is accompanied by a depreciation of the peso against the dollar.*

3 Data and institutional background

In the empirical analysis, we make use of high-frequency data for Colombia, available for the period 2002 to 2015. Specifically, we use daily data for new corporate loans of the entire Colombian banking sector. Moreover, we use daily data on foreign exchange intervention and sterilisation operations by the Bank of the Republic (BoR). The high frequency nature of the data coupled with the panel structure of the entire credit registry facilitates identifying and hence exploring more rigorously the effects of FX intervention on domestic financial conditions.

3.1 Credit registry

Daily bank-level data for new corporate loans come from the Colombian Financial Superintendency (*Superintendencia Financiera de Colombia*). The credit registry provides information on the amount disbursed for each new loan as well as the issuance date, maturity, interest rate, type of collateral, risk rating, and non-performing days (when

	Loan amount	Interest rate	Loan maturity
Mean	17.99	13.61	2.18
Std.Dev	45.95	6.47	2.71
Median	3.43	11.93	1.56
Quartile 25%	0.5	8.91	0.79
Quartile 75%	15.47	15.9	2.78
Observations	36,974	36,974	36,974
Between	38	38	38
Within	973	973	973

Table 1. **Credit registry statistics (2002-2015).** Authors' calculations. Units are in billions of pesos for loan amount, percentage for interest rate, and years for maturity.

applicable). Information on credit flows (i.e. new loans), as opposed to credit stocks, allows for a clearer identification of causal effects by filtering out pre-existing loans that would not be expected to react.

From January 2002 until December 2015 there were a total of 37,000 new loans extended to corporates by 38 commercial banks. Table 1 provides some summary statistics of these new corporate loans. The mean loan amount disbursed was 18 billion pesos, but with a rather large standard deviation (second column). The median loan amount was considerably lower, at 3.5 billion pesos. The average interest rate of the new loans was 13.6% with less variation compared to the loan amount (third column). The median interest rate amounted to 11.93%. The maturity of the new loans was rather short, with an average of just more than two years (fourth column).

Figure 1 shows the daily time series of new corporate loans for the total of all commercial banks (upper left-hand panel) as well as for five selected banks. The chart reveals that the flow of new loans was trending up over the sample period. To eliminate non-stationarity, we normalise in the analysis the (cumulative) flows of new loans by the outstanding stock of loans in the preceding period.

3.2 FX intervention

Data for sterilised FX intervention are from the BoR's Market Operations and Development Department (*Departamento de Operaciones y Desarrollo de Mercados -Mesa de Dinero*). Specifically, we use data on daily intervention flows, which are not affected by valuation changes of FX reserves due to exchange rate changes. The BoR, as an inflation targeter, never targeted a specific level of the exchange rate, but instead aimed to reduce

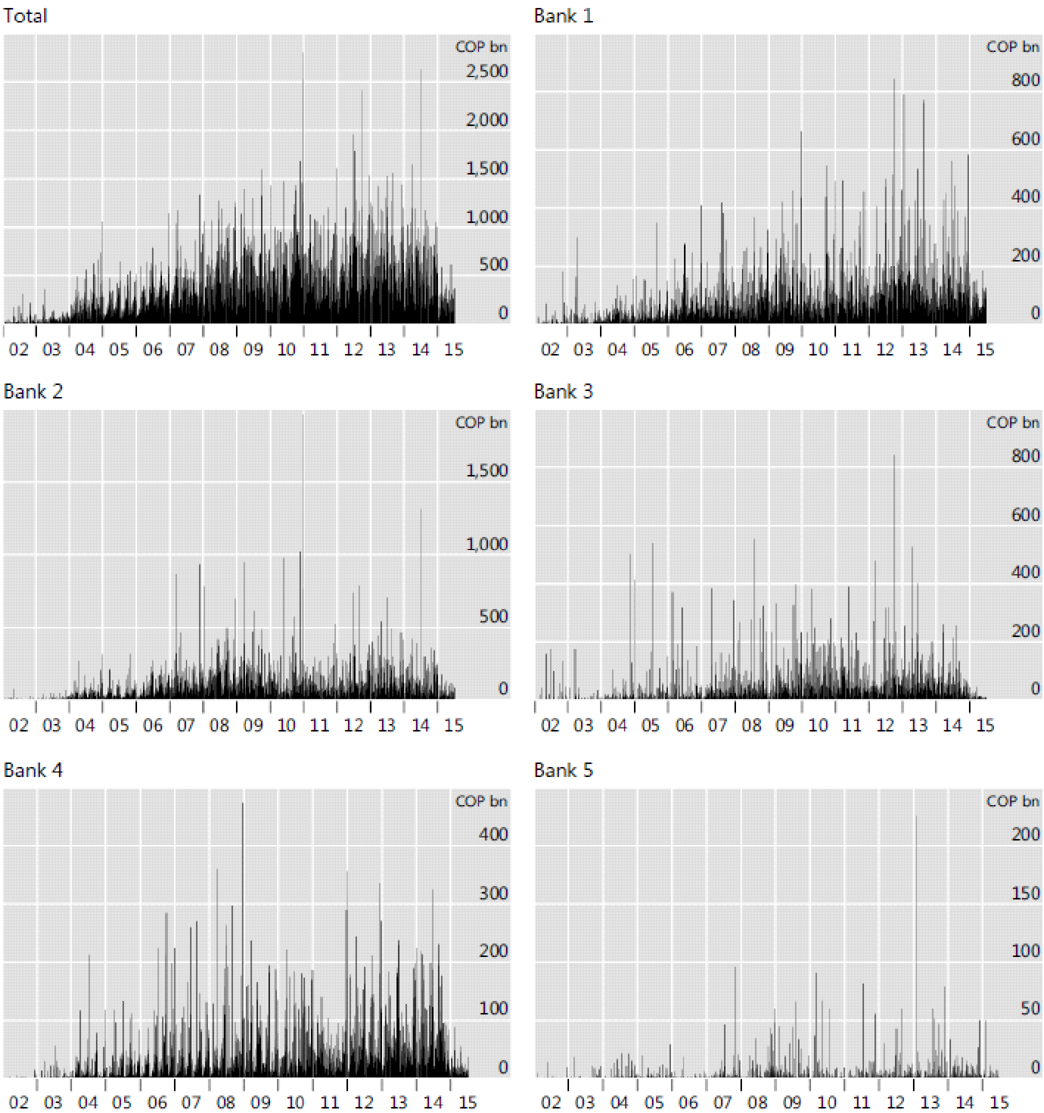

Figure 1. **New loans to Colombian corporates.** This figure shows the time series of the flow of new corporate loans at the daily frequency. The upper left panel shows the total across all commercial banks. The other panels show the flow of new loans at five selected banks (anonymised).

exchange rate volatility or to accumulate international reserves. Figure 2 shows that BoR conducted various types of FX intervention, Table 2 presents descriptive statistics.[5]

We distinguish four different intervention methods:

- Pre-announced FX interventions: Constant and pre-announced sterilised purchases of foreign currency intended to accumulate international reserves. Through these operations, the central bank purchased a total of \$23.9 billion dollars over the sample period.

- Discretionary spot market interventions: Sterilised FX interventions conducted in the centralised Colombian FX market (*ICAP-SETFX*) in order to avoid excessive exchange rate movements. Over time, the BoR purchased a total of \$11.7 billion dollars with these interventions.

- Rule-based options interventions: Operations conducted to stem exchange rate volatility, through which the central bank purchased (sold) a total of \$2.4 (\$2.3) billion dollars.

- Discretionary options interventions: Operations conducted to accumulate international reserves in order to reduce external vulnerabilities. Over the period considered, the BoR purchased (sold) a total of \$3.4 (\$0.6) billion dollars.

In total, the BoR purchased \$41 billion dollars in FX reserves, and sold \$3 billion dollars.[6]

Pre-announced daily purchases through FX auctions amounted to more than half of all interventions over the sample period. Due to their pre-announced nature, these interventions were anticipated by markets, which greatly complicates identifying their impact. Given that this type of intervention was concentrated in the period after 2010 (Figure 2), we focus in our empirical exercises on the period of 2002-2010. Over this period, interventions were discretionary, which should better enable identifying their effects on domestic credit, exchange rates and capital flows. We however assess robustness of our results to the use of the full sample of data.

[5] For a detailed review of the different FX intervention approaches employed by the BoR, see Banco de la República (2016).

[6] The asymmetry in purchases versus sales is analysed more in-depth in Villamizar-Villegas (2015).

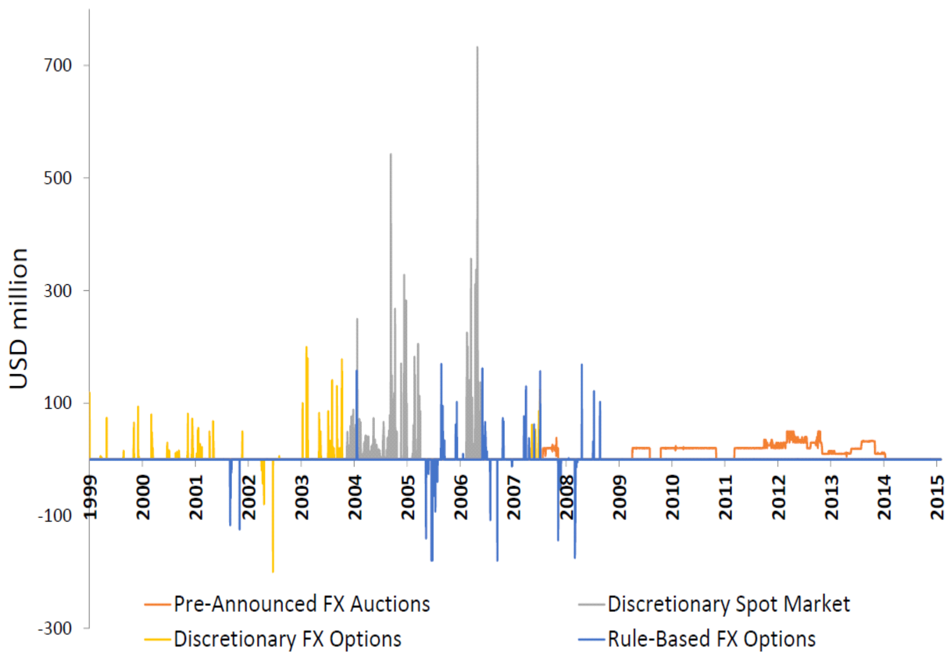

Figure 2. **Sterilised FX intervention in Colombia.**

Type of FX intervention	Total	Intervention days	Mean	Std.Dev	Quartile 25%	Quartile 75%
Pre-Announced auctions						
Purchases	23,867	1,098	21.7	7.94	19.8	24.9
Discretionary spot market						
Purchases	11,708	294	39.8	78.04	2.5	40.6
Rule-based options						
Purchased (exercised)	2,373	41	57.9	51.89	18	77.1
Sales (exercised)	-2,330	34	-68.5	59.74	-117	-16.5
Discretionary options						
Purchased (exercised)	3,355	83	40.4	44.10	10	62
Sales (exercised)	-600	6	-100.0	103.79	-199.9	-20

Table 2. **FX intervention statistics (1999-2015).** Authors' calculations. Units are in million dollars.

3.3 Sterilisation

In the sterilisation leg of the FX intervention, the central bank conducts open market operations (OMOs) in order to sterilise the effects of the intervention on domestic liquidity supply. OMOs adjust the day-to-day money supply in order to meet demand, so that the short-term money market rates are kept close to the policy rate (Borio and Disyatat (2010)). More specifically, the BoR targets the interbank overnight rate, which corresponds to the weighted average rate for all overnight non-collateralised transactions.

The mechanics of the BoR's OMOs work as follows: At the close of a business day, the BoR announces a liquidity quota for the following day at rate i^*, corresponding to the policy rate set by the board of directors. A contractionary (expansionary) auction would take place the following day, if the market had excess (shortage of) liquidity. Ideally, the amount auctioned by the central bank had to match the amount required for the overnight interbank rate to converge to i^*. Thus, the liquidity quota considers changes in the money demand and supply. On the demand side, the staff of the central bank conducts bimonthly forecasts (of the money demand) based on the banking system's reserve requirements as well as seasonal factors (holidays, pay days, etc.). On the supply side, the central bank monitors the issuance of public debt, changes in the monetary base brought forth by FX interventions, and other supply-driven changes such as expiring liquidity operations and government transfers (see Cardozo et al. 2016). Specifically, the central bank sets its OMOs based on the following equation:

$$OMO_t = \underset{(+)}{FXI_t} - \underset{(-)}{Gov_t} - \underset{(-)}{\triangle M_t(i^*)} + Other_t \tag{14}$$

where FXI_t denotes net purchases of foreign currency (expressed in domestic currency), Gov_t is the issuance of public debt, and $\triangle M_t(i^*)$ is the additional change in liquidity so that in equilibrium , the inter-bank rate coincides with the policy rate (i^*). While the central bank does not have a specific rule to determine the type of OMO it employs, it is often the case that large operations, past the threshold of \$10 billion COP, are carried out with government bond trades.

The BoR employs a variety of instruments in order to inject or withdraw liquidity from the financial system through OMOs. Contractionary operations consisted of sales of sovereign bonds in the secondary market (TES) and central bank-owned bonds (TCM)[7]

[7] Central bank-owned bonds (TCM) were implemented in 2013, with shorter maturities than TES.

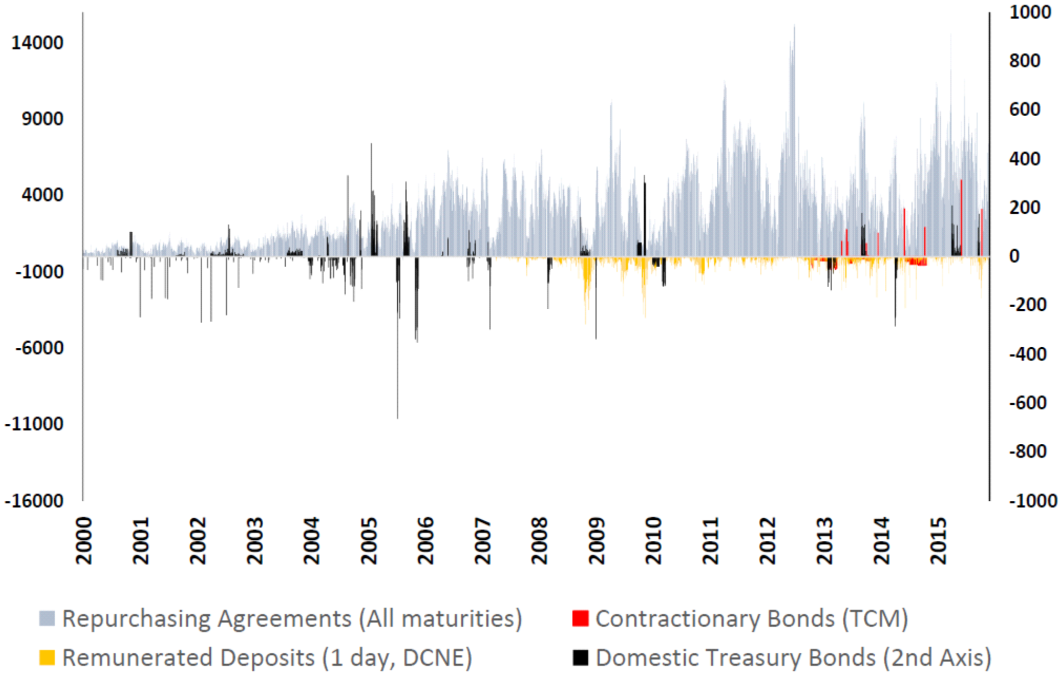

Figure 3. **Central bank open market operations in Colombia.**

as well as non-reserve interest bearing deposits (DCNE), implemented in 2007, and with maturities set at up to 90 days.[8] Expansionary operations consisted of purchases of sovereign bonds (TES) and repurchasing agreements (repos). Figure 3 displays all OMOs by the BoR and shows that repos (almost all with a 1-day maturity) were the dominant instrument, with auctions taking place every day of our sample. Reserve requirements were not used as an active tool to manage liquidity in money markets by the BoR.

Table 3 shows descriptive statistics for each of the OMO instruments employed by the central bank. Expansionary operations were significantly larger than contractionary operations. As documented in Cardozo et al. (2016), the central bank has been more often a net creditor than a net debtor with respect to the financial system. Notably, in episodes of low liquidity, financial entities with surplus resources preferred to lend to the central bank. Even in times of excess liquidity, financial institutions participated in the central bank's expansionary operations in order to cover idiosyncratic liquidity shortages.

[8] In recent years, given a shortage of demand for long matutities in DCNE, the BoR offers maturities of 7 and 14 days only.

	Total	Operation days	Mean	Std.Dev	Quartile 25%	Quartile 75%
Domestic sovereign bonds						
Purchases	1,257	20,965	0.06	0.09	0.01	0.07
Sales	-482	11,791	-0.04	0.05	-0.06	-0.01
Central bank bonds						
Purchases	1,451	958	1.51	1.53	0.08	1.92
Sales / Auctioned	-1,194	3,170	-0.38	0.22	-0.55	-0.17
Non-reserve deposits						
Purchases	1,534	7,444	0,21	0,26	0,05	0,27
Sales	-41,554	123,878	-0.34	0.46	-0.42	-0.06
Repos						
Auctioned	619,170	157,019	3.94	2.33	2.23	5.24

Table 3. **OMO statistics (2002-2015).** Authors' calculations. Units are in trillion pesos.

3.4 Control variables

In the empirical analysis that follows, we further make use of a large set of bank-level and macro-financial controls. From the credit registry, we obtain data on individual banks' total assets, capitalisation, liabilities, loan loss provisions as well as the internal loan risk grading as a measure of the riskiness of the loan book. The macro-financial controls include net portfolio capital flows, net bond issuance of the government, the bilateral Colombian peso/US dollar exchange rate, the VIX index, the BoR policy rate, the Colombian long-term government bond yield and the deviation of inflation from the BoR's inflation target. Data on daily portfolio capital inflows and outflows come from the International Affairs Department (*Departamento de Cambios Internacionales*) and the Statistical Department (*Departmento Tecnico y de Informacion Economica*). The net issuance of sovereign bonds (primary market) is obtained from the central bank owned electronic platform (Deposito Central de Valores-DCV). All other financial variables were taken either directly from the central bank's public website or from Bloomberg.

4 High-frequency panel evidence

In the empirical analysis, we first explore the dynamic effects of sterilised FX intervention on new corporate loans in Colombia. In the next step, we assess the relevance of the two main channels through which sterilised FX intervention may affect domestic credit. We test the exchange rate channel by estimating the dynamic effects of sterilised FX interventions on the exchange rate and on capital flows. We also test the relevance of the "crowding out" channel by exploring the impact of central bank OMOs (including those unrelated to FX intervention) on domestic lending. In the last empirical exercise, we assess the transmission of sterilised FX intervention based on the cross-sectional variation of our bank data set using a difference-in-difference approach. Specifically, we test whether sterilised FX intervention has a larger effect on banks that are financially more constrained, which would be indicative of FX intervention working through the described financial channels.

4.1 Estimation approach

The empirical methodology used for the analysis are panel local linear projection (LLP) regressions in the spirit of Jordà (2005). The LLP method has become a standard tool in empirical analyses to derive dynamic impulse responses. Compared to vector autoregressions (VARs), it is more robust to misspecification because it does not impose implicit dynamic restrictions on the shape of the impulse responses. Moreover, the LLP approach can more easily accommodate non-linearities of the type we are exploring in Section 4.4.[9]

We run LLP regressions over horizons up to 200 working days, regressing the cumulative flow of new corporate loans by bank i on the BoR's sterilised FX intervention FXI. We denote by $y_{i,t}$ the face value of new corporate loans granted by bank i in period t and by $Y_{i,t+h}$ the cumulative flow of new corporate loans by bank i over the period t to $t+h$ (respectively normalised by the stock of corporate loans of bank i in period $t-1$). The panel LLP model takes the form:

$$Y_{i,t+h} = \alpha_{h,i} + \lambda_h y_{i,t-1} + \beta_h FXI_{t-1} + \Gamma_h Z_{i,t-1} + \Psi_h F_{t-1} + \varepsilon_{i,t+h}. \tag{15}$$

for $h = 1, .., 200$. The matrix Z_i includes bank specific controls while the matrix F comprises the macro-financial controls. For bank-level controls, we include a bank's total assets, its capitalisation, liabilities, loan loss provisions as well as its internal loan risk grading. The purpose of including these variables is to control for differences in lending behaviour of the individual bank due to its size, capitalisation, liabilities as well as the riskiness of its loan book as captured by provisions and the internal loan grading.

[9] See e.g. Bernardini and Peersman (2018) for a discussion of the pros and cons of the LLP approach compared to the VAR approach.

The macro-financial control variables include net portfolio inflows, the change in the policy rate, the change in the long-term government bond yield, the deviation of inflation from the Bank of the Republic's target level, the Colombian government's net bond issuance, the log level of the VIX index and the change in the bilateral exchange rate of the Colombian peso against the US dollar. Moreover, we include a dummy variable for the period from May 7, 2007 to October 8, 2008 when the central bank introduced controls on capital inflows requiring foreign investors to deposit 40% of portfolio and debt investments at the BoR during a six-month period without interest payments (i.e. an unremunerated reserve requirements).[10]

The regressions also include a lagged dependent variable $y_{i,t-1}$ in order to capture persistence in the dynamics of the dependent variable. Since the time-series dimension is large, with on average about 1,000 observations for each individual bank, the Nickell bias is not a problem for our analysis and we can proceed with estimating the panel model by OLS rather than a GMM estimator.[11]

Since the control variables included in Z_i and F also include those variables that describe the BoR's FX intervention reaction function, equation (15) provides consistent estimates of the effects of unexpected FX intervention shocks (Caspi et al (2018)). The series of coefficient estimates $\widehat{\beta}_h$ for $h = 1, .., 200$ represents the cumulative impulse response of new corporate loans to an unexpected sterilised FX intervention shock of size one over horizons up to 200 working days.

The sample period of the estimations is 2002-2010. As mentioned before, the BoR conducted primarily pre-announced FX interventions from 2010 onwards, which could complicate the identification of the effects of intervention. For this reason, we perform the analysis over the shorter sample period covering exclusively discretionary interventions, but we also report results for the estimations when the period of pre-announced FX interventions is included as a robustness check.

[10] Other regulatory controls (*Posición Propia -PP, Posición Propia de contado -PPC)* required commercial banks to have a positive but limited exposure of foreign currency, defined as net assets denominated in foreign currency relative to total capital. However, this policy was never binding for *PP* and almost never binding for *PPC*.

[11] The inclusion of a lagged dependent variable in fixed-effects panel estimations can give rise to biases in panels with small time dimensions (Nickell (1981)). However, when the time dimension of the panel is sufficiently large, the Nickell bias should not be a concern.

4.2 Empirical results

Figure 4 presents the estimated dynamic effects of a sterilised FX purchase of the central bank for the sample 2002-2010 comprising only discretionary FX interventions (left-hand panel) and for the sample 2002-2015 which also includes the post-2010 pre-announced interventions (right-hand panel). The size of the impulse is in both cases normalised to 30 million US dollars which is comparable to the sample standard deviation of all sterilised FX interventions. The figures show the estimated coefficients of the LLP regression respectively with a 10% confidence band, calculated using Driscoll and Kraay (1998) standard errors.

The results support the hypothesis that sterilised FX intervention significantly affects domestic credit creation in Colombia. The impulse response to a sterilised FX purchase is persistently and significantly negative. The shape of the impulse response, especially the persistence of the impact on the cumulative flow of new loans reflects our focus on the gross flow of new loans. Since the gross flow of new loans is bounded below by zero, the cumulative impact reaches a plateau when the impact of the initial impulse fades out.

Quantitatively, the effect of the 30 million dollar intervention is a reduction (after 200 days) of about 1% in the accumulated gross flow of new loans as a percentage of the pre-intervention stock of corporate loans. The results are robust to the inclusion of the period of mainly pre-announced FX intervention since 2010 (right-hand panel), where the impulse responses to an FX purchase are however statistically less significant as reflected in the wider error bands. This is consistent with the notion that the inclusion of pre-announced FX interventions somewhat weakens the ability to identify the impact of interventions empirically. For this reason, we focus for the rest of the analysis on the sub-sample excluding pre-announced FX intervention. Full sample results are however generally very similar and available upon request.

4.3 Testing for the transmission channels

In order to shed light on the channels underlying the negative impact of sterilised FX purchases on domestic credit, we perform a number of additional empirical exercises. We first examine the impact of FX purchases on the persistence of the impact on exchange rate through a set of LLP regressions for the change in the value of the Colombian peso against the US dollar. We also run a similar exercise to examine the impact on portfolio

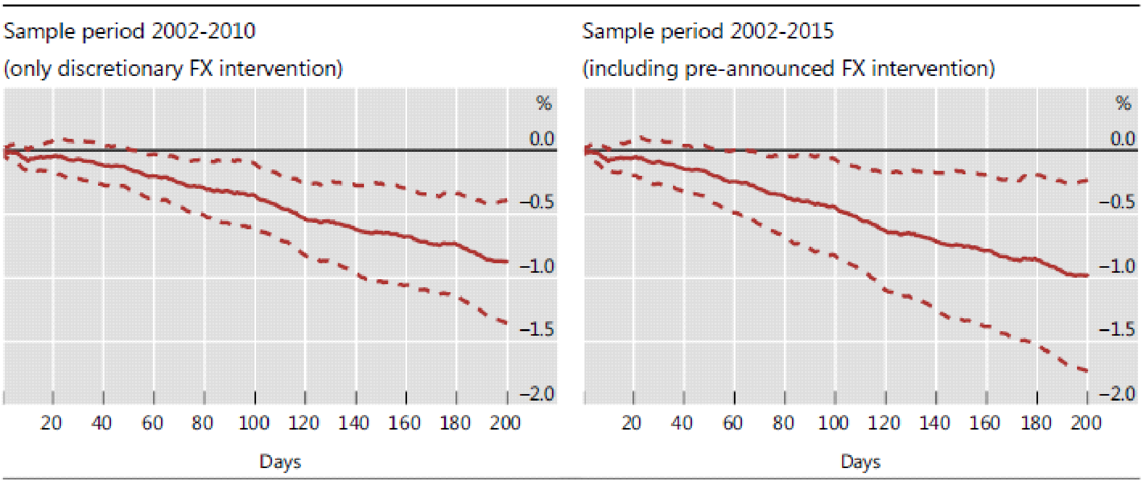

Figure 4. **Dynamic impact of sterilised FX intervention on new corporate loans in Colombia.** Impulse responses from local linear projection regressions in 10% confidence bands based on cross-section and period cluster robust standard errors. The size of the impulse is 30 million US dollars (sample standard deviation of all sterilised FX interventions). The impact is in percent of the pre-shock stock of loans.

inflows. Specifically, we run LLP regressions of the form:

$$X_{t+h} = \alpha_h + \lambda_h x_{t-1} + \beta_h FXI_{t-1} + \Xi_h F_{t-1} + \varepsilon_{t+h}. \tag{16}$$

where x_t is respectively the log change in the Colombian peso's US dollar exchange rate or the level of net portfolio inflows (in US dollars) and X_{t+h} is the cumulative sum of x_t over the period t to $t+h$. The regressions are run in daily frequency for horizons up to 200 days. The set of control variables F includes the change in the policy rate, the change in the long-term government bond yield, the Colombian government's net bond issuance and the log level of the VIX index.

The results of this exercise are shown in Figure 5. Regarding the impact on the exchange rate, a 30 million dollar sterilised FX intervention is followed by a depreciation of the peso exchange rate against the dollar and the impulse response is statistically highly significant (based on heteroskedasticity and autocorrelation robust Newey-West standard errors). Interestingly, the effect of the intervention, while being already significant on impact, further builds up over time. The immediate impact is a depreciation of roughly 0.4%, but the peak impact is a depreciation of more than 2% after 120 days. Quantitatively and qualitatively, the response pattern of the exchange rate that we find

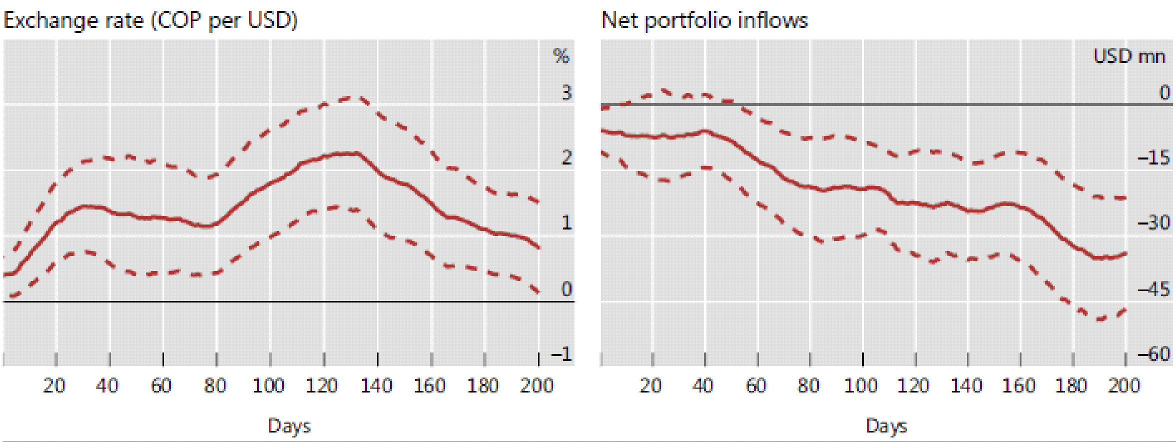

Figure 5. **Dynamic impact of sterilised FX intervention on the bilateral exchange rate against the US dollar and on portfolio inflows in Colombia.** Impulse responses from local linear projection regressions in 10% confidence bands based on heteroskedasticity and autocorrelation robust standard errors. The size of the impulse is 30 million US dollars (sample standard deviation of all sterilised FX interventions).

is consistent with the recent evidence of persistent effects of FX intervention in Israel reported in Caspi et al (2018)).

The persistence in the exchange rate response probably reflects the additional effect from the slowdown in capital inflows that follows the intervention with a lag (right-hand panel). Net capital inflows significantly decline in the wake of the intervention, and the response is similarly sluggish as that of the exchange rate. Specifically, a 30 million sterilised FX intervention slows capital inflows by also about 30 million US dollars after 200 days. This observation suggests that sterilised FX intervention not only has the capacity to break the mutually reinforcing feedback loop between exchange rate appreciation and capital inflows that emanates from the exchange rate risk taking channel, but that it can even make it play out in reverse through the initial depreciation impact.

In order to test the "crowding out" channel of sterilised FX intervention, we re-run the panel equation (15), but replace sterilised FX intervention with the BoR's open market operations. As explained above, the crowding out channel is one where the sterilisation leg of the FX intervention can absorb balance sheet capacity so that it is precluded from being utilised into domestic credit creation. That reasoning implies, however, that such an absorption effect could also be achieved through OMOs more generally, not only those that are linked to an FX intervention. This is a testable hypothesis.

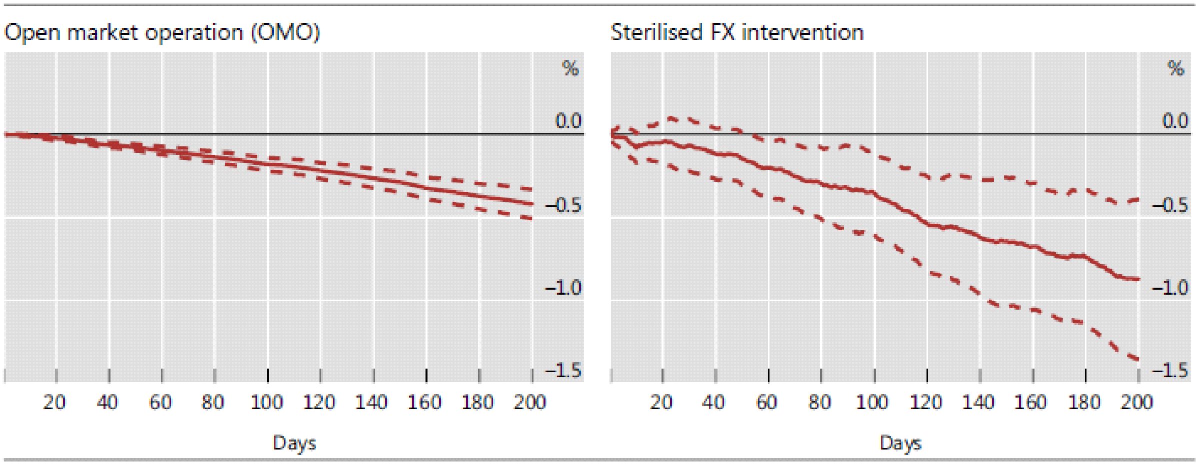

Figure 6. **Dynamic impact of central bank open market operation and of sterilised FX intervention on new corporate loans in Colombia.** Impulse responses from local linear projection regressions in 10% confidence bands based on cross-section and period cluster robust standard errors. The size of the impulse is 30 million US dollars (sample standard deviation of all sterilised FX interventions). The impact is in percent of the pre-shock stock of loans.

The impulse responses obtained from re-running equation (15) are consistent with this hypothesis, albeit with a smaller quantitative impact. An OMO worth 30 million USD is followed by a significant reduction of new domestic lending to corporates (Figure 6, left-hand panel). Quantitatively, the effect is much smaller (around one half) than that for sterilised FX intervention (right-hand panel, reproduced from Figure 4), suggesting that the exchange rate channel is the key mechanism through which sterilised FX intervention impacts domestic credit. Similar results obtain when we zoom in on periods without FX interventions. Specifically, re-running the same LLP regressions as before but excluding observations coming from periods when there was a sterilised intervention in the FX market yields basically the same results (not reported).

The effect of OMOs on domestic credit however seems to depend on the sterilisation instrument used. We re-run equation (15) replacing the total OMOs with its two main sub-components, bond OMOs (including both government bonds and central bank sterilisation bonds) and repo operations. The results of this exercise show that there is a highly significant negative effect of OMOs conducted in bonds, while the impact of repo operations is not statistically significant (Figure 7). Thus, while the sale of longer maturity instruments such as central bank sterilisation bonds or government bonds may crowd out domestic credit on banks' balance sheets, this does not seem to be the case for

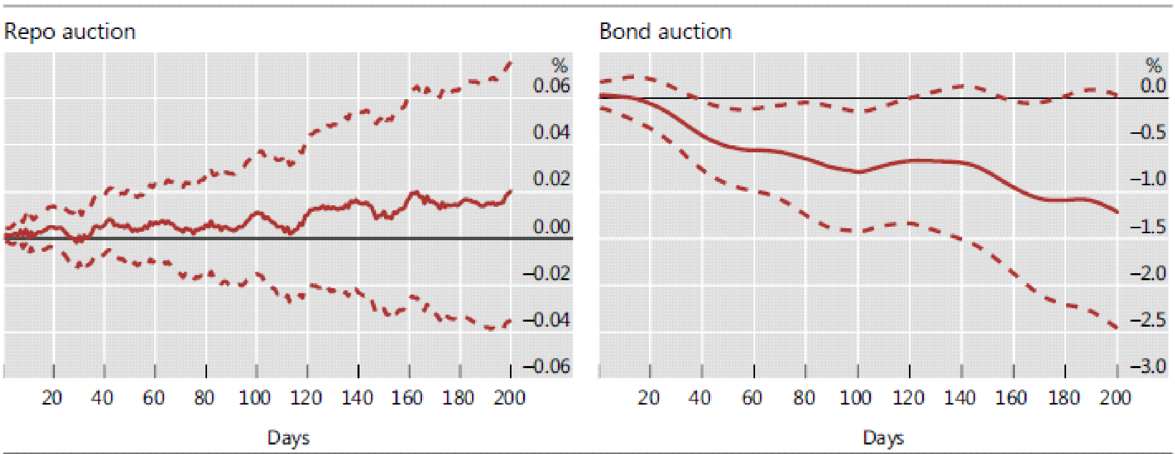

Figure 7. **Dynamic impact of repo and bond auction on new corporate loans in Colombia.** Impulse responses from local linear projection regressions in 10% confidence bands based on cross-section and period cluster robust standard errors. The size of the impulse is 30 million US dollars (sample standard deviation of all sterilised FX interventions). The impact is in percent of the pre-shock stock of loans.

repos. This finding reflects the different maturities of the underlying operations. While repos have mostly one-day maturities, operations in longer maturity bonds have a longer lasting effect on banks' balance sheet capacity which can affect their lending decisions.

4.4 Panel evidence across banks

Another way to identify the effects of sterilised FX intervention on domestic financial conditions is through the differences of the impact across banks.

The literature on the exchange rate risk-taking channel suggests that a depreciation of a country's exchange rate is associated with a tightening of financial conditions more generally (e.g. Hofmann et al (2017)). At the same time, the literature on the bank lending channel of monetary transmission (Bernanke and Blinder (1988), Mishkin (1996)) has shown that a monetary tightening has a stronger impact on financial institutions that are financially more vulnerable, i.e. small banks with limited access to non-deposit funding or banks with low capitalisation or high debt (e.g. Kashyap and Stein (1995, 2000), Kishan and Opiela (2000), Gambacorta (2005)). If similar mechanisms are also at work when financial conditions tighten more generally, sterilised FX purchases that depreciate the currency and tighten financial conditions through the exchange rate risk-taking channel would be expected to have a stronger effect on banks which are financially more vulnerable.

Similarly, the theoretical analysis of Chang (2018) suggests that the effectiveness of sterilised FX intervention depends on the financial sector being borrowing constrained. If banks are borrowing constrained they will be less able to circumvent the effects of sterilised FX intervention on their balance sheets by raising additional funds to rebalance their asset portfolio. In other words, more financially constrained banks would be expected to be more adversely affected by a sterilised FX purchase by the central bank and to constrain new lending by more.

Taken together, these considerations imply that intervention has a stronger effect on financially weaker banks. This provides another test of the hypothesis that sterilised FX intervention affects domestic credit conditions through financial channels.

We adopt a difference-in-difference approach in the spirit of Rajan and Zingales (1998) to test how financial channels of intervention work through banks' balance sheets. Specifically, we augment the panel LLPs from equation (15) with interaction effects, interacting the central bank's sterilised FX intervention with bank level proxies for the degree of the banks' balance sheet strength or weakness. The augmented panel LLPs take the following form:

$$Y_{i,t+h} = \alpha_{h,i} + \theta_{h,t} + \lambda_h y_{i,t-1} + \Theta_h FXI_{t-1} \times Z_{i,t-1} + \Gamma_h Z_{i,t-1} + \varepsilon_{i,t+h}. \quad (17)$$

In order to focus on the interaction terms as an alternative way to test the effectiveness of sterilised FX intervention, we further include in the amended specification time-fixed effects θ_t so that all macro-financial variables that vary only in the time series dimension, including the FX intervention itself, drop out. Identification of the intervention effects is thus achieved exclusively through cross-sectional variation at the bank level (difference-in-difference).

Following the empirical literature on the bank lending channel of monetary policy (e.g. Gambacorta (2005)), we consider the following bank characteristics to measure a bank's financial weakness: bank capitalisation and bank size, with better capitalised and larger banks expected to have easier and cheaper access to funding; bank total leverage (debt over assets), with more leverage expected to limit a bank's financial room for manoeuvre; and loan loss provisions, with higher provisions indicating higher financial vulnerability of the bank through loan losses.

The results reported in Table 4 support the notion that sterilised FX intervention

	20 Days	40 Days	60 Days	80 Days	100 Days
Capitalisation	0.020***	0.039***	0.058***	0.077***	0.097***
	(0.001)	(0.002)	(0.002)	(0.003)	(0.004)
Bank Size	0.014***	0.029***	0.044***	0.060***	0.077***
	(0.001)	(0.002)	(0.002)	(0.003)	(0.004)
Debt	-0.003***	-0.006***	-0.01***	-0.013***	-0.016***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Provisions	-0.017***	-0.033***	-0.049***	-0.065***	-0.082***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
FXI*Capitalisation	0.10***	0.16***	0.19**	0.25**	0.31**
	(0.034)	(0.55)	(0.077)	(0.10)	(0.12)
FXI*Bank Size	0.11***	0.15***	0.18**	0.26***	0.31**
	(0.033)	(0.055)	(0.077)	(0.10)	(0.12)
FXI*Debt	-0.008***	-0.011**	-0.013*	-0.021**	-0.024**
	(0.003)	(0.005)	(0.007)	(0.009)	(0.012)
FXI*Provisions	-0.024	-0.036	-0.031	-0.035	-0.037
	(0.015)	(0.026)	(0.036)	(0.047)	(0.058)

Table 4. **Interaction effects between FX intervention and bank characteristics.** Estimation based on local linear projections. Cross-section and period cluster robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively. Capitalisation is defined as equity over assets. Bank size corresponds to total assets relative to average banking sector assets. Debt is defined as bank debt plus accounts payable over total assets. Provisions are defined as loan loss provisions over assets.

has a larger effect on weaker banks. Bearing in mind that the baseline effect of FX intervention on corporate loans is negative, the results suggest that the impact of FX intervention significantly decreases in the capital ratio; it significantly decreases in bank size; it significantly increases in the level of bank debt relative to total assets; and it increases in the amount of loan loss provisions albeit not in a statistically significant way. Table 4 also shows that higher provisions and higher debt dampen new lending, while higher capital and greater size tend to increase it in a significant way. These findings suggest that greater financial constraints, measured in different ways, not only amplify the transmission of FX intervention, but also have an independent negative effect on bank lending.

In sum, the difference-in-difference panel evidence supports the idea that FX intervention works through financial conditions and banks' balance sheet capacities. This heterogenous effect of intervention on the domestic financial sector could also contribute to medium-term financial stability by leaning against financially weaker banks unduly increasing exposures during capital inflow surges and sheltering them from the fallout when the flows ebb.

5 Conclusions

Emerging market economies have come a long way since the crises of the 1990s. The combination of floating exchange rates, financial deepening and development, resilient banking systems and prudent macro policy frameworks leave them better prepared to meet the challenges of capital flow swings. However, these developments have not removed the policy challenges from fluctuations in capital flows. These challenges stem from the imperfect nature of exchange rates as shock absorbers that bring real macro variables back into equilibrium in the way that textbooks suggest. Specifically, capital inflows are associated with currency appreciation that in turn attracts more capital inflows as it flatters borrowers balance sheets and loosens lender value-at-risks constraints. The result is often a mutually reinforcing feedback loop fueling domestic financial imbalances.

The theoretical and empirical analysis of this paper supports the notion that sterilised FX intervention can help stem capital inflows in an emerging market economy. Sterilised FX purchases significantly dampen future bank lending. The effects work mainly through an exchange rate channel. A sterilised FX purchase significantly depreciates the exchange rate and reduces future net capital inflows, reversing the mutually reinforcing feedback loop between the two variables arising from the exchange rate risk-taking channel. In addition, central bank sterilisation operations with the banking sector seem to exert an independent negative effect by "crowding out" new lending.

Our findings suggest that FX intervention provides a leaning element that can usefully complement the cleaning elements that are provided through the global financial safety net (GFSN)[12] in promoting macro-financial stability in EMEs, and globally. In many policy discussions, the build-up of FX reserves is seen as a second best to the provision of a comprehensive and reliable GFSN. However, this conclusion may not be so clear-cut in practice. As documented in this paper, the build-up of FX reserves that leans against credit developments may actually have a prudential element that dampens the size of the

[12] The GFSN is comprised of four main elements: the level of national FX reserves, bilateral currency swap agreements, regional financing arrangements, and the IMF instruments. For more details, see ECB (2016), IMF (2016) and Scheubel and Stracca (2016).

boom itself. In this sense, the debate on the relative merits of "leaning versus cleaning" in the domestic monetary policy sphere has a counterpart in the international sphere, also. As such, leaning by building up reserves may have merits that go beyond the GFSN.

The challenge with any systematic use of FX intervention is the charge of "beggar thy neighbour" currency manipulation for trade competitiveness reasons. One way to avoid this problem would be to conduct FX intervention with a view to reduce exchange rate volatility and by slowing the pace of currency appreciation and depreciation, as opposed to targeting a certain level of the exchange rate. FX interventions may be used in a targeted and symmetric way to lean against exchange rate swings during capital inflow surges and ebbs, and against associated building up financial imbalances. In this way, they can usefully complement monetary policy and macroprudential tools contributing to a policy approach that leans against capital flow volatility and its consequences.

The design and use of FX intervention as a complementary policy tool for financial stability purposes must of course be assessed in the broader context of FX reserve adequacy. Precautionary considerations are the main motive for reserve accumulation in EMEs, and the perceived benefits depend on the external exposure of the economy and on the risks of adverse external shocks. Our analysis suggests that dampening the impact of expansionary external factors on the domestic financial system could be another benefit. However, accumulating FX reserves is also associated with significant fiscal costs The extent of precautionary reserve accumulation and of the use of intervention as a stabilisation tool will depend on the assessment of the net benefits, taking into account all perceived benefits and costs, which will vary across countries and over time.[13]

[13] See IMF (2015) for a discussion of the issues relevant for the assessment of FX reserve adequacy.

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Appendix

A Proof of Lemma 1

Borrower j repays the loan when $Z_j \geq 0$, where Z_j is the random variable:

$$\begin{aligned} Z_j &= d_j + \sqrt{\rho} Y + \sqrt{1-\rho} X_j \\ &= -\Phi^{-1}(\varepsilon) + \sqrt{\rho} Y + \sqrt{1-\rho} X_j \end{aligned} \tag{18}$$

where ε is the probability of default of borrower j, defined as $\varepsilon = \Phi(-d_j)$ and Φ is the standard normal c.d.f.

Conditional on Y, defaults are independent. In the limit where the number of borrowers becomes large, the realised value of one peso face value of loans can be written as a deterministic function of Y, by the law of large numbers. The realised value of one peso face value of loans is the random variable $w(Y)$ defined as:

$$\begin{aligned} w(Y) &= \Pr\left(\sqrt{\rho} Y + \sqrt{1-\rho} X_j \geq \Phi^{-1}(\varepsilon) \,|Y\right) \\ &= \Phi\left(\frac{Y\sqrt{\rho} - \Phi^{-1}(\varepsilon)}{\sqrt{1-\rho}}\right) \end{aligned} \tag{19}$$

The c.d.f. of w is then given by

$$\begin{aligned} \Pr(w \leq z) &= \Pr\left(Y \leq w^{-1}(z)\right) \\ &= \Phi\left(w^{-1}(z)\right) \\ &= \Phi\left(\frac{\Phi^{-1}(\varepsilon) + \sqrt{1-\rho}\,\Phi^{-1}(z)}{\sqrt{\rho}}\right) \end{aligned} \tag{20}$$

where $\Phi(.)$ is the c.d.f. of the standard normal. Hence,

$$F_\theta(z) = \Phi\left(\frac{\Phi^{-1}(\varepsilon(\theta)) + \sqrt{1-\rho}\,\Phi^{-1}(z)}{\sqrt{\rho}}\right) \tag{21}$$

and $\varepsilon(\theta)$ is the probability of default of an individual borrower, where $\varepsilon(\theta)$ a decreasing function of θ. This proves the lemma.

B Proof of Lemma 2

Loan losses do not exceed E_i^C as long as the realised value of $w(Y)$ exceeds the unit's notional liabilities. Then, the VaR constraint of the loan unit binds, and lending is the maximum loan amount consistent with the VaR constraint. Denoting by C_i the total lending by bank i, the binding VaR constraint implies:

$$F((1+f)L_i) = \Phi\left(\frac{\Phi^{-1}(\varepsilon) + \sqrt{1-\rho}\,\Phi^{-1}\left(\frac{(1+f)L_i}{(1+r)C_i}\right)}{\sqrt{\rho}}\right) = \alpha \tag{22}$$

Re-arranging (22), we can write the ratio of notional liabilities to notional assets of bank i's loan unit as:

$$\frac{\text{Notional liabilities}}{\text{Notional assets}} = \frac{(1+f)\,L_i}{(1+r)\,C_i} = \Phi\left(\frac{\sqrt{\rho}\Phi^{-1}(\alpha) - \Phi^{-1}(\varepsilon)}{\sqrt{1-\rho}}\right) \tag{23}$$

We will use the shorthand:

$$\varphi(\alpha, \varepsilon, \rho) \equiv \Phi\left(\tfrac{\sqrt{\rho}\Phi^{-1}(\alpha) - \Phi^{-1}(\varepsilon)}{\sqrt{1-\rho}}\right) \tag{24}$$

Clearly, $\varphi \in (0, 1)$. From (23) and the balance sheet identity $E_i^C + L_i = C_i$ of the bank's loan unit, we can solve for the supply of loans by bank i, which is given by

$$C_i = \frac{E_i^C}{1 - \frac{1+r}{1+f} \cdot \varphi} \tag{25}$$

We can re-write this expression as $C_i = \lambda E_i^C$ where λ is the leverage of the loan unit, given by

$$\lambda = \frac{1}{1 - \frac{1+r}{1+f} \cdot \varphi} \tag{26}$$

Finally, we note from (24) that λ does not depend on i. This completes the proof of Lemma 2.

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