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Breaking the Trilemma:
The Effects of Financial Regulations on Foreign Assets*

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Abstract

In this paper we analyze the effects of financial constraints on the exchange rate through the portfolio balance channel. Our contribution is twofold: First, we construct a tractable two-period general equilibrium model in which financial constraints inhibit capital flows. Hence, departures from the uncovered interest rate parity condition are used to explain the effects of sterilized foreign exchange intervention. Second, using high frequency data during 2004-2015, we use a sharp policy discontinuity within Colombian regulatory banking limits to empirically test for the portfolio balance channel. Consistent with our model's postulations, our findings suggest that the effects on the exchange rate are short-lived, and significant only when banking constraints are binding.

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1 Introduction

The extensive literature on the effectiveness of sterilized foreign exchange intervention identifies two main channels through which the exchange rate can be affected: the *signaling* and the *portfolio balance channel*. The theoretical underpinnings of these channels are portrayed in Sarno and Taylor (2001), Evans (2005), Lyons (2006), and Villamizar-Villegas and Perez-Reyna (2017). However, the empirical literature has yet to reach a consensus regarding the effectiveness of foreign exchange intervention.[1] One reason might be that managing the exchange rate while at the same time allowing for free capital flows and having monetary policy autonomy is an impossible *trilemma* due to arbitrage by foreign investors. In principle, policy effects should be limited.

In this paper we attempt to disentangle the portfolio balance channel by studying the effects of banking limits on the exchange rate. We first construct a tractable two-period general equilibrium model with a representative household, firm, bank, and an economic authority (government) that holds a net foreign debt position. The bank chooses how much to hold in domestic assets (loans to the firm) and faces a constraint on its holdings of foreign assets. As such, our model shares similar features as Gabaix and Maggiori (2015) and Kuersteiner et al. (2016a); namely that the uncovered interest rate parity (**UIP**) condition breaks as a result of some market friction. In particular, the friction in our model results from a financial regulation, construed as lower and upper bounds on the bank's foreign exchange position. In contrast, frictions found in Gabaix and Maggiori and Kuersteiner et al. consist of either imperfect intermediation by financiers due to limited commitment, or to taxes on capital inflows.[2]

In our model, UIP holds as long as constraints on the bank are not binding. In this case, the bank is indifferent between holding foreign and domestic assets, so portfolio changes will not have an equilibrium effect on the exchange rate. This applies to foreign exchange interventions, which essentially modifies the government's debt foreign position. Hence, even if the bank's holdings of foreign assets is altered (through market clearing), it has no effect on the exchange rate.

[1]Empirical surveys on the effects of sterilized intervention include Dornbusch (1980), Meese and Rogoff (1988), Dominguez and Frankel (1993), Edison (1993), Dominguez (2003), Fatum and Hutchison (2003), Neely (2005), and Menkhoff (2010).

[2]We limit our analysis to the effects of existing financial regulations, not whether or why regulations should be implemented.

If, however, any of the two constraints is binding, then the UIP is violated. In this equilibrium the bank is no longer indifferent between holding different currency denominated assets. For example, the case in which the upper constraint binds yields a higher return of holding foreign assets. Any change in asset compositions will have an effect on the exchange rate. Furthermore, foreign exchange intervention will also affect the exchange rate through changes in equilibrium portfolio levels.

In order to test the postulations of our model, we build on Cardozo et al. (2016) to conduct a sharp regression discontinuity design (RDD) so as to fit the description of the data generating process in Colombia's financial sector. Specifically, we compare episodes of exchange rate and portfolio balances, when banks' foreign exchange exposures reached a binding limit, to episodes in which they barely missed it. Hence, our identifying strategy is based on the way that regulatory authorities imposed banking limits on the amount of foreign exposure. When limits are binding, portfolio shifts should, in principle, have an effect on the exchange rate, i.e. shifting from an *impossible trinity* to a *possible binity*. Moreover, effects should be amplified if the central bank simultaneously conducts sterilized interventions, by issuing or purchasing domestic sovereign debt.

In the empirical application we employ proprietary and high frequency (daily) data from every financial institution in the country during 2004-2015. The data include: (i) domestic asset holdings, (ii) loans denominated in domestic and foreign currency, and (iii) foreign exposure (net assets in foreign currency). We also employ official intervention data provided by the Central Bank of Colombia (**CBoC** henceforth) consisting of both the timing and amount of every foreign exchange market transaction conducted within our sample period.

Our findings indicate that the effects of financial restrictions on the exchange rate are short-lived, and significant only when financial regulations are binding. Moreover, we find significant effects on portfolio balances (both on loans and foreign exposure) when banks are faced with binding constraints. Finally, we find that exchange rate effects are larger in episodes when the CBoC intervened in the foreign exchange market. These results can be construed as evidence of the portfolio balance channel when the monetary trilemma does not hold (i.e. when financial regulations limit capital flows).

The rest of the paper is organized as follows. Section 2 presents the theoretical model that incorporates financial constraints to study the effectiveness of sterilized foreign exchange intervention. Section 3 describes the data, explains the empirical methodology and highlights the main empirical results. Finally, Section 4 concludes.

2 Model

Our model incorporates most of the attributes needed to rationalize the effect of banking limits on the bank's portfolio and how this choice affects the exchange rate. Furthermore, we analyze the effects of foreign exchange intervention. We consider a two-period small open economy with a representative household, a representative firm, a representative bank and an economic authority (government) that holds net foreign debt.

The main dynamics of our model are as follows: the firm needs to borrow from the bank in order to produce. The bank raises costly equity and chooses how much to lend to the firm and how much to invest in a foreign asset. We assume that the bank faces constraints on its holdings of the foreign asset. We find that, if these constraints don't bind, the portfolio choice of the bank has no effect on the exchange rate. Moreover, the government has no control on the exchange rate. Both results stem from the fact that UIP holds. On the other hand, when constraints bind, UIP is violated and the exchange rate is affected by the portfolio choice of the bank. In this case, the equilibrium exchange rate will depend on the government's net foreign debt. This implies that a foreign exchange intervention, denoted as a change in foreign exchange reserves, affects both the foreign net position and the equilibrium exchange rate.

We keep our model as simple as possible in order to highlight the main mechanism through which the portfolio-balance channel operates, i.e. the breakup of UIP due to financial constraints. In our model the household derives utility from consuming only in the second period. We do this to abstract from inter-temporal choices. The household owns both the representative firm and the representative bank. The income of the household therefore consists of profits from the firm and bank. Consequently, the problem of the household is

$$\begin{aligned} &\max_{c} \quad u(c) \\ &\text{s. t.} \quad c \leq \pi^f + \pi^b, \end{aligned} \tag{1}$$

where π^f denotes the profits of the firm and π^b the profits of the bank. We assume that $u(\cdot)$ is strictly increasing so that the budget constraint binds.

We assume that the firm needs to borrow in order to get the capital it needs to produce. Also, we assume that the firm can only borrow from the bank.[3] Furthermore, capital takes one period to be usable, so the firm only produces in the second period. The firm borrows from the bank at the beginning of period 1 and pays its debt back with a gross interest rate of R in period 2, which the firm takes as given, but will be endogenously determined. We assume that the firm has a constant returns to scale production function, which allows us to directly pin down the equilibrium interest rate. Formally, the firm solves the following problem:

$$\pi^f \equiv \max_k \quad Ak - RK, \tag{2}$$

where A is a productivity parameter.

The main action of the model comes from the bank. The bank maximizes profits by choosing how much to lend to the firm and how much to invest in a foreign asset. The bank must raise equity, which is costly. We model this cost by means of a quadratic cost, in order to get some analytical solutions, but our results would follow through as long as this cost is increasing and convex in the amount of equity raised. For every unit of equity that the bank lends to the firm it receives a return equal to R. For every unit of equity that the bank invests in the foreign asset it receives a return equal to $\frac{e_1}{e_0}R^*$, where e_t denotes the exchange rate, measured as units of domestic good per units of foreign good. We are only able to pin down $\frac{e_1}{e_0}$, so we will set $e_0 = 1$ and denote e_1 by e. R^* is the exogenous interest return of foreign assets. We assume that the banks is subject to a constraint in its holdings of the foreign asset. Specifically, the problem of the bank is

$$\begin{aligned} \pi^b \equiv \max_{L,B^*,E} \quad & RL + eR^*B^* - \frac{\gamma}{2}E^2 \\ \text{s. t.} \quad & L + B^* = E \\ & \underline{\kappa} \leq B^* \leq \overline{\kappa}, \end{aligned} \tag{3}$$

where L is how much the bank lends to the firm, B^* is how much the bank invests in the foreign asset and E is how much equity it raises. $\underline{\kappa}$ and $\overline{\kappa}$ denote the constraints on the holdings of the foreign asset.

[3] This assumption is motivated by how the financial sector in Colombian operates, where most of the Firm's financing is done through banks.

Finally, we assume that the government has an outstanding net foreign exchange debt position, which we denote by B_G^*. If $B_G^* < 0$ then the bank has more foreign assets than foreign debt. Therefore when we refer to foreign exchange intervention, we will be referring to changes in B_G^*. Specifically, a reduction in B_G^* is equivalent to the government increasing foreign assets. Since buying foreign exchange reserves precisely does this, a reduction in B_G^* is related to an intervention in the foreign exchange market where the government is buying foreign currency. It is worth noticing that the fact that our economy is a real economy implies that every foreign exchange intervention is sterilized.

There are three markets in this economy: loan market, foreign goods market and domestic good market. By Walras law, we will focus on the market clearing of the first two markets. The loan market clears when loan demand, k, is equal to loan supply, L. The foreign goods market clears when demand for foreigns goods in this economy, B_G^*, is equal to supply of foreign goods, eB^*.

We will focus on a competitive equilibrium. That is, on prices $p \equiv \{R, e\}$ and allocations $x^h = \{c\}$, $x^f = \{k\}$ and $x^b = \{L, B^*, E\}$ such that

1. given p, x^h is a solution to problem (1);
2. given p, x^f is a solution to problem (2);
3. given p, x^b is a solution to problem (3);
4. and markets clear

$$k = L$$
$$B_G^* = eB^*.$$

We will first find an equilibrium of an economy where the constraints on the foreign exposure of banks don't bind. Since the firm produces with a constant returns to scale production function, in equilibrium it must be the case that $R = A$. Therefore loan supply will pin down k. To solve the problem of the bank, we plug in $E = L + B^*$ into the objective function in (3) and take first order conditions with respect to L and B^*:

$$R = \gamma(L + B^*) \tag{L}$$
$$eR^* = \gamma(L + B^*). \tag{B^*}$$

This implies that $R = eB^*$, which is precisely UIP. Intuitively, as long as the constraints on holdings of the foreign asset don't bind, the bank is indifferent between holding either type of asset, which is consistent with UIP holding. In these equilibria, the exchange rate will not depend on the portfolio choice: since we already pinned down R, we can use UIP to derive e in equilibrium:

$$e = \frac{A}{R^*}.$$

Notice that the exchange rate does not depend on B_G^* either. In other words, as long as the constraints on foreign exposure for the bank don't bind, intervention in the foreign exchange market does not affect the exchange rate. We make this result explicit in a lemma.

Lemma 1. *If the constraints for B^* in (3) don't bind, then UIP holds in equilibrium. Furthermore, the portfolio choice of the bank does not determine the exchange rate. Additionally a foreign exchange intervention does not affect the exchange rate.*

We will now derive the equilibrium allocations. Equation (L) above allows us to pin down the equity that the bank issues

$$E = \frac{R}{\gamma} = \frac{A}{\gamma}$$

From market clearing on foreign goods we can derive B^*:

$$B^* = \frac{B_G^*}{e} = \frac{R^* B_G^*}{A}.$$

Finally we can use the balance sheet constraint for the bank to determine L and k:

$$L = k = E - B^* = \frac{A}{\gamma} - \frac{R^* B_G^*}{A}.$$

This last equation allows to infer how the parameter space should be constrained to guarantee that $L \geq 0$:

$$\frac{A^2}{\gamma R^*} \geq B_G^*.$$

Now we will analyze what happens when one of the constraints on holdings of the foreign asset for the bank binds. Assume first that the upper constraint binds. This occurs when

$$\frac{R^* B_G^*}{A} > \overline{\kappa}$$

since the right hand side of this inequality is the holdings of the foreign asset by the bank when the constraints don't bind. Therefore $B* = \overline{\kappa}$. Since this constraint binds, equation (B^*) becomes an inequality

$$eR^* > \gamma(L + B^*).$$

This implies that $R < eR^*$. Therefore UIP doesn't hold anymore. Furthermore, the bank is not indifferent between holding either type of assets. In order for the upper constraint to bind, the bank must prefer to hold the foreign asset. In this case the exchange rate will be affected by the portfolio choice. We can see this by deriving the equilibrium exchange rate. In order to pin down e, we now use the market clearing condition for foreign goods:

$$e = \frac{B_G^*}{B^*} = \frac{B_G^*}{\overline{\kappa}}.$$

Notice that now the exchange rate depends on B_G^* and on the bank's holdings of the foreign asset. So as long as the constraint binds, the portfolio channel is in play. Furthermore, the government can affect the foreign exchange rate by changing its level of net foreign debt. This can be done by intervening in the foreign exchange rate market, since this changes the level of foreign reserves and, therefore, B_G^*.

We now finish characterizing the equilibrium in this case. As before, $R = A$, since this is a result of the problem of the firm.

$$E = \frac{R}{\gamma} = \frac{A}{\gamma}$$
$$L = k = E - B_G^* = \frac{A}{\gamma} - \overline{\kappa}.$$

We're still pending on characterizing the equilibrium when the lower constraint on the foreign exposure of the bank binds. This equilibrium will be very similar to the one we just described, so we will omit some steps. The lower constraint binds when

$$\frac{R^* B_G^*}{A} < \underline{\kappa}.$$

In this case $B^* = \underline{\kappa}$. Now equation (B^*) also becomes an inequality

$$eR^* < \gamma(L + B^*),$$

which implies $R > eR^*$, so UIP doesn't hold either. Similar to before, $R = A$ and the exchange rate will depend on B_G^*:

$$e = \frac{B_G^*}{\underline{\kappa}}.$$

Following similar steps we can finish characterizing the equilibrium:

$$E = \frac{A}{\gamma}$$
$$L = \frac{A}{\gamma} - \underline{\kappa}.$$

So, as long as either constraint binds, the portfolio of the bank affects the exchange rate. Additionally, a foreign exchange intervention will also affect the exchange rate. We summarize this result in a lemma to make it explicit.

Lemma 2. *If the constraints for B^* in (3) bind, then UIP does not hold in equilibrium. Furthermore, the bank is no longer indifferent between holding either type of asset and its portfolio choice affects the equilibrium exchange rate. Additionally, a foreign exchange intervention also affects the foreign exchange rate.*

We can characterize when the constraints will bind, and, therefore, when the portfolio channel will come into play. When net foreign government debt is high enough, the upper constraint for bank's holdings of the foreign asset will bind. Further increases in B_G^* will raise the foreign exchange (devaluation), while lowering B_G^* will cause a revaluation.[4] But B_G^* can only decrease up to a point before the exchange rate is no longer affected by changes. But if B_G^* is low enough, then the lower constraint in the bank's foreign exposure will bind and B_G^* will affect the exchange rate again. We posit this characterization in the following proposition

Proposition 1. *As long as $B_G^* \in \left(\frac{\overline{\kappa}A}{R*}, \frac{A^2}{\gamma R^*}\right]$, the upper constraint for the bank's holdings of the foreign asset binds. In this case the portfolio of the banks affects the equilibrium exchange rate and a foreign exchange intervention has an effect on the exchange rate. In particular,*

$$e = \frac{B_G^*}{\overline{\kappa}}.$$

For $B_G^* \in \left[\frac{\underline{\kappa}A}{R*}, \frac{\overline{\kappa}A}{R*}\right]$ the exchange will not be affected by B_G^* and will be equal to $\frac{A}{R^*}$. Finally, for $B_G^* < \frac{\underline{\kappa}A}{R*}$ the lower constraint for the bank's foreign exposure binds. In this case the portfolio of the banks affects the equilibrium exchange rate and a foreign exchange intervention

[4] To be strict, our results concern comparative statistics across different equilibria, not transitions.

has an effect on the exchange rate. In this case,

$$e = \frac{B_G^*}{\underline{\kappa}}.$$

Having constraints on foreign exposure is, in essence, a constraint on free mobility of capital. When the constraints are not binding, there is local free mobility of capital. The impossible trinity implies that the portfolio channel is muted. Furthermore, an intervention in the foreign exchange market has no effect on the foreign exchange rate. When either constraint binds, there is in effect a constraint on free mobility of capital: given that the bank cannot hold the foreign assets that it wants, capital cannot flow freely between the domestic economy and abroad. In this situation the portfolio of the bank will affect the exchange rate and an intervention in the foreign exchange market will have an effect over this rate as well.

3 Empirical methodology and results

In order to test for the postulations of our model, we estimate the causal effect of banking limits on the exchange rate by using a sharp policy discontinuity within the Colombian regulatory framework. In essence, we compare observations of outcome variables in the immediate neighborhood of a given threshold, dictated by the existing financial regulations on foreign holdings. Intuitively, the cutoff creates a natural experiment in which financial institutions arbitrarily face binding constraints (i.e. treatment group) as long as they are in close proximity to the required limit. Alternatively, institutions which barely miss the threshold (i.e. control group) represent ideal counterfactuals to financially constrained institutions, had the constraint not been binding.

3.1 Data

Our running variable corresponds to foreign exchange exposure of banks, and is defined as the difference between assets and liabilities denominated in foreign currency (USD) relative to total equity, without including positions in derivatives.[5] By regulation, banks cannot have

[5] This ratio is computed as the 3-day average liquid foreign exchange exposure relative to total equity. For references to these controls see the external regulation no. 12 of 1999 of the Central Bank of Colombia.

a foreign exposure that exceeds 50% of their capital and it cannot be negative. The lower limit of 0% was initially introduced to control for speculative attacks that would intensify the appreciation of the Colombian peso.[6] That is, speculators could sell forward contracts (in dollars) to the financial system while financial intermediaries borrowed from abroad to hedge their position. The resulting monetization of external debt could then exert appreciation pressures over the peso. Alternatively, the upper bound of 50% was established in order to avoid sizable build-ups of assets in foreign currency. However, this limit was never binding, in part due to the prolonged currency appreciation during the first decade of the 2000's, with peak values of 2,969 COP/USD in February 2003, and 1,652 in June 2008.

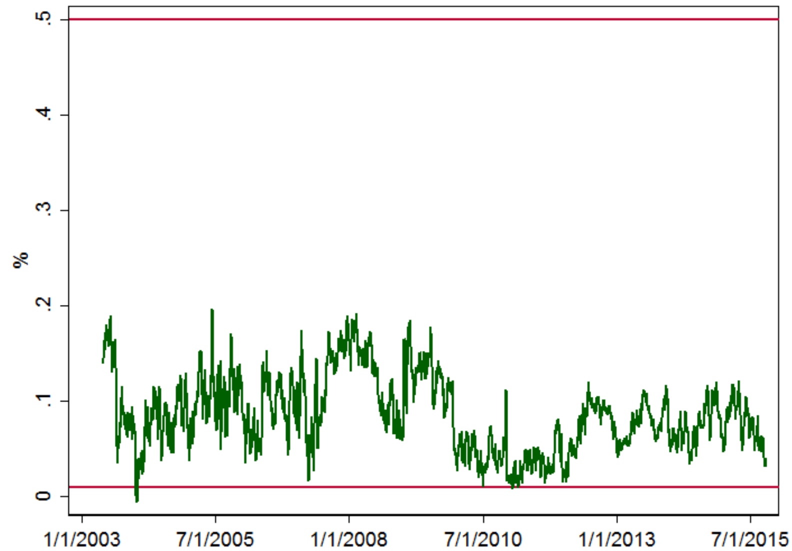
Even though regulation states that the lower limit on foreign exchange exposure for banks is 0%, we notice that the actual limit, relevant for banking operations, is a threshold of 1%. The main reason for this concern is the penalty involved when banks violate the imposed lower bound. Given that banks face unexpected changes in their daily exposures, they take preemptive measures to avoid being penalized. As it turns out, the total (daily) change in banks foreign exposure relative to their capital during 2004-2015 was, on average, 1% (see Appendix B).[7] Consequently, financial institutions generally require a capital buffer of at least this amount in order to avoid monetary sanctions. We thus proceed with the effective lower bound of 1% in the estimations that follow.

Figure 1 depicts foreign exposure (in dollars) relative to total capital of the entire financial system, where the two horizontal lines denote the upper (50%) and lower (1%) bounds. As observed, the upper limit was never binding and foreign exposure relative to capital oscillated between -0.6% (Jan 15, 2004) and 19.68% (June 10, 2005). We restrict our sample to the period of January 01, 2004 up until October 15, 2015, given that regulations for the lower limit changed to -20% on October 16, 2015.

[6]The 0% limit was established on January 23, 2004. Banks that initially had a negative foreign exposure had to adjust it by March 31, 2004.

[7]We estimated the daily average change of banks foreign exposure relative to their capital using different windows. This ratio was, on average, equal to 1% for the total sample.

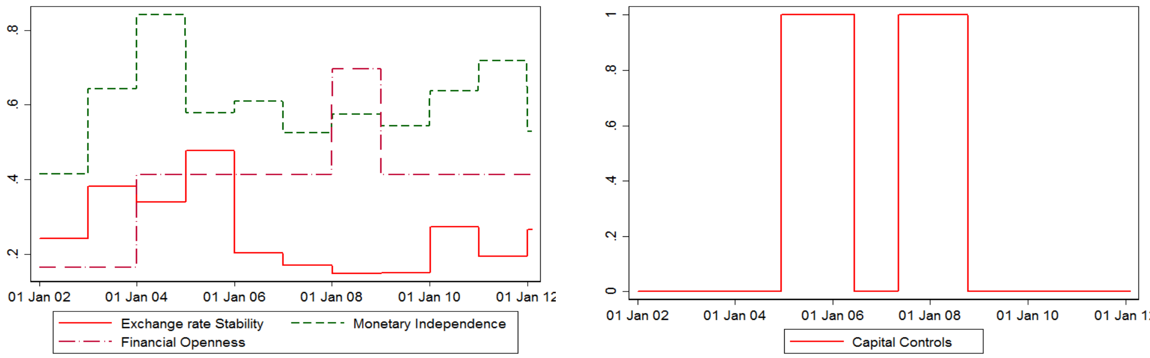
Figure 1: Foreign exposure of the financial system as % of equity



We note, however, that a number of other regulations coexisted during our sample period. We present some of these in Figure 2.[8] In particular, panel (a) depicts three indices presented in Aizenman et al. (2008), which consist of exchange rate stability, monetary independence, and financial openness. Therefore, the *monetary trilemma* limits a country from achieving high values of all three (e.g. high values of exchange rate stability and monetary independence would yield low values of financial openness). Similarly, panel (b) depicts a measure of capital controls as presented in Clements and Kamil (2009), Rincón and Toro (2010), and Magud et al. (2011). This dummy variable corresponds to the enactment of unremunerated reserve requirements, mostly due to a strong currency appreciation and a surge in inflows. A more detailed description of the financial regulations applied to the Colombia case is found in Mora-Arbeláez et al. (2015).

[8]We also acknowledge the large empirical literature that document deviations from the uncovered and covered interest rate parities (UIP and CIP). Some departures of UIP and CIP are captured in the financial openness index in Figure 2, with particularly low values at the onset of the 2000's due to thin forward markets. Studies on UIP and CIP applied to the Colombian case include Edwards (1984) and Echavarria et al. (2008).

Figure 2: Other measures of capital controls



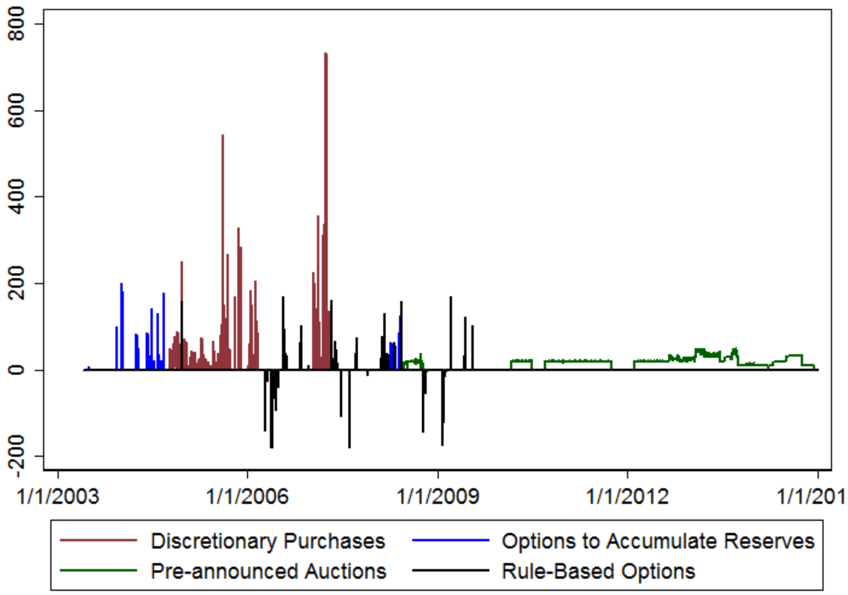
(a) Aizenman et al. (2008) (b) Magud et al. (2011)

Measures of capital controls shown in Figure 2 encompass different information from what is contained in foreign holdings. In fact, the correlation of financial exposure with unremunerated deposits (panel b) and with the financial openness index (panel a) is relatively low, with values of 0.3 and 0.1, respectively. This suggests that our measure of controls is not being driven solely by other measures of controls. Moreover, the high frequency of our data, compared to the lengthened duration of controls, enables us to estimate the effects of regulations on foreign holdings for a given value of other regulations.

We finally control for episodes of foreign exchange intervention (Figure 3) in order to avoid potential confounding factors between the proximity of banks' foreign exposure to regulatory limits and the decision of the CBoC to intervene in the foreign exchange market. Nonetheless, the fact that our study uses a focalized approach in which we narrow in on the immediate neighborhood of the binding threshold, is sufficient to break free from this and other confounding effects, regardless of these being observable or non-observable. As stated in Lee and Lemieux (2010), "one need not assume the RD design isolates treatment variation that is 'as good as randomized'; instead, such randomized variation is a consequence of agents' inability to precisely control the assignment variable near the known cutoff."[9]

[9]Lee and Lemieux (2010), page 282.

Figure 3: Official Foreign Exchange Intervention



Positive (negative) values correspond to purchases (sales) of million USD.

3.2 RDD setup

Since the early 2000's, RDD has been applied to a variety of fields including health, labor, and education.[10] Most of the RDD framework was formalized during this time (see Hahn et al. (2001); Porter (2003); McCrary (2008); and Imbens and Kalyanaraman (2012)) and useful surveys include the works of Imbens and Lemieux (2008), Lee and Lemieux (2010), Jacob et al. (2012) and Villamizar-Villegas et al. (2016). However, RDD studies have seen limited applications to macroeconomic questions and none to our knowledge, besides Kuersteiner et al. (2016a), have been applied to study the effects of monetary policy.

In the standard **Sharp** RDD setup, the assignment of treatment, D_t, is completely determined by a cutoff rule based on an observable running variable, X_t,

$$D_t = \Im\{X_t \geq x_0\}, \tag{4}$$

where $\Im\{\cdot\}$ is an indicator function. The discontinuity arises because no matter how close X_t gets to the cutoff value, the treatment is unchanged until $X_t = x_0$. If the treatment has

[10] See, for example, Hahn et al. (1999), Angrist and Lavy (1999), van der Klaauw (2002), Lemieux and Milligan (2008), Carpenter and Dobkin (2009), Cellini et al. (2010), and Lee (2008), among others.

an effect, then it should be measured by comparing the conditional means of the outcome variable at the limit on either side of the discontinuity point:

$$\begin{aligned}
\text{Average Treatment Effect} &= E\left(Y_{1t} - Y_{0t} \mid X_t = x_0\right) \\
&= E\left(Y_{1t} \mid X_t = x_0\right) - E\left(Y_{0t} \mid X_t = x_0\right) \\
&= \lim_{\epsilon \downarrow 0} E\left(Y_t \mid X_t = x_0 + \epsilon\right) - \lim_{\epsilon \uparrow 0} E\left(Y_t \mid X_t = x_0 + \epsilon\right), \quad (5)
\end{aligned}$$

where Y_{1t} and Y_{0t} denote potential outcomes with and without exposure to treatment and the final equality holds as long as the conditional distributions of potential outcomes, $\Pr\left(Y_{1t} \leq y \mid X_t = x\right)$ and $\Pr\left(Y_{0t} \leq y \mid X_t = x\right)$, are continuous at $X_t = x_0$.[11]

Our setup is somewhat different from the conventional analysis in a cross-sectional framework. Namely, given the time-series nature of our data, the probability of treatment in one period can potentially affect the probability of treatment in subsequent periods. Consequently, we follow the methodology presented in Kuersteiner et al. (2016b) who note that the running variable may itself be a determinant of the outcome, but as long as the association is smooth then the sharp discontinuity in treatment at the cutoff can be used to estimate causal effects. This extension is useful in our context given that foreign holdings may carry some persistence (such as the case of any auto-regressive process).

To further clarify, our empirical analysis does not employ a panel RDD. That is, we first study the effects of the financial sector as a whole, and then focus separately on the foreign holdings of the five largest banks in the country. The running variable at each point in time is thus categorically either treated or not treated. Table 1 illustrates this point more clearly, by examining episodes in which controls were barely binding and barely missed.

3.2.1 Testable implications

Even though the continuity and unconfoundedness assumptions required in RDD analysis cannot be empirically tested, they do have some testable implications. In particular, evidence of a discontinuity at the threshold of the running variable would suggest that observations are

[11] In our case, $x_0 = 0.01$. We note that, as shown in Figure 1, the upper bound was never binding.

Table 1: Descriptive Statistics: 20% above (+) or below (−) threshold

Outcome Variable (Means)	Financial Sector	5 Largest Banks
Exchange rate +	1,944	1,929
	(252)	(243)
Exchange rate −	2,815	2,061
	(417)	(409)
1-month Forward rate +	1,919	1,870
	(211)	(60.7)
1-month Forward rate −	2,499	1,871
	(438)	(35.0)
6-month Forward rate +	1,934	1,881
	(225)	(62.4)
6-month Forward rate −	2,560	1,876
	(484)	(33.1)
Domestic Gov Bonds +		20.0
		(1.52)
Domestic Gov Bonds −		19.4
		(0.73)
Loans in COP +		100
		(10.3)
Loans in COP −		96.1
		(4.97)
Loans in USD +		8.3
		(2.50)
Loans in USD −		7.6
		(1.54)

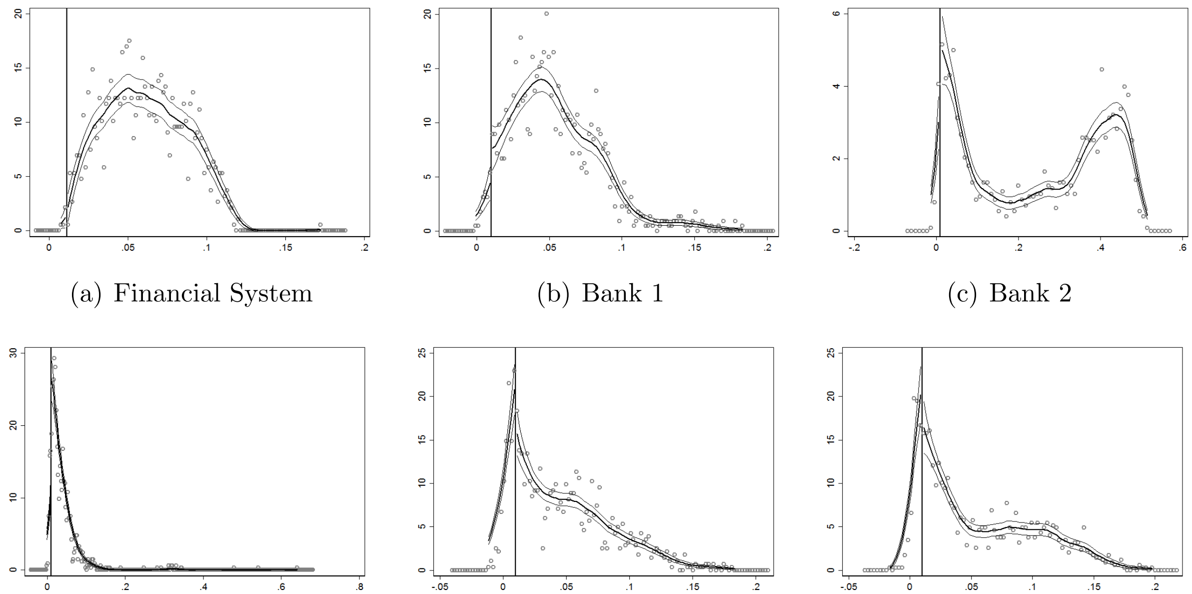
Authors' calculations. Values correspond to simple averages. The running variable for the financial sector and for each bank (on average) crosses the threshold a number of 9 and 80 times, respectively. The exchange rate and forward rate are expressed in COP/USD. Values in parenthesis correspond to standard deviations. Government Bonds and Loans (in pesos and in dollars) are expressed in COP trillions (10^{12}).

not randomly allocated (i.e. evidence of "*manipulation*", as presented in Lee and Lemieux 2010). This is opposite of what is wanted for when considering outcome variables, given that a discontinuity in the latter case would suggest a significant effect of treatment.

Following McCrary (2008), Figure 4 shows whether the densities of the running variables (i.e. foreign exposure relative to capital of the financial system and of the five largest banks in the country) exhibit a discontinuity at the cutoff point. In essence, the test separately estimates the density of the running variable on either side of $x_0 = 0.01$ and provides a Wald estimate in which the null corresponds to the non-existence of a discontinuity at the cutoff. As it turns out, the null is accepted in all cases with a p-value of: 0.12, 0.24, 0.17, 0.11, 0.14

and 0.12, respectively.

Figure 4: McCrary's Test for Different Running Variables



(a) Financial System

(b) Bank 1

(c) Bank 2

(d) Bank 3

(e) Bank 4

(f) Bank 5

3.2.2 Impulse response functions

We estimate the effects of regulatory limits by using both a parametric and a non-parametric approach. The parametric (global) approach consists of the following specification:

$$\Delta e_t = \beta_0 + \beta_1 D_t + \varphi_0(X_{t-1} - x_0) + \varphi_1(X_{t-1} - x_0) * D_t + \epsilon_t \quad (6)$$

where Δe_t denotes the exchange rate change (in logs) and φ_0 and φ_1 are polynomial functions of the running variable.[12] The treatment effect is then captured by β_1 when evaluating the conditional mean of outcome at the discontinuity point, comparing values above and below the threshold.

Our non-parametric approach consists of minimizing the following two objective func-

[12]We report polynomials of order 2. The reason for this is that while estimating regressions with large polynomials yields consistent estimates of treatment, they can be influenced by data far from x_0.

tions, each for windows above and below the discontinuity point:

$$\sum_{x_0-w<X_t<x_0} (\Delta e_t - \{\beta_0 + \beta_1(X_t - x_0)\})^2 \quad , \quad \sum_{x_0<X_t<x_0+w} (\Delta e_t - \{\alpha_0 + \alpha_1(X_t - x_0)\})^2 \qquad (7)$$

where w is the window size. The treatment effect in this case is captured by $\alpha_0 - \beta_0$. Finally, we follow Jorda (2005) method of local projections to estimate the implied impulse response functions (IRF's), using the treatment effects obtained from equations (6) and (7). Essentially, we estimate sequential regressions in which the endogenous variable (i.e. exchange rate change or portfolio balance) is shifted at each forecasting period.

3.3 Results

In this subsection we present separate results for the effects on the exchange rate and on portfolio shifts. A caveat, however, is that while changes in asset compositions can provide some insight into the inner workings of the bank-lending and risk-taking channels, we do not provide a direct link of how these channels influence the exchange rate.[13] Moreover, there can be additional drivers embedded in agent's expectations or other government policies that might help explain some our findings. Nonetheless, while future work is warranted on the connection between financial balance sheets and the exchange rate, we sustain that separate effects are still useful in order to evaluate the impact of a particular financial constraint.

3.3.1 Changes in exchange rate

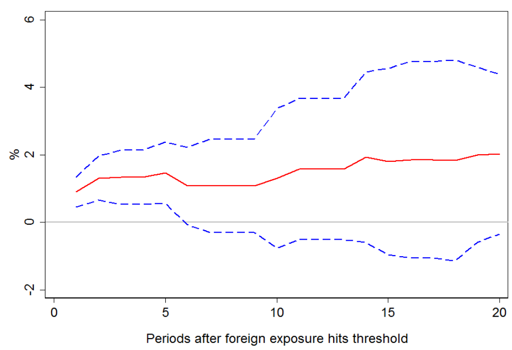
Figure 5 depicts the IRF's of exchange rate changes in response to financial constraints imposed on the entire financial sector. Estimates using a polynomial *global* regression (panel a) and using a sharp regression discontinuity (panel b) show that the effects on exchange rate changes are short-lived. Namely, the exchange rate depreciates in up to 2% following the enactment of controls, and the effects are significant only during the first couple of weeks.

Figure 6 further analyzes the effects of banking limits on the exchange rate, in episodes

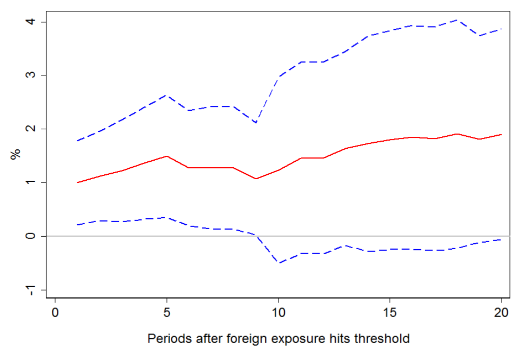
[13]For studies on the bank-lending and risk-taking channels see: Dominguez (2003), Gabaix and Maggiori (2014), and Bruno and Shin (2015), and Shin et al. (2018), among others.

of foreign exchange intervention (panel a) and in episodes of no intervention (panel b).[14] As shown, effects are significant only in episodes in which the CBoC intervened in the foreign exchange market. While these last results should be read with caution (especially since intervention dates account for 52% of our total sample), they do suggest that capital restrictions (i.e. banking limits) enable foreign exchange intervention to be effective. In other words, a transition from the *impossible trinity* to a *possible binity*.[15]

Figure 5: IRFs of changes in exchange rate on entire financial sector

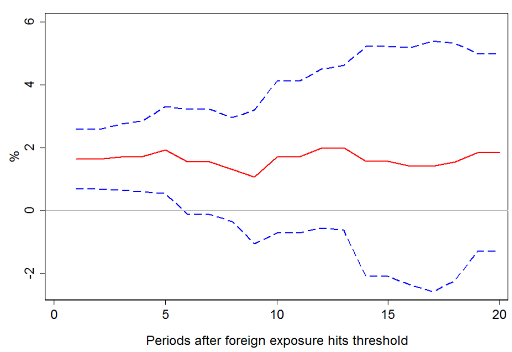


(a) Polynomial regressions

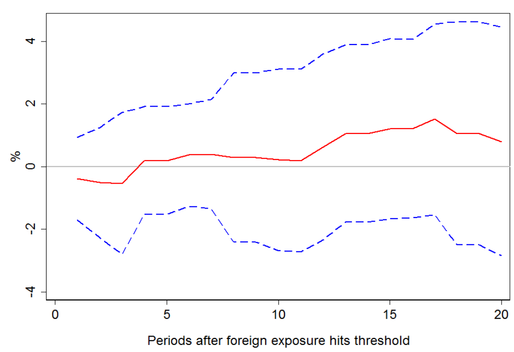


(b) RDD

Figure 6: IRFs of changes in exchange rate with and without FX intervention



(a) RDD Episodes of intervention



(b) RDD Episodes of no intervention

[14] We present results using only the RDD methodology but results are similar when using polynomial regressions.

[15] A caveat however, is that results vary depending on the sample period. For instance, effects on the exchange generally last for less than a week if the sample starts in March 2004 rather than in January 2004. In some cases, there can even be a reversal (negative effects on the exchange rate after the first week). Nonetheless, the immediate positive effect on the exchange rate is robust across all sub-samples considered.

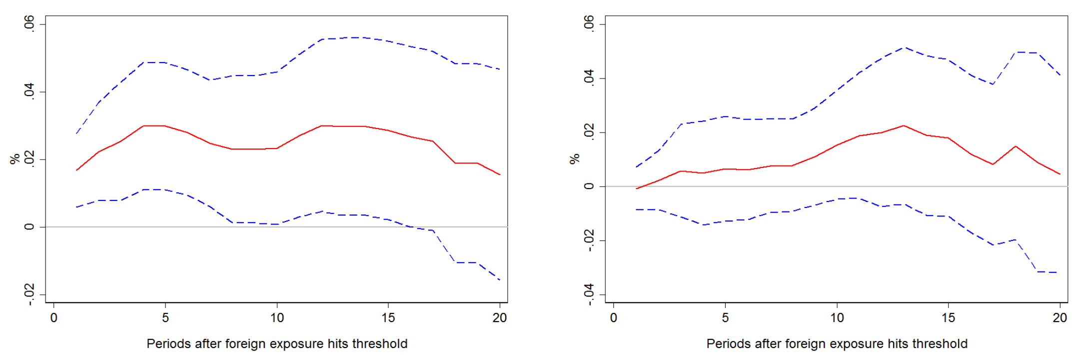
3.3.2 Portfolio shifts

We next consider the effects of banking limits on portfolio balances measured as:

- $\frac{(A_t^* - L_t^*)e_t}{A_t}$: Assets minus Liabilities in dollars (expressed in pesos) as a share of domestic assets
- $\frac{L_t^* e_t}{L_t}$: Loans denominated in dollars (expressed in pesos) as a share of domestic loans

Figures 7 and 8 show the IRFs for $\frac{(A_t^* - L_t^*)e_t}{A_t}$ and $\frac{L_t^* e_t}{L_t}$ when considering the five largest commercial banks in the country.[16] Results show that for all cases (except for panel (b) of Figure 7), there is a significant portfolio re-composition when banking limits bind. This confirms the portfolio channel's *modus operandi*. In other words, when banks' foreign exposures narrow in on the established regulatory limit, they immediately shift their assets and liabilities (denominated in dollars) so as to move away from the threshold. We sustain that it is mostly through this recomposition that the exchange rate is affected, although additional research on the expectations' channel is warranted.

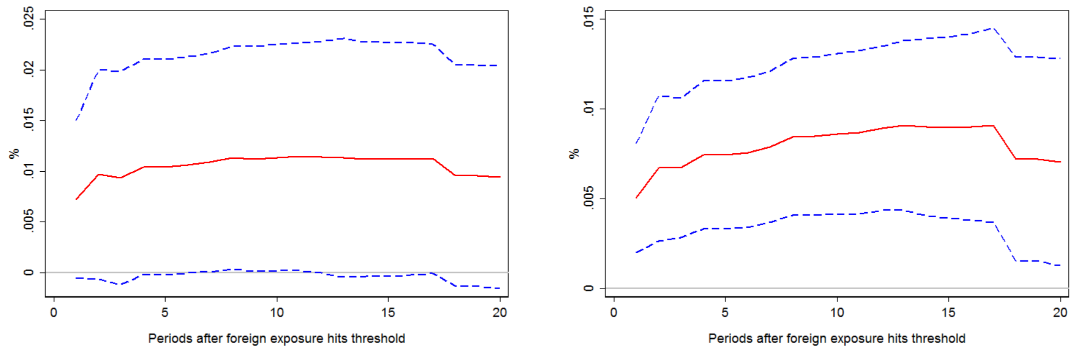
Figure 7: Implied IRFs of portfolio measure $\frac{(A_t^* - L_t^*)e_t}{A_t}$ on five largest banks



(a) Polynomial Regressions (b) RDD

[16]In accordance to law no. 1266 of 2008 ("Habeas Data"), we do not disclose the names of these banks.

Figure 8: Implied IRFs of portfolio measure $\frac{L_t^* e_t}{L_t}$ on five largest banks



(a) Polynomial Regressions

(b) RDD

4 Concluding remarks

We analyze the portfolio balance channel by studying the effects of banking limits established by financial regulations. We contribute to the literature in two important ways. First, we construct a general equilibrium model that allows us to portray the mechanism behind the portfolio channel when constraints on bank holdings of foreign assets bind. Second, we empirically test these predictions for the Colombian case during 2004-2014. We use a sharp regression discontinuity design to fit the description of the data generating process imposed by banking limits on foreign exchange exposure.

In our theoretical model, we find that when constraints on bank holdings of foreign assets bind, then there is a departure from UIP. This causes that the portfolio choice of the banks affects the equilibrium exchange rate. Furthermore, in this case a foreign exchange intervention can also determine the equilibrium exchange rate. These results don't hold when constraints don't bind. These postulations are consistent with our empirical findings which indicate that the effects of financial restrictions on the exchange rate are significant (albeit short-lived), only when banking limits bind. We also find significant effects on portfolio balances which can be construed as evidence of the portfolio balance channel when the monetary trilemma does not hold.

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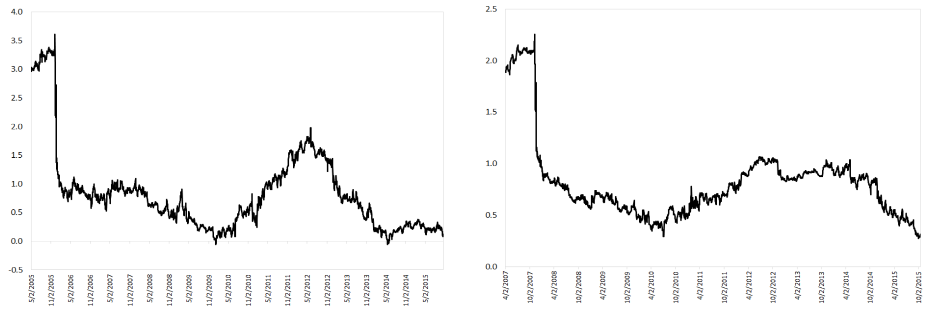
Appendix A Foreign exposure of banks

Figure B.1: Daily Average Change of Banks Foreign Exposure as % of Capital



(a) 500-Days Moving Average (b) 1000-Days Moving Average

Appendix B Stationarity properties

Table 2: Elliott-Rothenberg-Stock Test for Unit Root

Variable (up to 28 lags)	t-statistic	1% critical value	10% critical value
Financial System's Foreign Exposure[a]	-5.434	-3.480	-2.570
Five Largest Banks Foreign Exposure[a]	-5.064	-3.480	-2.570
Exchange rate Change	-7.756	-3.480	-2.570
Foreign Exchange Interventions	-6.131	-3.480	-2.570
Assets minus Liabilities (USD)[b]	-4.852	-3.480	-2.570
Change in Loans (USD)[c]	-23.976	-3.480	-2.570

Authors' calculations.([a]) expressed as share (%) of total capital.([b]) expressed as share (%) of domestic assets. ([c]) expressed as share (%) of domestic loans. The minimum lag is determined using the modified akaike's information criterion (MAIC).

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