FX interventions in Brazil: A synthetic control approach ☆

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ARTICLE INFO

ABSTRACT

In the aftermath of the taper tantrum, the Central Bank of Brazil announced a major program of sterilized foreign exchange intervention. We use a synthetic control approach to estimate its impact on the level and volatility of the exchange rate. Our counterfactual results, based on the experience of other emerging markets, indicate the program led to an appreciation of the Brazilian real in excess of 10%. Some of our estimates also point to a decline in the option-implied volatility. A second announcement extending the program had more muted effects, and subsequent extensions had little or no impact.

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1. Introduction

Are sterilized interventions effective? Do they change the level and/or volatility of the exchange rate? This is a very important question for central banks, but one where the empirical literature has struggled to find an answer. Studies on FX intervention face a substantial, perhaps insurmountable, endogeneity problem since a central bank tends to purchase FX when it wants to slow down an appreciation, and vice-versa. That can bias regression estimates (perhaps even to the point of flipping the sign of the "true" effect). Different strategies have been used to address this problem, including VARs, IV strategies, and relying on high-frequency data. All of these strategies have some drawbacks, including the extent to which they truly tackle the endogeneity bias. In this paper we explore a large "pre-announced" FX intervention program deployed by the Brazilian central bank, and use a synthetic control approach to quantify its impact on the exchange rate.

The Fed's taper announcement on May 2013 led to a major repricing of risk, adding pressure on several emerging market currencies. The Brazilian real (BRL) depreciated about 15% during the following three months, despite sizable interventions by the Brazilian Central Bank (BCB) in the foreign exchange market, and the removal of the last significant restrictions on capital inflows that had been previously deployed (see Chamon and Garcia, 2016 for details). On August 22, 2013, the BCB announced a major program of intervention through FX swaps, with the aim of satisfying the excess

demand for hedging and providing liquidity to the FX market. The program consisted of daily sales of US$500 million worth of currency forwards (USD swaps) in the Brazilian markets, that provided investors insurance against a depreciation of the real. These swaps settle in domestic currency and provide investors the very same hedging they would obtain by buying spot dollars and holding them until the maturity of the swap.[1] The program also indicated that on Fridays, the central bank auction offer US$1 billion on the spot market through repurchase agreements (short term credit lines in USD). The program announcement stated it would last until at least December 31, 2013. On December 18, 2013, the BCB announced that it would extend the program until at least mid-2014, although the daily interventions were reduced to US$200 million. On June 24, 2013, that program was extended until at least end-2014, and eventually extended until March 31, 2015.[2,3]

Fig. 1 shows the behavior of the BRL exchange rate (an increase in the exchange rate denotes a depreciation of the BRL) and the magnitude of these interventions. The BRL was depreciating at a rapid pace prior to the announcement, despite sizable ad hoc FX swap sales by the BCB. That trend is immediately reversed, with the BRL appreciating 10% in the month following the announcement. All in all, the announcement implied a cumulative intervention of about US$50 billion through end-2013. The program was extended, as discussed above, and the total amount of currency swaps stood at about US$110 billion at the end of March-2015, when new issuances of FX derivatives under this program ended. This amounts to almost a third of total FX reserves, making the program one of the largest episodes of reserve deployment in countries with a floating exchange rate regime. Another unique aspect of the program is that intervention took place through swaps, which is a temporary form of intervention since the additional FX hedge liquidity provided is eventually removed once the swaps expire. The program and its extensions spanned a year and a half, so much of the maturing swaps were rolled-over. Nevertheless, it still provides an example of large scale temporary intervention (albeit over a long horizon), which stands in contrast to many other country experiences (and studies) where intervention occurs mainly in the direction of accumulating reserves.

Most modern open economy models, assume uncovered interest parity holds, which leaves no scope for FX intervention to affect the exchange rate (some noteworthy exceptions include Benes et al., 2015 and Ghosh et al., 2016). Nevertheless, there is a very large empirical literature analyzing the effectiveness of central bank interventions. Sarno and Taylor (2001) survey the early literature, which typically focused on Advanced Economies and generally concluded that sterilized intervention was not very effective (with the possible exception of signaling future monetary policy). That is not surprising, since the amount of FX intervention pursued in advanced economies was a tiny fraction of the size of their bond markets. But in the case of Emerging Economies (EMEs), FX intervention has a non-trivial effect on the relative supply of local currency bonds. For example, in the case of Brazil, the stock of reserves corresponds to about a quarter of the stock of government bonds. So it seems reasonable to expect that a change in the relative supply of assets of that magnitude to have some effect on the exchange rate. More recent papers focusing on emerging markets tends to find more supportive evidence for an effect, but the evidence remains somewhat mixed. Menkhoff (2013) provides an excellent survey of that literature.

In the Brazilian context, a number of papers have shown that FX intervention, including through swaps, can affect the exchange rate. For example, Andrade and Kohlscheen (2014) show that the Brazilian real moved about 0.33 bps following the announcement of a currency swap auction. Barroso (2014) estimates that a purchase or sale of US$1 billion lead to a 0.51% depreciation or appreciation of the Brazilian real. Vervloet (2010) found that the effects of sterilized interventions are small on its magnitude (between 0.10 and 1.14% for each US$1 billion) and of low duration. More generally, estimates for the effect of a US$1 billion dollar intervention on the exchange rate typically range from 0.10 to 0.50%.

In this paper we use a synthetic control approach to estimate the effects of the Brazilian swap program. To our knowledge, we are the first paper to use this technique to study the effect of FX interventions.[4] We follow Abadie et al. (2010), which in a nutshell, consists of constructing a synthetic control group that provides a counterfactual exchange rate against which we can compare the evolution of the Brazilian real after that announcement. This methodology is not appropriate for studying the effect of frequent interventions, but it is well suited for an event-study setting where a large change in intervention policy is announced, as in the case of Brazil.[5] Our counterfactual uses data from other countries, with weights that are based on the pre-announcement co-movement with Brazil. As a result, whatever noise and error is involved in this type of analysis, it will be orthogonal to the endogeneity problem that plagues the literature on FX intervention. Moreover, to the extent that other emerging markets also intervened to stabilize their currencies in the aftermath of the Fed's tapering announcement, our results will underestimate the true effect of the Brazilian intervention program (since the counterfactual will not take into account that others also intervened). Synthetic controls are also particularly appropriate in the context of a large common external shock, where drivers of the exchange rate that are unobservable or hard to quantify were likely similar across emerging markets.

Our findings point to an appreciation of the BRL in the first few weeks following the announcement of the program in excess of 10 percentage points. This is consistent with a surprise effect on the market, which by all accounts was not expecting the program. This result is particularly striking, once we take into account that the BCB was already intervening substantially in the market prior to the program, albeit in a discretionary fashion. In fact, the pace of intervention declined after the program (as shown in Fig. 1). Focusing on the first weeks can sharpen the focus on the impact of the announcement, but may underestimate the overall impact of the program. While the exchange rate is a forward-looking variable and markets would price-in that future intervention, the standard portfolio effect of intervention would only materialize after the intervention actually takes place. But despite that potential downward-bias, the results still point to a sizable impact. This type of frontloaded response is not unusual, and has been observed in other contexts. For example, Pincheira (2013) documents a significant depreciation of the Chilean

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[1] Because they settle in real, they involve convertibility risk. For a detailed discussion of these contracts, please refer to Garcia and Volpon (2014). Except for convertibility risk, intervention through currency forwards produces the same effects of sterilized interventions as far as changes in central bank and private sector portfolios are concerned.

[2] For a detailed discussion of the program, please refer to Kang and Saborowski (2015).

[3] Pre-announced rules-based FX sales have been used in a number of other countries. For example, Colombia has followed rules, whereby it would automatically intervene in the spot market once the exchange rate depreciated beyond a certain threshold compared to its 20-day moving average. Mexico used pre-announced rules involving daily sales of foreign exchange over a period of time, as well as sales that were only triggered following a sufficiently large depreciation relative to the previous day. What really sets this Brazilian program apart from all others is the massive scale of the intervention deployed under the pre-announced rules.

[4] Jinjarak et al. (2013) use the synthetic control method to analyze the effects of the adoption and removal of capital controls in Brazil on capital flows and the exchange rate. Their results show that capital controls had no effect on capital flows and small effects on the exchange rate.

[5] Another technique from the applied micro-literature that has been used in the international finance literature is propensity-score matching (e.g. Forbes and Klein, 2015). But synthetic controls is the appropriate technique for the purposes of our paper where we only have one treated unit (the intervention program in Brazil).
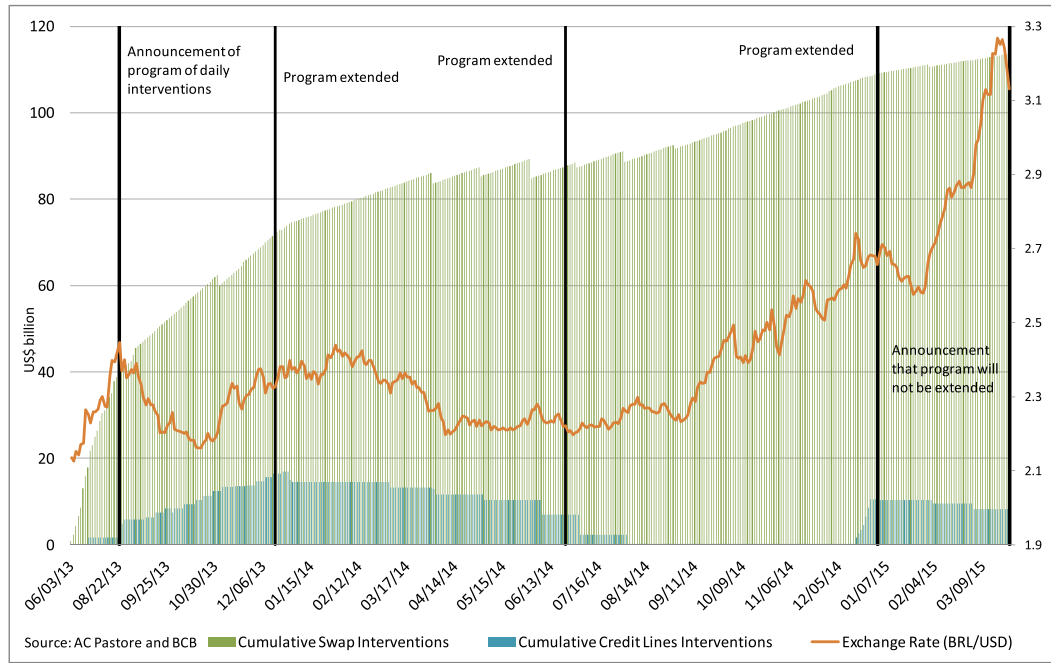
Fig. 1. Cumulative swap interventions, cumulative credit line interventions and exchange rate (BRL).
Source: BCB and AC Pastore.

peso in the aftermath of the central bank's announcement of reserve accumulation programs in 2008 and 2011 (with sizable currency depreciation taking place before actual dollar purchases began).

We also construct synthetic control groups using the methodology proposed by Carvalho et al. (2016), which extends the original technique to use the time-series dimension of data, and provides standard-errors, allowing for statistical inference. That approach points to a similar effect on the BRL (if anything stronger) following the announcement of the program, and that effect is statistically significant. Our results on the option-implied volatility are more mixed, with some of our estimates pointing to a tangible decline while others do not. A similar analysis of the follow-up announcements (extending the program) point to a more muted effect, which is not surprising since by most accounts the market was already expecting the program to be extended in some form. Please note that we cannot estimate the effect of interventions using a more standard regression approach because of the lack of variation in the intervention data (which followed the scheduled announcement during the program).[6]

When we compare the impact of the program's announcement on the exchange rate with the total amount of intervention involved in that announcement, it is broadly in line with the estimates for the effectiveness of FX Intervention in Brazil from previous studies. The confirmation of the estimates from those studies is a result worth highlighting. It suggests that the endogeneity problems that plague this literature can indeed be overcome using strategies such as IV (or at a minimum, they have been overcome in those particular studies). This provides useful information not only to researchers but also to central banks, which often have to rely on standard regression approaches to gauge the effectiveness of their intervention due to the absence of episodes suitable for an event study/synthetic control estimation.

The remainder of the paper is organized as follows. Section 2 outlines the methodologies used, Section 3 presents data description and Section 4 shows our results. Section 5 revisits the comparison with previous studies to shed light on which strategies were effective in dealing with the endogeneity problem. Finally, Section 6 concludes.

2. Methodology

In this section, we describe the synthetic control approach.

2.1. *Abadie et al. (2010)*

Let Y_{it}^I denote the exchange rate in country i in period t, which adopts a policy (e.g. an FX intervention program) at time T_0, and Y_{it}^N denote non-observed exchange rate that would have occurred had the country not adopted that policy.

We assume that there is no effect of the intervention program in the period preceding the policy change ($t < T_0$), i.e., $Y_{it}^N = Y_{it}^I$. Hence, the effect of the program is given by $\alpha_{it} = Y_{it}^I - Y_{it}^N$ from period T_{0+1} to T. Without loss of generality, suppose the policy change occurred on country $i = 1$ (Brazil in our case). We assume that Y_{it}^N follows a factor model given by

$$Y_{it}^N = \delta_t + \theta_t Z_i + \lambda_t \mu_i + \varepsilon_{it} \tag{1}$$

where λ_t is an unknown common factor that depends on time, Z_i is a vector of observable variables, θ_t is a vector of parameters and μ_i is a vector of factor loadings. At last, ε_{it} is a mean zero iid shock.

Consider a vector of weights $W = (\omega_2, \dots, \omega_{j+1})'$, such that $\omega_i \geq 0$ and $\sum_{i=2}^{j+1} \omega_i = 1$. Suppose that there is an optimal weight vector $\hat{W}$ that can accurately replicate pre-treatment observations in Brazil. Abadie et al. (2010) show that under regular conditions $Y_{it}^N = \sum_{i=2}^{j+1} \hat{\omega}_i Y_{it}$. Thus, we can calculate $\hat{\alpha}_{1t} = Y_{it} - \sum_{i=2}^{j+1} \hat{\omega}_i Y_{it}$ for $t \geq T_0$.

Define X_1 as a vector of pre-treatment characteristics for Brazil that contains Y and Z, and similarly X_0 for the control countries.

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[6] We did perform a more standard event-study regression analysis, which is available upon request. It confirms a large effect on the exchange rate following the August announcement (with a cumulative appreciation of about 10%), but not for the extension of the program.

Hence, the optimal weight vector $\hat{W}$ is chosen through the minimization of the following criterion:

$$\sqrt{\left(X_1 - X_0\hat{W}\right)' V \left(X_1 - X_0\hat{W}\right)} \qquad (2)$$

where V is a $k \times k$ symmetric and positive semi-definite matrix (k is the number of explanatory variables). Also V is chosen to minimize the mean square prediction error in the period prior to the policy change. We use the STATA *synth* routine to obtain V.

Finally, we use permutation tests to examine the significance of our results, since the usual methods for statistical inference are not available. For each control country in our sample, we estimate a "placebo" effect assuming that it also implemented an FX intervention program at T_0. We can then compare the effect estimated for the Brazilian exchange rate with the one for these placebos.

2.2. *Carvalho et al. (2016)*

Consider n countries for T periods indexed by $i \in \{1, \ldots, n\}$. As in Abadie et al. (2010), assume that one country implemented a policy change in T_0. Furthermore, consider that we observe q variables for each country i and that they all follow jointly a covariance-stationary process. We can then stack all the n countries in a vector $y_t = (y_{1t}, \ldots, y_{nt})'$ and use the Wold decomposition to write the following equation for $1 \le t \le T$:

$$\mathbf{y_t} - \mu_{\mathbf{t}} = \sum_{j=0}^{\infty} \phi_{t-j} \varepsilon_{t-j} \qquad (3)$$

where each ϕ_{t-j} is a $(nq \times nq)$ matrix and the constraint $\sum_{j=0}^{\infty} \phi_{t-j}^2 < \infty$ must be satisfied for $1 \le t \le T$. Also, ε_t is a nq-dimensional serially uncorrelated white noise with covariance matrix Σ_t.

Let Brazil be indexed by 1 and define the direct effect in our variable of interest y_{1t} as

$$\delta_{\mathbf{1t}} = \mathbf{y_{1t}} - \mathbf{y_{1t}^*} \qquad (4)$$

where $\mathbf{y_{1t}^*}$ is our variable of interest without the FX intervention program. But, $\mathbf{y_{1t}^*}$ is not observed, therefore, we have to estimate $\mathbf{y_{1t}^*}$ before estimating $\delta_{\mathbf{1t}}$. For this reason, we consider the best linear predictor as $\left(\mathbb{E}\left(y_{1t}^* | 1, y_{-1t}^*\right)\right)$

$$\mathbf{y_{1t}} = \mathbf{y_{1t}^*} = \mathbf{w_0} + \mathbf{w_1}\mathbf{y_{-1t}} + \mathbf{v_{1t}}, 1 \le t \le T_0. \qquad (5)$$

where $\mathbf{y_{-1t}}$ is a matrix with all q variables for all $n-1$ countries (not including Brazil), $\mathbf{w_1}$ is a $(q \times (n-1)q)$ matrix and $\mathbf{w_0}$ is $(q \times 1)$ vector.

We estimate w by OLS for all the q equations.[7] While Abadie et al. (2010) constraint the weights to be non-negative and to add up to one, Carvalho et al. (2016) allow for negative weights which can capture information that would otherwise be missed, and also relaxes the assumption on their sum. For example, consider an extreme case where there is a perfectly negatively correlated country with Brazil. Under the restrictions adopted by Abadie et al. (2010), this peer would be disregarded despite the fact that it provides a perfect synthetic counterfactual. Similarly, consider the case where all peers are uncorrelated to Brazil. Due to the restriction that weights sum to one in Abadie et al. (2010), the estimator would assign weights even though the peers cannot help explain the counterfactual for Brazil.

Differently from Abadie et al. (2010), Carvalho et al. (2016) presents the statistical inference for the average direct effect between period T_{0+1} and T. Hence, we can test if the effect of the intervention program on the Brazilian exchange rate is statistically significant. In addition, other moments can be tested. We are also interested on whether the program had an effect on the exchange rate volatility. We consider the same linear specification as in Eq. (5) and our dependent and independent variables become $\ddot{\mathbf{y}}_{\mathbf{1t}} = (\mathbf{y_{1t}} - \bar{\mathbf{y}}_{\mathbf{1t}})^2$ and $\ddot{\mathbf{y}}_{\mathbf{-1t}} = (\mathbf{y_{-1t}} - \bar{\mathbf{y}}_{\mathbf{-1t}})^2$, respectively. Therefore, the average effect is also estimated and all the hypothesis testing can be carried on (see Carvalho et al. (2016) for more details).

3. Data

Our analysis consider three outcome variables of interest: the exchange rate (bilateral exchange rate with respect to the USD), its 3-month option-implied volatility, and risk reversal. The latter measures the difference between the volatility implied by an out-of-the-money put option (25 delta) and an equivalent out-of-the-money call option, which is a measure of the insurance premium investors are willing to pay to insure against a risk-off episode. Fig. 2 plots the evolution of the option-implied volatility over time. There was a rapid increase in volatility following the "tapering" speech. Volatility declines substantially after the program announcement, eventually settling at a lower level (although still higher than the volatility prior to the tapering speech). Volatility does not respond much in the immediate aftermath of the program extension announcements. Fig. 3 is analogous to Fig. 2 but plots the evolution of the option-implied risk reversal. There is a marked reduction following the program and the first extension.

In addition to these outcome variables, explanatory variables include capital flows, and stock and bond market indices. The source of all data is Bloomberg, except for the capital flow series which comes from the Emerging Portfolio Fund Research (EPFR) database. We use weekly data in our synthetic estimates (the highest frequency at which the capital flows series is available). For each event, we consider a window consisting of the 12 weeks prior to the announcement, the week of the announcement, and the 12 weeks afterwards. While the choice of a 12-week window is arbitrary, the main results are robust to considering alternative shorter and longer windows.

We consider a sample of 16 countries when estimating the synthetic for Brazil, which includes Australia, Chile, Colombia, India, Indonesia, Korea, Malaysia, Mexico, New Zealand, Peru, Philippines, Poland, Russia, South Africa, Thailand, and Turkey. We included all the emerging market countries with EPFR data plus Korea, and
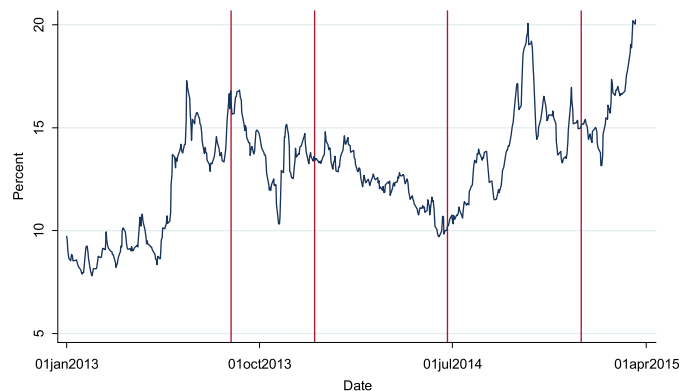
Fig. 2. Brazilian real option-implied volatility. Notes: Vertical bars indicate the program announcement and extensions.
Source: Bloomberg.

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[7] As stressed by Carvalho et al. (2016), it is one of the possible ways to estimate Eq. (4).
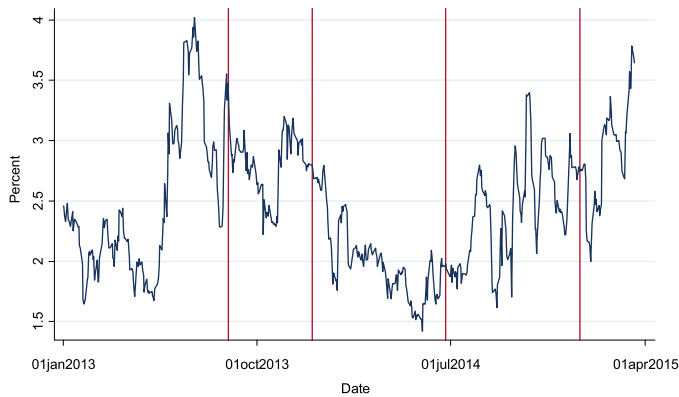
Fig. 3. Brazilian real option-implied risk reversal. Notes: Vertical bars indicate the program announcement and extensions. Risk Reversal measures the difference between implied volatility of out-of-the-money put and out-of-the-money call (25 delta).
Source: Bloomberg.

Australia and New Zealand (the latter two because they are major carry trade currencies).

For the implementation of both methodologies, the series used should be stationary. For this reason, we use the log difference of the exchange rate, equity and bond indices, and the difference of the option-implied volatility and risk-reversal in our analysis. Capital flows are scaled by the 2012 GDP in US dollars for each country.

4. Results

In this section, we estimate the impact of the FX intervention program in Brazil.

4.1. Program announcement

4.1.1. Level effect
Fig. 4 presents our estimates for the effect of the program announcement on the exchange rate. As mentioned in the introduction, there was a ramp-up in (ad hoc) FX intervention prior to the program announcement, which failed to stem the depreciation pressures. But since this took place prior to the announcement (during the estimation window, but prior to the post-event window), if anything it would bias the estimates downwards (i.e. underestimate the impact of the program). The announcement came during a monetary policy tightening cycle, which had started back in April 2013 (the pace of tightening remained the same before and after the announcement).[8]

The estimation uses the log change in the exchange rate as the dependent variable. But in order to more easily illustrate the resulting effect on the level, we accumulate the weekly log differences for the actual and for the synthetic exchange rates, and report the gap between the two. That gap is set to zero on the last observation prior to the announcement (so the level at any date *t* corresponds to the gap in the accumulated log differences from *t* to the announcement, and vice-versa). Fig. 4(a) shows the estimates using the Abadie et al. (2010) approach. In addition to the log change in the exchange rate, the explanatory variables considered include capital flows, the change in volatility, and the log change in the equity and bond

indices. The thick dark line indicates the gap between the actual BRL and its synthetic (a negative value indicates that the BRL was more appreciated than its synthetic), while light gray lines indicate the gap for the other countries, which are used as a placebo test. The gap for the BRL is slightly negative and broadly stable during most of the pre-announcement period. But the gap declines sharply after the announcement, remaining at a substantially negative level. The bulk of the change takes place in the first week (about 10 percentage points). But the trend persists with the gap peaking at close to 15 percentage points before narrowing slightly. This pattern is consistent with a large response following the announcement, since the exchange rate is a forward-looking variable, but some delayed response as some of that additional FX liquidity only materialized down the road. If the market anticipates a large portfolio effect coming in the near term, it will expect the BRL to appreciate. But an expected gradual appreciation would imply a near-arbitrage opportunity, which would increase the demand for BRL, causing the exchange rate to appreciate today in response to the portfolio effect coming down the road, explaining the frontloaded impact of the program. On a related point, please note the exchange rate did not behave significantly differently on Fridays, when there was an additional $1 billion USD intervention on top of the daily $500 million swaps (consistent with pre-announced interventions being priced-in by the market).[9] These results imply that the BRL was over 10 percentage points stronger than what its synthetic would suggest for several weeks after the announcement. Moreover, please note that the gap for the BRL is a major outlier vis-a-vis the placebos in the post-announcement period, with none of the placebos experiencing nearly as large a shift (in the pre-announcement period, both the BRL and placebos should hover around zero by construction). The weights and countries used for the construction of the synthetic control group do not have an economic interpretation, a point that is stressed in the literature (e.g. Abadie et al., 2010).[10,11] The means for Brazil and for its synthetic are reported in Table 1.

The effect of this program is also estimated using a univariate approach that considers only the exchange rate, following the methodology proposed in Carvalho et al. (2016). Under this approach, we cannot consider all peers and control variables (otherwise there would be more parameters being estimated than the data available). We choose 3 peers that maximize the fit of the exchange rate regression: South Africa, Thailand and Peru. The counterfactual is estimated through a regression of the BRL on the others peers' change in log of exchange rate and a constant.[12] The gap between the actual and synthetic BRL is reported in Fig. 4 (b). The results point to a cumulative effect that is even stronger, peaking at around 20 percentage points. This approach provides a statistical inference for the average effect, which is statistically significant (with a p-value below 2% at four lags). The effect is smaller when the counterfactual is estimated without a constant (around five percentage points).

4.1.2. Volatility effect
The approach in Carvalho et al. (2016) allows us to estimate other moments of the exchange rate. We can estimate an effect on volatility by using the squared change in the log of the exchange rate as the dependent variable (and the corresponding variable for other countries as the explanatory variable). The estimates suggest the average effect on the variance is close to zero and not statistically significant.

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[8] Other noteworthy policy measures included the removal of the last key controls on capital inflows that Brazil had adopted earlier. A tax on fixed income inflows was removed on June 4, 2013, and a tax on the notional amount of currency derivatives was removed on June 12, 2013. But again, both measures took place prior to the program's announcement.

[9] A simple test of difference in means for the change in the exchange rate does not reject the hypothesis that they are the same on Friday and the other week days (with a t-stat of 0.13).
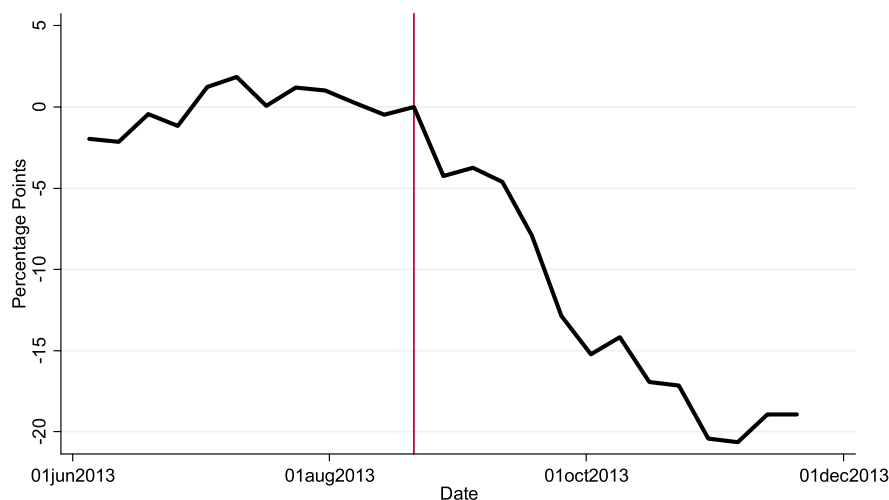[10] With that caveat in mind, the synthetic draws from India, Indonesia and Malaysia, with weights of 14, 76, and 9%, respectively.
[11] Results are similar when we consider only inflation targeting countries.
[12] The R^2 of a regression of BRL in these currencies is equal to 0.8.
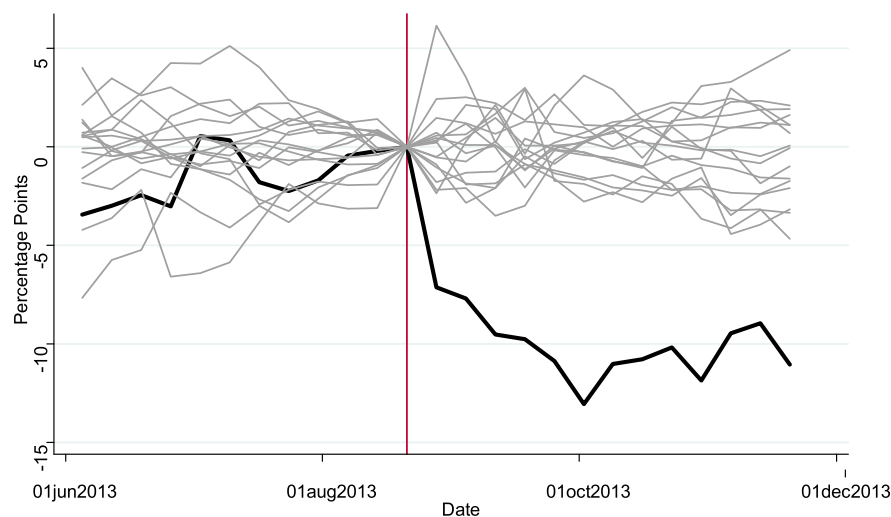
(a) Gap Between Actual and Synthetic

(b) Gap Between Actual and Univariate Synthetic

Fig. 4. Effect of the program announcement on the level of the exchange rate and placebo tests. Notes: Figures plot gap between the cumulative change in the log of the actual exchange rate and that implied by the synthetic estimates. Thick dark line indicates the gap for Brazil, and light gray lines indicate the gap for estimates from other countries (placebos). For ease of illustration, gaps are set to zero on the last observation prior to the announcement, which is indicated by the vertical line. Panel a based on the methodology in Abadie et al. (2010) and panel b based on Carvalho et al. (2016).

We can also assess the impact of the program on volatility using the option-implied exchange rate volatility. This readily available series provides a forward-looking measure of volatility (since it is based on option prices) that can quickly respond to the program (unlike say, measures of volatility constructed from past exchange rate data). Fig. 5 reports the results. In addition to the change in the volatility, we use the changes in the exchange rate, equity and bond indices, and capital flows as explanatory variables. For ease of illustration, we accumulate all the changes so as to report the resulting level of effect (setting the level at the last observation prior to the announcement to zero). Again, the thick dark line corresponds to the BRL while the thin gray lines to the placebo tests. There is a sharp decline in the gap in volatility after the announcement, by 5 percentage points, which is driven mainly by an increase in volatility among the countries in the synthetic control (India in particular) rather than an absolute decline in volatility for Brazil.[13] If we drop

India from the pool of potential countries for the synthetic control, the results continue to point to a decline in volatility, but of only 2 percentage points.[14] That would still be a sizable decline (to put magnitudes in perspective, the volatility of the BRL was about 17% in the last observation prior to the announcement, so a 2 percentage point decline amounts to over 10% of the original volatility). The placebo tests point to the BRL being an outlier after the announcement. But the discrepancies in Fig. 5 (a) between the BRL and the placebos is much smaller than in Fig. 4 (a).

Fig. 5 (b) reports the results using the univariate approach, drawing on Peru and India. The results are more muted, and not statistically significant.

Finally, Fig. 6 is analogous to Fig. 5 (a) but reports results for the risk-reversal measure. There is a sharp decline following the announcement (driven mainly by a decline in that variable for Brazil,

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[13] The synthetic draws on Australia and India, with weights of 31 and 69%, respectively.

[14] The synthetic would draw on Australia and Indonesia, with weights of 64 and 36%, respectively.

Table 1

Predictor means for the synthetic estimates. Notes: Treatment corresponds to the means for Brazil, and synthetic to the means for its synthetic estimates in the figure indicated by the different columns. For example, the results under the Fig. 4 (a) heading correspond to the means and synthetic for the log change in the exchange rate in the sample around the program announcement. For ease of illustration, variables are scaled to 100 times the log change in the exchange rate, equity and bond indices, and volatility, risk reversal and capital flows are measured in percentage terms.

	Fig. 4 (a)		Fig. 5 (a)		Fig. 6		Fig. 7 (a)	
Variable	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic
$\Delta\log(ExchangeRate)$	1.257	0.913	1.1257	0.938	1.257	0.528	0.364	0.252
$\Delta\log(Volatility)$	0.379	0.737	0.379	0.371	0.379	0.364	−0.066	−0.171
$\Delta(RiskReversal)$					0.034	0.040		
$\Delta\log(EquityIndex)$	−0.671	−1.687	−0.671	−0.747	−0.671	−0.692	−0.587	−0.587
$\Delta\log(BondIndex)$	−0.993	−0.986	−0.993	−0.399	−0.993	−0.562	−0.268	−0.030
$Capitalflows/GDP$	−0.002	−0.002	−0.002	−0.001	−0.002	−0.002	−0.002	−0.001

	Fig. 8 (a)		Fig. 9		Fig. 10		Fig. 11	
Variable	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic
$\Delta\log(ExchangeRate)$	0.364	0.364	0.364	0.095	−0.277	−0.266	0.692	0.686
$\Delta\log(Volatility)$	−0.066	−0.066	−0.066	−0.028	−0.096	−0.181	−0.152	0.301
$\Delta(RiskReversal)$			0.001	−0.003				
$\Delta\log(EquityIndex)$	−0.587	−0.586	−0.587	−0.280	1.171	0.884	−0.019	−0.019
$\Delta\log(BondIndex)$	−0.268	0.026	−0.268	−0.175	0.393	0.411	0.260	0.259
$Capitalflows/GDP$	−0.002	−0.001	−0.002	−0.001	0.001	0.001	−0.001	−0.001
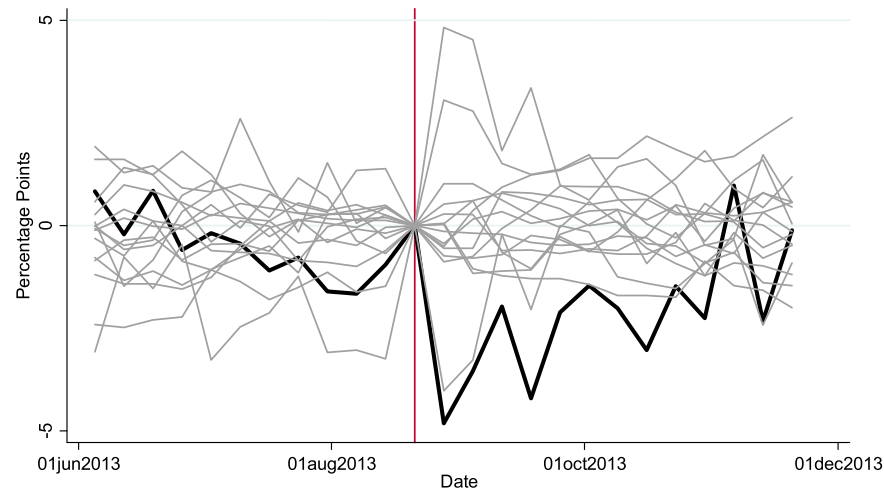
(a) Gap Between Actual and Synthetic
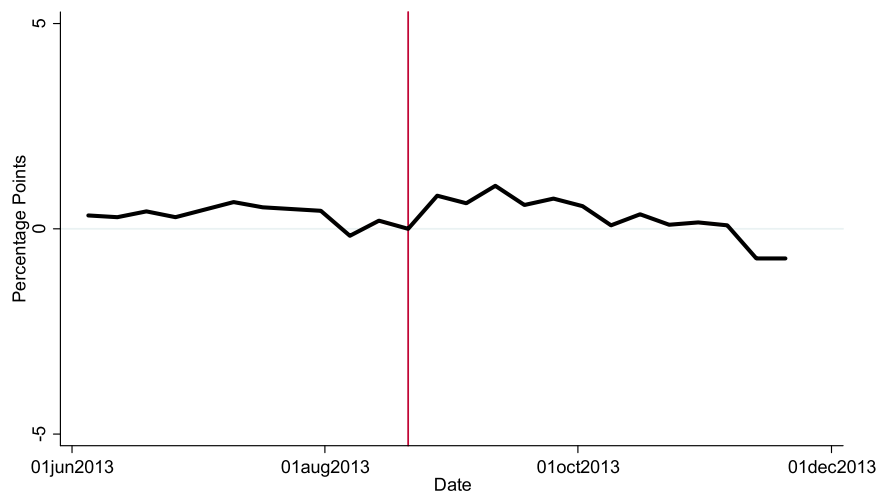
(b) Gap Between Actual and Univariate Synthetic

Fig. 5. Effect of the program announcement on the option-implied volatility of the exchange rate and placebo tests. Notes: See notes to Fig. 4.
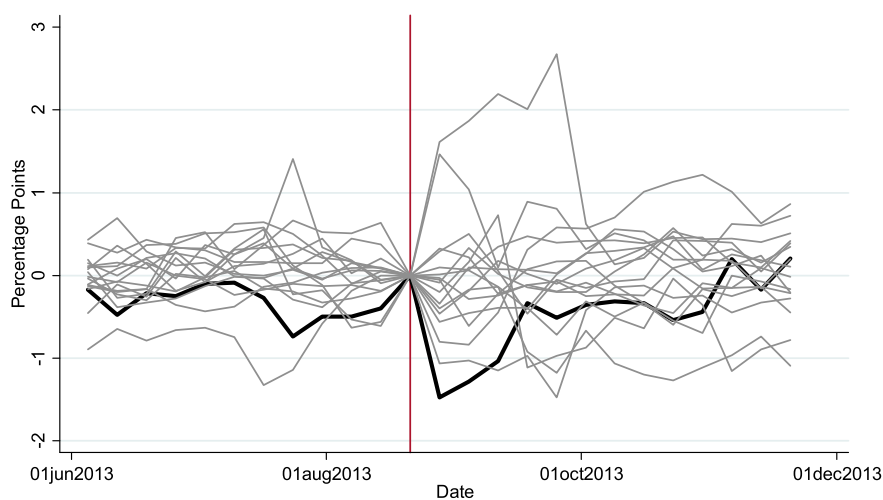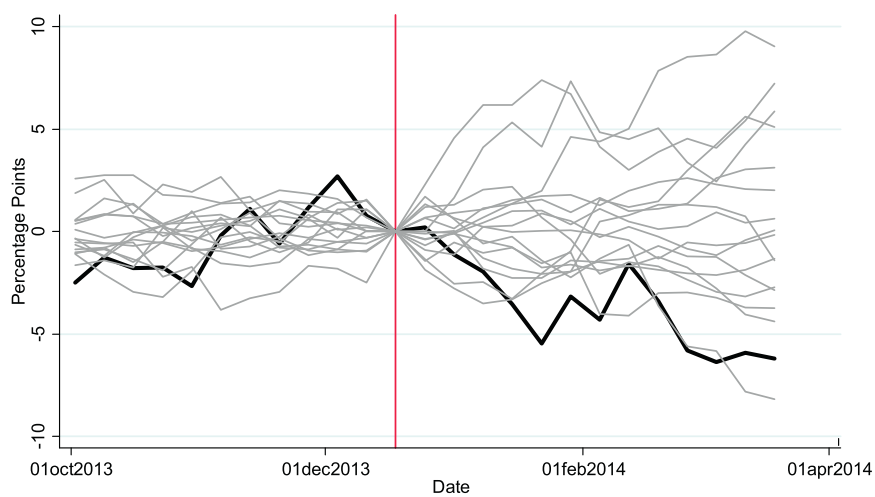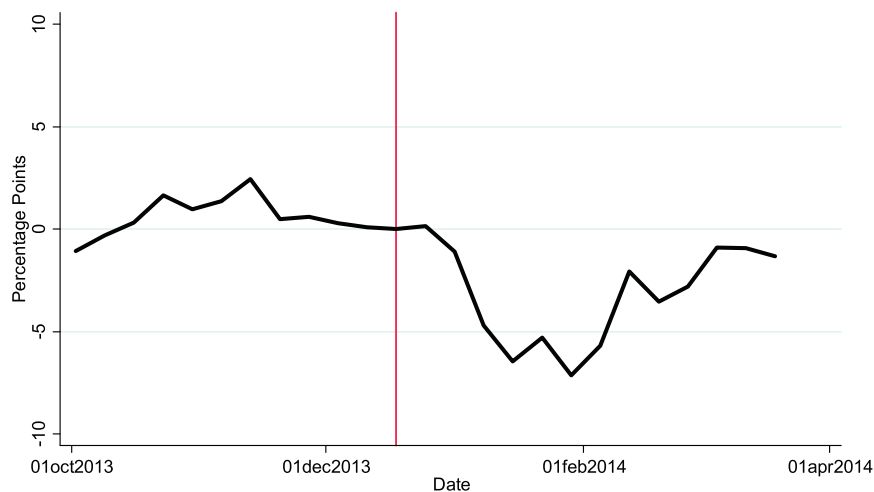
Fig. 6. Effect of the program announcement on the option-implied risk reversal of the exchange rate and placebo tests. Notes: See Notes to Fig. 4, panel a.

(a) Gap Between Actual and Synthetic

(b) Gap Between Actual and Univariate Synthetic

Fig. 7. Effect of the December 2013 announcement on the level of the exchange rate and placebo tests. Notes: See notes to Fig. 4.

(a) Gap Between Actual and Synthetic

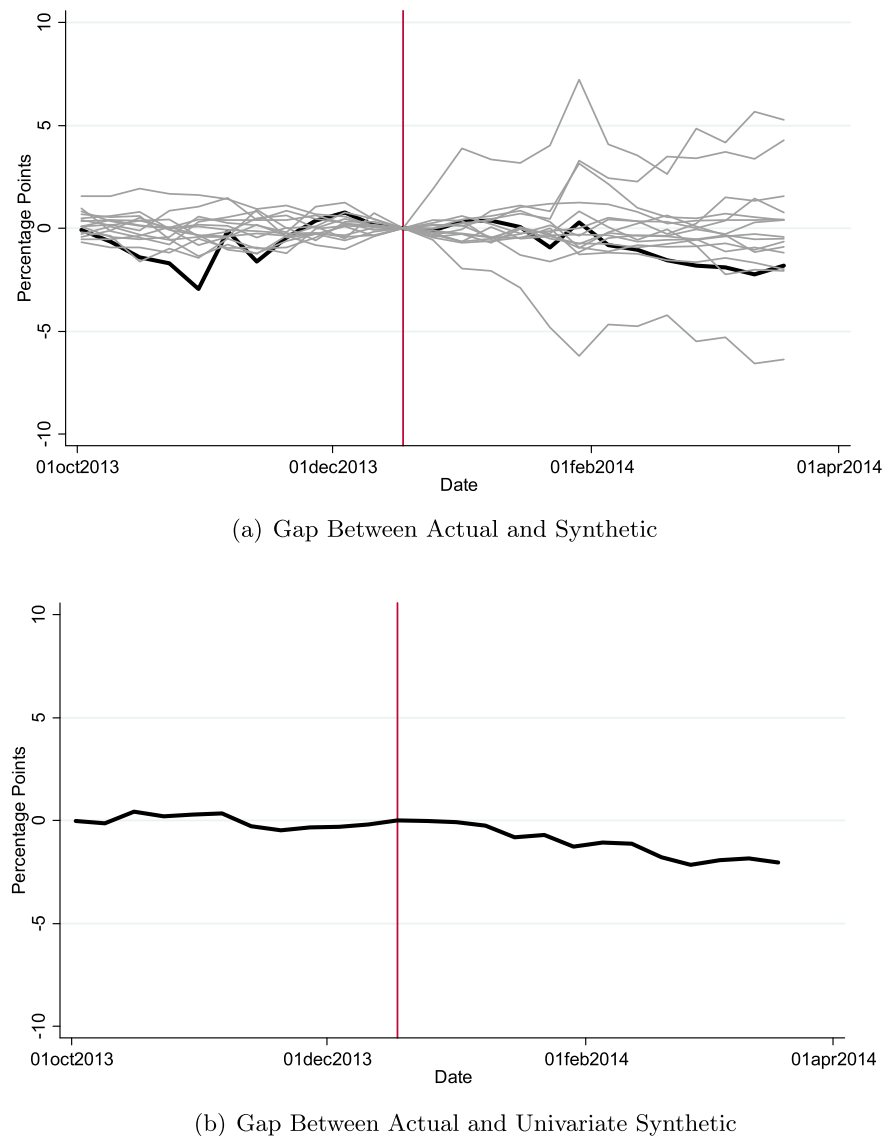(b) Gap Between Actual and Univariate Synthetic

Fig. 8. Effect of the December 2013 announcement on the option-implied volatility of the exchange rate and placebo tests. Notes: See notes to Fig. 4.

which goes from 3.5 to 2.7 in the two observations before and after the announcement). A comparison with the placebos suggests the behavior of the BRL was an outlier in the two weeks following the announcement, but not afterwards.

4.2. Program extension announcement

4.2.1. Level effect

On December 18, 2013, the intervention program was extended until mid-2014, but with reduced daily interventions. There were expectations that the swap sales would continue (i.e. the market did not expect it to end abruptly at the end of 2013), but the announcement removed that uncertainty and clarified the scope of the program going forward. Therefore, the announcement could still impact the exchange rate, but that impact should be less dramatic than the one following the first announcement.

Fig. 7 is analogous to Fig. 4, but reports the results for the cumulative changes in the exchange rate around this second announcement. Fig. 7 (a) points to a gradual appreciation of the BRL vis-a-vis its synthetic, with that gap reaching about 5 percentage points, and remaining close to that level. A comparison with the gaps for the

placebos suggest that the BRL was clearly on the stronger side, but was not nearly as much of an outlier as in Fig. 4 (a).[15]

Fig. 7 (b) reports the result under the univariate approach. The results also point to a decline of around 5 percentage points over the first four weeks, but that is gradually reversed over time. The effect is not statistically significant under any lag structure.

4.2.2. Volatility effect

Fig. 8 is analogous to Fig. 5, but reports the effect on the option-implied volatility following the second announcement. There is virtually no change in volatility under neither of the methodologies considered. We also do not find any statistically significant effect of the second announcement when we estimate the synthetic for the squared log change in the exchange rate, using the univariate approach. There is also virtually no effect on the risk reversal following the second announcement (Fig. 9). While there is a sharp decline in risk reversal for Brazil, as shown in Fig. 3, the same was true for its

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[15] The synthetic draws on Australia, Indonesia, Peru and Turkey, with weights of 19, 9, 5 and 67%, respectively.
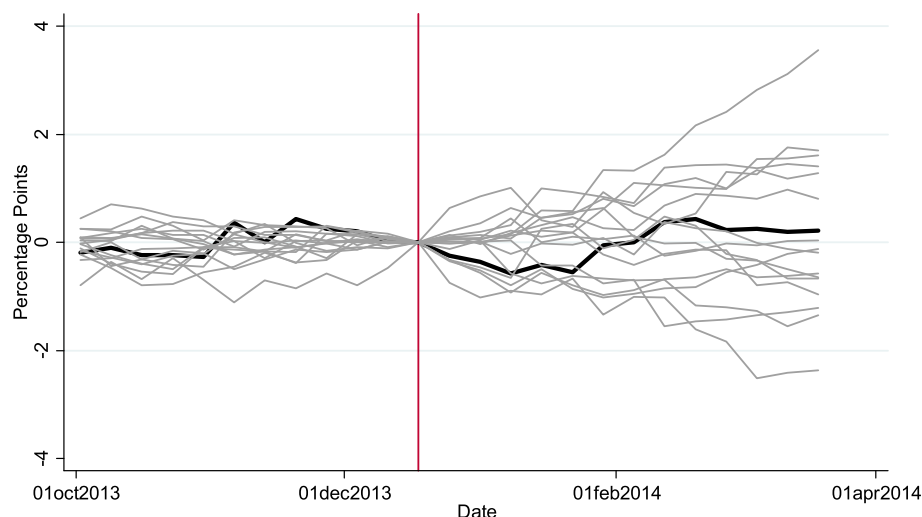
Fig. 9. Effect of the December 2013 announcement on the option-implied risk reversal of the exchange rate and placebo tests. Notes: See notes to Fig. 4

synthetic (which draws heavily from Peru, where a sizable decline also took place around that time).

4.3. Additional program extensions

There were two additional announcements. One on June 24, 2014 extending the program until at least 2014-end, and a final announcement on December 30, 2014 extending the program until March 31, 2015. Figs. 10 and 11 reports the results for the level of the exchange rate. The estimates suggest virtually no effect on the BRL exchange rate following the June 2014 announcement. The results point to a larger gap following the December 2014 announcement, which peaks at an appreciation of around 5% before quickly reversing. But overall, the results for the BRL are broadly in line with the placebos during most of the post-announcement period, suggesting no significant effect. The results for the volatility and risk reversal also point to little or no effect, and are not reported for the sake of conciseness. This small response is consistent with the extensions already being priced-in by the market.

5. Comparison with previous studies

In this section, we compare our results with previous studies on FX intervention in Brazil. Vervloet (2010) estimates the effects of sterilized interventions, both via swaps and spot USD, using a six year daily sample (1578 working days, from 2004 to 2010). OLS estimates point to an effect of 7 bps per 1 USD billion of intervention, that is marginally statistically significant. Instrumenting the intervention with exchange rate volatility, improves both the statistical and economic significance of the effect, which reaches 42 bps. When he splits the intervention in purchases (or long) and sales (or short), the effect of purchases becomes stronger, at 59 bps per 1 USD billion vs 33 bps for sales. His VAR and VEC estimates show that the effect of intervention is temporary. Finally, splitting by the modality of intervention (swap vs spot), suggests that spot purchases have the largest impact (40 bps per 1 USD billion), followed by swap purchases (BCB long in USD, at 20 bps per 1 USD billion), while swap sales are not statistically significant.

Barroso (2014) applies IV techniques, both parametric and non-parametric, to assess the impact of FX sterilized interventions in
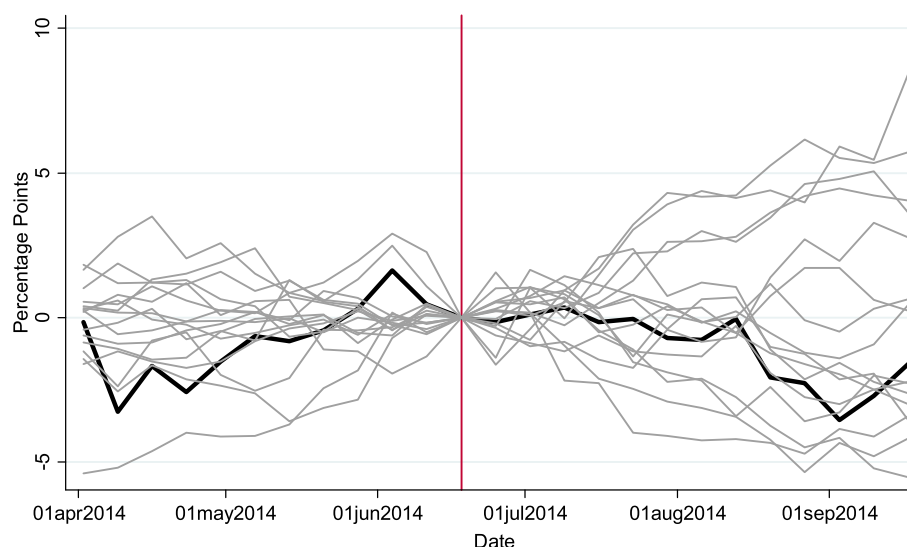

Fig. 10. Effects of the June 2014 announcement on the level of the exchange rate and placebo tests. Notes: See notes to Fig. 4.
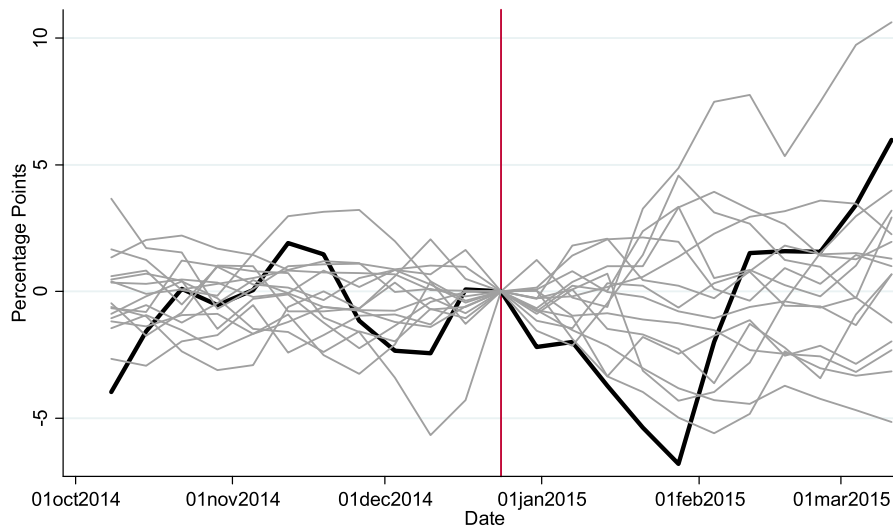
Fig. 11. Effects of the December 2014 announcement on the level of the exchange rate and placebo tests. Notes: See notes to Fig. 4.

Brazil, from 2007 to 2011. As a Brazilian Central Bank staff member, he had access to a proprietary dataset including full records of official intervention and net order flow intermediated by the financial system. With these data, he runs different specifications, the main ones using intra-day volatility as an instrument. He concludes that, on average, the effect of a 1 billion USD intervention moves the exchange rate by 51 bps. His OLS results were also significant, but had the "wrong" sign (−0.22 bps per 1 USD billion). This shows how strong the endogeneity bias is, and the importance of tackling it with appropriate instruments or other strategies.

Andrade and Kohlscheen (2014) use high-frequency data to study the effects of currency swap auctions carried out by the Brazilian Central Bank. They use several GARCH(1,1) models, and find that official currency swap auctions impact the exchange rate in a significant way. They show that, during the sample period (2011–2013, stopping before the taper tantrum), auctions of contracts in which the Central Bank "sold" USD, i.e., took a short USDBRL position, had larger effects than those in which the Central Bank took a long position: 71 bps vs 20 bps per average size swap announcement. Taking into account the difference in the size of those swaps, the effects would amount to 29 bps per USD billion "sold" and 12 bps per USD billion "bought" by the BCB.

These studies, in line with the entire literature on the effectiveness of sterilized interventions, struggle with an inherent endogeneity problem stemming from the fact that the central bank will intervene to buy (sell) FX when it wants the local currency to depreciate (appreciate). Given appreciation/depreciation pressures from other shocks, the data we observe will have movements in the exchange rate that are much smaller than what we would expect (or even in the "wrong" direction) given the amount of intervention. This traditional identification problem, which was tackled through IV in these previous studies, does not apply to our paper given the event study/synthetic control approach. By validating the quantitative estimates from other papers, we shed new light on this literature by providing evidence that this traditional endogeneity problem can be largely overcome, at least in the context of the studies using daily data for Brazil that we cite. This provides very useful information, not only to researchers but also to policy makers, since estimating the impact of FX intervention with daily data is much easier for a researcher/central bank to do, than to rely on a handful of episodes suitable for an event study/synthetic control approach. A number of caveats are in order, since our comparison is based on previous studies using high frequency data and focusing on Brazil. But we do

feel that by corroborating those results with a completely orthogonal approach has implications that go beyond the particular intervention program that we study in the paper, and that this information can be useful to researchers and central bankers working on that topic.

In terms of replicating these studies in our sample, please note that we cannot meaningfully estimate a regression for the changes on the exchange rate on FX intervention during the program because there is no variation on the intervention variable. For example, from the moment the program was announced until end-December 2013, the central bank sold US$500 million worth of swaps each day, plus an additional US$1 billion through a short-term credit line on Fridays.[16] If we were to estimate a regression, the only source of variation in our explanatory variable would be the additional (pre-announced) intervention taking place on Fridays.[17]

On a related point, please note that a simple test of difference in means for the change in the log of the exchange rate does not reject the hypothesis that the change on Fridays (when there was an additional $1 billion worth of intervention) was the same as in the other week days (with a t-stat of 0.13). Thus, the only meaningful estimation we can perform with the available variation in the amount of intervention is to show that the additional intervention on Fridays did not seem to affect the exchange rate more on those days. This is consistent with the view that expected intervention should be priced in by the market. In other words, for the particular intervention program that we study, the usual methods applying IV to daily data would not work, because of the lack of variation of the intervention variable, but synthetic controls provide an ideal alternative.

6. Conclusion

The gyrations in international capital markets have brought renewed interest in the management of capital flows, with sterilized foreign exchange interventions being one of the most commonly used tools. This paper has analyzed the effect of the large scale program of FX swaps that the BCB has embarked following the

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[16] The credit lines, auctioned on Friday, actually involve the delivery of USD by the Brazilian Central Bank to the banks, while the swaps are settled in BRL at the prevailing exchange rate.

[17] There is a tiny amount of variation in the volume of swaps actually sold each day, but this range from 480 to 498.4 million, with this small variation likely reflecting market conditions on the day.

market's "taper tantrum" of 2013. This program was fairly unique because of its large scale (amounting to almost a third of international reserves) and the fact that the intervention took place through swaps (which makes the intervention temporary in nature, despite the long horizon of the program).

Immediately after the announcement of the program, on August 22 2013, the Brazilian real reverted its depreciation trend, and eventually stabilized at a significantly more appreciated level. Our synthetic estimates point to an eventual appreciation relative to the synthetic in the range of 10–19 percentage points. If we compare this effect with the total volume of intervention mobilized during that program, it would be broadly in line with the point estimates for the effectiveness of FX intervention in Brazil from previous studies. This suggests that standard IV techniques used in the literature can be effective in addressing the inherent endogeneity problem associated with FX intervention. Despite this large effect on the level of the exchange rate following the first announcement, the results on the volatility are more mixed. Some estimates point to a sizable decline, but overall the estimates are less robust than those for the level. Our estimates for the announcement of the extension of the program on December of 2013 had smaller effect on the exchange rate, ranging from no effect to 5%, and does not seem to have had an effect on its volatility. This smaller response may be due to that extension already being expected and priced-in by the market. The third and fourth extensions had a fairly muted effect, likely for the same reason.

The large size of the program, and the market surprise following its announcements facilitate the identification of an effect, which would be more challenging in the context of small and frequent interventions that have come to be expected by the market. However, to the extent that our empirical strategy relies on comparing the evolution of the exchange rate in Brazil with that of other countries, we cannot pin point the particular channels though which intervention affected the exchange rate. One of the standard channels for intervention to affect the exchange rate is the portfolio effect.[18] But the response of the exchange rate in the aftermath of the announcement suggests that much of the effect took place before the actual interventions were made. While the market was already expecting and pricing-in those interventions, in principle the portfolio effect of expected interventions should not be as strong as the portfolio effect of the actual intervention. This suggests that a change in market expectations following that announcement may have been an important factor in the response of the exchange rate.

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[18] Signaling effects of monetary policy, another standard channel, seem less relevant in the Brazilian context during that period. To assess whether or not signaling was important, we checked what happened to the yield curve before and after the program announcement on 8/23/2013. The yield curve had a downward shift. This is precisely the opposite of what would be required for the signaling effect to produce an appreciation of the BRL.

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