

Identifying the Effects of Simultaneous Monetary Policy Shocks Fear of Floating under Inflation Targeting

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Abstract

During the period of 1999-2012, the Central Bank of Colombia conducted frequent and large-scale purchases of foreign currency but only occasional and moderate sales, revealing a bias towards trying to depreciate domestic currency. Concurrently, the central bank adjusted its intervention interest rate to meet inflationary targets and stimulate economic growth. However, the use of two simultaneous policy instruments does not necessarily equip monetary authorities with better tools to achieve their targets. On the contrary, the two effects can potentially offset each other. Using proprietary data from the Central Bank of Colombia, I study the effects of simultaneous policies by first deriving new measures of monetary shocks and then determining their impact on economic activity. The main findings indicate that (i) while interest rate interventions have a significant impact on real and nominal variables, foreign exchange interventions tend to have limited effects; and (ii) empirical anomalies, such as the price puzzle, are eliminated when properly accounting for the systematic responses of policy.

Key Words: Central bank intervention, simultaneous policy objectives, monetary shocks, foreign exchange rate, intervention interest rate, price puzzle

JEL Codes: E31, E43, E52, E58, F31

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“But it remains a fact that compared to conventional policy, the effects of unconventional monetary policy are very limited and uncertain”

-Olivier Blanchard¹

1 Introduction

Ever since the demise of the Bretton Woods system, several emerging economies that claimed to have a floating exchange rate under an inflation targeting regime have, in fact, tried to limit currency appreciation. Colombia is no exception. During 1999-2012, the Central Bank of Colombia (**CBoC** henceforth) conducted frequent and large-scale purchases of foreign currency but only occasional and moderate sales, revealing a bias towards trying to depreciate domestic currency. During this time, the CBoC also adjusted its intervention interest rate in order to meet inflationary targets and stimulate economic growth. However, the use of two simultaneous policy instruments –*foreign exchange* and *interest rate interventions*– does not necessarily equip monetary authorities with better tools to achieve their targets. On the contrary, the two effects can potentially offset each other. Given the monetary policy trilemma for open economies, combining both instruments raises the question of whether central banks sometimes overreach and underdeliver by having overambitious targets when the effects of monetary policy are limited.

The main objective of this paper is to study how simultaneous central bank policies affect the economy. I extend the framework presented in Romer and Romer (2004) to allow for a multivariate policy model in which monetary instruments are governed by dependent decision processes. In the empirical application, I employ proprietary data from the CBoC (at a daily frequency) that includes the timing and amount of direct monetary interventions, as well as the internal forecasts that the board of directors considered when setting its policy decisions. These detailed data allow me to match the actions of the CBoC with stated targets and observable covariates.

Consequently, I model the undertakings of monetary authorities using a parametric approach in order to extract the unexpected component of policy (i.e. policy surprises). Similar to Angrist and Kuersteiner (2004, 2011), my identifying assumption presumes that conditional on internal forecasts and real-time financial data, policy variations can be used to identify causal effects. This assumption, sometimes referred to as selection-on-observables (covariates to be held fixed are assumed to be known and observed), provides a strong foundation for causal inference.

To date, there is a general lack of consensus within the literature on the effects of monetary policy, especially in emerging markets. To my knowledge, only a handful of studies exist that directly

¹IMF blog “Monetary Policy Will Never Be the Same” published on November 19, 2013

address the issue of having multiple policy instruments, few of which estimate their dependence, and none of which center on the Colombian economy.² Most studies therefore fail to capture the full interaction of policy decisions and the monetary channels through which they operate. A better understanding of these mechanisms will help design more effective policy regimes and enhance our analysis of causal effects in a dynamic setting.

My investigation confirms some of the previous findings from the literature, but also uncovers new results. In contrast with a number of earlier studies such as Sims (1992), Zha (1997) and Christiano et al. (1999), I find that empirical anomalies, such as the price puzzle, are eliminated when properly accounting for the systematic responses of policy. An advantage of my estimation strategy is that it does not require the inclusion of commodity prices to resolve these anomalies as is the case for Kim and Roubini (2000), Kim (2003), and Sims and Zha (2006). On the other hand, similar to Fischer (2001a, 2001b), I find that while interest rate interventions (**IRI** henceforth) have a significant impact on real and nominal variables, foreign exchange interventions (**FXI** henceforth) tend to have more limited effects. This finding suggests that monetary authorities should conduct most of their policy through the intervention interest rate. It also supports the idea that allowing for free capital flows while having autonomous monetary policy and a managed exchange rate is, in fact, an “impossible trinity”.

This paper is organized as follows: Section 2 presents the statistical regression-based setting. Section 3 describes the data, provides a brief overview of the Colombian context and presents the two policy instruments (*FXI* and *IRI*) undertaken by the CBoC. It also describes the key variables that systematically affected policy decisions. Sections 4 and 5 present the methodology and results. Finally, section 6 concludes.

2 Statistical Regression-Based Setting

Ideally, policy effects could be identified by conducting a randomized macroeconomic experiment. In this hypothetical scenario, different values of intervention would be drawn from some underlying probability distribution at each period. Dates with a non-zero intervention value would represent the treatment group and dates with no intervention would represent the control group. It follows that, since assignment to treatment would be -by construction- random, any possible selection bias disappears. Accordingly, the *average causal effect of policy* would be obtained by computing the difference between the average outcome variable after intervention episodes and after episodes of no intervention.

²See Ostry et al. (2012), or IMF reports No. 12/16, 12/106 for evidence found in Turkey and Switzerland

In practice however, policy decisions seldom behave this way and it is infeasible to conduct experiments at the level of national economies. The problem is that, since policy decisions are rarely isolated from economic developments, the timing and magnitude of interventions are likely to respond endogenously to factors correlated with monetary targets. It is therefore essential to extract the random component of policy from anything that may systematically react to informative variables. This component, which acts as a substitute for policy experiments, forms the basis for the statistical identification of causal effects.

This section provides the basis of my statistical regression-based setting. Notation here will mostly follow that of Angrist and Kuersteiner (2004, 2011) and the methodology will closely follow that of Romer and Romer (2004).³ The economy is described by a stochastic process $\xi_t = (Y_t, X_t, D_t)$ where Y_t is a vector of outcome variables, D_{it} comprises policy instruments (FXI_t and IRI_t for the Colombian case) and X_t are all other variables needed to characterize the policy function.⁴ Histories of policy, outcomes and exogenous variables are explicitly characterized by:

$$\begin{bmatrix} \bar{D}_t \\ \bar{X}_t \\ \bar{Y}_t \end{bmatrix} = \begin{bmatrix} D_t & D_{t-1} & \cdots & D_{t-k} \\ X_t & X_{t-1} & \cdots & X_{t-k} \\ Y_t & Y_{t-1} & \cdots & Y_{t-k} \end{bmatrix}$$

The “sufficient” statistic that policymakers use to determine policy at time “ t ” is described by $z_t = \Phi_t(\bar{Y}_t, \bar{X}_t, \bar{D}_{t-1})$, for any mapping Φ_t , and decisions about policy are governed by a deterministic component of observed random variables $D_i(z_t, t)$, and by an unobserved idiosyncratic shock e_{it} . Note that z_t may contain the realization of policy instruments up to period “ $t - 1$ ”.

The policy setting equation, in a linear model, is therefore:

$$D_{it} = D_i(z_t, t) + e_{it} \quad \text{for } i = 1, 2 \quad (1)$$

If we define $Y_{t,j}^\psi(d_i)$ as the value of Y_{t+j} when $D_{it} = \Psi(\cdot) = d_i$, that is to say the “potential outcome” of Y_{t+j} for a specific realization of D_{it} , then the Conditional Independence Assumption (CIA) can be formulated as:

$$Y_{t,1}^\psi(d_i), Y_{t,2}^\psi(d_i), \dots \perp D_{it} \mid z_t \quad \forall d_i, \forall \psi \in \Psi, i = 1, 2 \quad (2)$$

³See also Angrist and Pischke (2009) for a related exposition in identifying treatment effects.

⁴Outcome variables are admissible in X_t as long as they have at least a 1-period lag.

In words, the CIA states that conditional on z_t , policies are independent of potential outcomes, or as good as randomly assigned.⁵ This critical assumption establishes the foundation based on which “regressions can also be used to approximate experiments in the absence of random assignment”.⁶ The CIA hence allows us to compare treatment and control groups without the need to conduct any formal experiments. This setting is particularly useful when counterfactual outcomes cannot be observed (e.g. what would have occurred if monetary authorities had not intervened, given that they did; and vice versa).

In the related literature, Romer and Romer (2004) use the intended Fed funds rate as their instrument variable D_t , the “Greenbook” forecasts, unemployment and inflation as exogenous variables in X_t and industrial production growth as well as the producer’s price index as outcome variables in Y_t . Another example is Wasserfallen and Kuersteiner (1994), who, in setting a Central Bank policy for the Swiss case use the money supply target as D_t and nominal interest rates and exchange rates as X_t . Examples using foreign exchange purchases as D_t with a GARCH methodology include Rincon and Toro (2010), Echavarria et al. (2009b), Kamil (2008), Toro and Julio (2005) and Guimaraes and Karacadag (2004). Finally, estimations that follow the early works of Christiano et al. (1996, 1999) or Bernanke and Blinder (1992), use the effective Federal Funds Rate as D_t , and a set of real and nominal variables as X_t to analyze the effects of monetary shocks with the use of VARs. Examples of these studies include Christiano et al. (2010), Kim and Roubini (2000), Bagliano and Favero (1998), Clarida and Gertler (1997) and Sims and Zha (2006).

A methodological complication that arises when measuring the impact of policy in Colombia is the fact that the CBoC does not target a single policy instrument, as is the case for most of US monetary policy. Rather, it employs two separate policy instruments (FXI_t and IRI_t) to achieve its targets. In a fully fleshed out structural model, such as SVAR, implementing this dual strategy is potentially complicated. Also, “a monetary policy innovation (in VARs) reflects both the effect of the initial innovation and the effect of the predictable subsequent moves in the policy measure”.⁷ Other drawbacks include the numerous disentangling restrictions needed to identify structural shocks and the fact that “spurious result(s) of in-sample data fitting (or of serially correlated omitted variables)”⁸ can reduce the variation of monetary shocks, which is necessary to identify causal effects.

This paper avoids these issues by focusing on the process that determines monetary policy with a parametric model, while leaving the response of the economy unspecified (and estimated

⁵Equation (2) implies that $Y_{t,1}^\psi(d_i), Y_{t,2}^\psi(d_i), \dots \perp \epsilon_{it} \mid z_t$ since ϵ_t is the only random source of D_{it} .

⁶Angrist and Pischke (2009), pg 18.

⁷Romer and Romer (2004), pg 1078.

⁸See Rudebusch (1998), pg 919.

with a non-parametric procedure). Modeling thus concentrates on the decisions of the central bank, which in principle are observable and non-linear.

3 Data and Context

3.1 Data

There are two crucial steps needed to identify policy shocks. The first step consists of explicitly analyzing policy instruments. Failing to observe the exact decisions of monetary authorities can lead to an endogenous relationship between economic conditions and the policy’s measurement error. This, for example, is the case for some studies that use changes in international reserves to implicitly derive FXI (in the absence of official data).⁹ The problem with using this measure is that it does not only capture the different mechanisms of FXI, but also valuation effects driven by exchange rate and interest rate differentials. In addition, monetary authorities can accumulate reserves for a variety of reasons, including self-insurance against sudden stops or financial shocks. The resulting policy effects would thus reflect a combination of factors (i.e. different intervention mechanisms, valuation effects, etc.) with no way of separating individual effects.

The second step consists of capturing the relevant information that monetary authorities use when setting their policy decisions, or in other words, *being able to see what they see*. In the potential outcomes framework described in section 2, this would be equivalent to finding out what variables should be included in X_t . In the present context, the main candidates would unquestionably include the internal forecasts of the central bank. In this regard, the CBoC (like many other central banks) has entire divisions in charge of forecasting key variables such as inflation, exchange rates, unemployment and output growth so that policymakers can make more informed decisions. Analogous to the Federal Reserve’s Greenbook forecasts, the CBoC has its own internal forecasts that feed into the board’s discussions whenever they meet to decide over FXI or IRI. These include:

- **Exchange Rate Misalignment Forecasts:** Seven “in house” structural models are estimated by the *Observatorio de Tasa de Cambio Real* (CBoC division) and results regarding the forecasted equilibrium exchange rate are presented monthly to the board of directors. Specifically, two models are based on the purchasing power parity condition (PPP), two models are based on Structural Vector Error Correction (SVEC) methodologies, two models are based on the current account equilibrium and one model simply uses Hodrick and Prescott filters. The average forecast of all seven models is depicted in Figure 1a. Exchange rate misalignments, measured as the log-difference of the exchange

⁹See for example Dominguez et al. (2012) or Adler and Tovar (2011).

rate minus the average forecasted equilibrium value, $(e_t - Forecast(e_t))$, constitute a key variable used to capture most of the deterministic component of $D(z_t, t)$ as presented in equation (1).

- **Monetary Transmission Mechanism Forecasts:** Inflation forecasts are estimated by the *Departamento de Modelos Macroeconomicos* (CBoC department). Since 2001, the CBoC adopted a model proposed by Gomez and Julio (2001) to forecast future inflation. This model includes 9 equations that govern prices, aggregate demand, wages, an interest rate rule, the uncovered interest rate parity condition, foreign real interest rates, risk premium, terms of trade and policy rates. The difference between forecasted inflation and the yearly target rate ($Forecast(\pi_t) - \pi_t^{Target}$), depicted in Figure 1b, is also a key variable within X_t .
- **Long Term GDP (PATACON) Forecasts:** The GDP gap is also estimated by the *Departamento de Modelos Macroeconomicos* and is particularly relevant for the board’s discussions since a long term equilibrium value of GDP is extremely sensitive to the applied methodology. This DSGE model (PATACON) incorporates nominal and real rigidities with the use of 5 main equations: cascade of Calvo pricing, staggered wages, endogenous depreciation, external habits in consumption, and investment costs. The forecasted GDP gap ($y_t - Forecast(y_t)$), depicted in Figure 1c, is also crucial to capture the deterministic component of $D(z_t, t)$.

The remainder of my data set is described in Appendix 1.

3.2 The Colombian Context

Colombia adopted an inflation-targeting scheme with a floating exchange rate in October of 1999 during the aftermath of the strongest economic crisis of its history.¹⁰ Prior to this date, pre-announced exchange rate bands were established dating back to 1994. After 1999, however, the CBoC continued to conduct widespread FXI in spite of having a “free floater” status.

During 1999-2012, the nominal exchange rate between the Colombian peso (COP) and the US dollar (USD) underwent severe appreciation and depreciation episodes that doubled and halved the value of each currency. Peak values ranged from 1,542 (COP/USD) in January 1999 to 2,969 in February 2003, and to 1,652 in June 2008. During this period, inflation dropped from 15.4% to 3.6%, and inflation targets set forth by the CBoC were, to some extent, able to anchor inflation expectations as depicted in Figure 2.¹¹

The period of 2006-2008 was particularly interesting since it exhibited high inflation and a strong appreciation of the exchange rate in an overheated economy. Specifically, inflation was well above the target rate (by more than 3% during the second semester of 2008), the COP gained 37%

¹⁰See Echavarría and Villamizar (2006).

¹¹The credibility of the CBoC concerning its ability to achieve its targets remained high amongst surveyed agents, in spite of the CBoC not being able to meet its inflation targets during 1999, 2001, 2002, 2006, 2007, and 2008.

of its value and the GDP gap was close to 2.8% during most of 2008. This combination of factors led to what can be thought of as a “Perfect Storm” for central bankers: objectives consisting of lowering inflation, depreciating the currency and expanding economic output conflicted.¹² During this time, the CBoC raised interest rates by 400 basis points and simultaneously purchased over 7.5 billion dollars in what later became a controversial set of policies. This period also coincided with the first presidential reelection in the country, after the Uribe administration amended the constitution of 1991. As a result, the board of directors of the CBoC (entity in charge of all monetary and exchange rate policy) went from having 3 out of 7 board members appointed by the president in 2002 to 5 out of 7 members in 2006.¹³

3.3 Monetary Policy through FXI

From 1999 to 2012, the CBoC officially claimed to be an advocate of FXI with the goal of stemming exchange rate and output volatility.¹⁴ Additional reforms were implemented throughout the years in order to include objectives that sought an “adequate” level of international reserves and to hinder “excessive” devaluation/revaluation trends in the exchange rate. However, interventions were not symmetric. Purchases of USD totaled 28.5 billion whereas sales amounted to only 2.6 billion.¹⁵ Also, international reserves more than quadrupled: from 8 billion USD in January 1999 to 34 billion USD in September 2012.

Purchases of USD can be further sub-categorized into 3 groups: discretionary interventions conducted in the spot market (22.8 billion), discretionary interventions through foreign exchange rate options (3.3 billion) and rule-based volatility options (2.4 billion). In this paper, FXI consists of the first two groups since volatility options are deterministic in nature and exclude any part of the policy decision process.¹⁶ Sales of USD, on the other hand, were almost all conducted through volatility options (2.3 billion).

Figure 3 depicts the different methods of FXI as well as the COP/USD exchange rate. Discretionary interventions, which account for 73% of all interventions, were concentrated in two periods: 2005-2007 and 2010-2012. While the former period consisted of large, unexpected purchases

¹²According to the Mundell-Fleming model, an increase in interest rates can lower future inflation but appreciates domestic currency. The conflict arises when trying to lower inflation and, at the same time, depreciate the exchange rate.

¹³In accordance with chapter 6 of the Colombian constitution of 1991, the board of directors of the CBoC is comprised of seven members that include: The minister of finance, the Governor of the board (elected by the board), and five members (two of which are appointed by the president).

¹⁴See Appendix 2 for a list of selected fragments of reports that were presented to the Colombian Congress.

¹⁵More than 80% of international reserves were invested in AAA securities (mostly in US treasury bonds).

¹⁶This mechanism, which was introduced in October 2002 to smooth exchange rate volatility, was triggered whenever daily deviations (with respect to the moving average of the last 20 working days) were greater or equal to a specific threshold.

of US currency, the latter period consisted of small (close to 20 million USD) purchases conducted daily since September of 2010.¹⁷ The figure also shows that after March 2003, the exchange rate appreciated rapidly. In some episodes, such as the one from December 2006 to May 2007, exchange rate changes were so pronounced that Colombia was ranked as the country with the highest currency appreciation vis--vis the USD.¹⁸ Table 1 shows the total amount of FXI (excluding volatility options) as well as the number of intervention days. The years 2005 and 2007 were peak years of intervention with purchases of 4.6 and 4.5 billion USD, respectively. Intervention days were also highly concentrated in 2005 and 2011.

3.4 Monetary Policy through IRI

Intervention interest rates drastically declined from 26% in January 1999 to 4.75% in September 2012, reaching its lowest value (3%) in 2010 during the aftershocks of the financial world crisis. During 1999-2012 the board of directors met over 160 times to decide whether to change the intervention interest rate, effectively doing so in 62 occasions. In all of the minutes of the board's meetings and the official reports presented to Congress, inflation and output were stated as the main variables that the CBoC considered when deciding over *IRI*.

Figures 4a and 4b depict both the intervention and inter-bank interest rates. As can be observed, the inter-bank rate is more volatile than the intervention rate¹⁹ and is most likely subject to endogenous effects brought forth by liquidity demand. The intervention rate, on the other hand, is ideal for estimating monetary policy decisions as it exclusively captures the treatment undertaken by monetary authorities. The fact that the CBoC explicitly states its interest rate targets makes Colombia an ideal case study. In other countries (including the United States) a researcher has to sometimes infer the intended rate with the use of narrative records (see for example Romer and Romer, 2004).

Figure 4a shows that the intervention interest rate followed a similar path as that of inflation in Figure 2. This close and positive relationship can be misconstrued as evidence of the Price Puzzle in which monetary tightening is followed by an increase in price levels. However, a more consistent explanation is that the CBoC raised interest rates in periods of high inflation in order to lower price levels, and reduced interest rates in periods of low inflation to stimulate economic growth. The true negative correlation between inflation and interest rates can only be uncovered by removing the systematic responses to inflation brought about by the Taylor rule or some other identification

¹⁷Daily interventions after September 2010 were also excluded from FXI_t , as they also became deterministic.

¹⁸See Kamil (2008).

¹⁹This volatility can be explained by the 3,000 basis points difference between the maximum borrowing rate and the minimum lending rate, which was reduced to 800 basis points in the year 2000.

strategy.

4 Methodology

The CIA assumption, $Y_{t,1}^\psi(d_i), Y_{t,2}^\psi(d_i), \dots \perp \epsilon_{it} \mid z_t$, justifies the two-step procedure of first identifying exogenous monetary shocks and then estimating their effects on economic variables. Accordingly, the first step of the methodology consisted of modeling both policy rules in order to remove systematic responses to informative variables.

4.1 Computation of Monetary Shocks

If the two policy instruments were assumed to be conditionally independent (i.e. conditional on a set of variables in z_t of equation (2), the observed value of one instrument does not alter the probability distribution of the other), then they would follow different univariate processes exemplified by equations (3) and (4):

$$\begin{aligned} FXI_t^* &= x'_{1t}\beta_1 + v_t \\ FXI_t &= \max[0, FXI_t^*] \\ v_t &\sim N(0, \sigma_1^2) \end{aligned} \tag{3}$$

$$IRI_t = x'_{2t}\beta_2 + \epsilon_{2t} \tag{4}$$

where FXI_t^* is the unobserved latent foreign exchange intervention (which takes positive and negative values), $x'_{1t}\beta_1$ and $x'_{2t}\beta_2$ are the deterministic components of policy (corresponding to $D_1(z_t, t)$ and $D_2(z_t, t)$), and v_t is assumed to be normally distributed with zero mean and variance σ_1^2 . This setting, much like what is seen in the related literature, assumes FXI_t to be left-censored at zero given the numerous dates with zero-value interventions and the lack of USD sales.

Monetary shocks $(\epsilon_{1t}, \epsilon_{2t})$ can be computed by subtracting the conditional mean of policy from its observed value, as described in equations (5) and (6):

$$\begin{aligned}
\epsilon_{1t} &= FXI_t - E[FXI_t | x_{1t}] \\
&= FXI_t - \int_{FXI_t > 0} (FXI_t) dF(FXI_t | x_{1t}) \\
&= FXI_t - \Phi\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) \left[x'_{1t}\beta_1 + \sigma_1 \lambda\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) \right]
\end{aligned} \tag{5}$$

$$\begin{aligned}
\epsilon_{2t} &= IRI_t - E[IRI_t | x_{2t}] \\
&= IRI_t - x'_{2t}\beta_2
\end{aligned} \tag{6}$$

where $\phi(\cdot)$ and $\Phi(\cdot)$ correspond to the pdf and cdf of a standard normal distribution, respectively. The term $\Phi\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right)$ of equation (5) is the probability of observing a positive intervention ($\Pr(FXI_t^* > 0 | x_{1t})$) and the last term in brackets is the expected value of the latent variable FXI_t^* (where the term $\lambda(\cdot) = \phi(\cdot)/\Phi(\cdot)$ corresponds to the inverse-mills ratio). In short, ϵ_{1t} can be thought of as the censored residual of the FXI policy rule while ϵ_{2t} of equation (6) is the linear residual of the IRI policy rule.

However, there is no reason a priori to believe that policy instruments were independent. After all, the board of the CBoC conducts monetary policy through both FXI and IRI and it is entirely plausible that decisions about one instrument affect decisions about the other. The following specification allows to parameterize and estimate this dependence:

$$\begin{aligned}
FXI_t^* &= x'_{1t}\beta_1 + v_t \\
FXI_t &= \max[0, FXI_t^*] \\
IRI_t &= x'_{2t}\beta_2 + \epsilon_{2t}
\end{aligned}$$

$$\begin{pmatrix} v_t \\ \epsilon_{2t} \end{pmatrix} \sim N(0, \Sigma) \tag{7}$$

The only difference with respect to the previous setting is that residuals v_t and ϵ_{2t} are now

assumed to be jointly normal with zero mean and variance-covariance matrix $\Sigma = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix}$. The construction of a maximum likelihood function for the bivariate process described in equation (7) is hence warranted in order to obtain estimates of all individual regressors as well as the estimated covariance between v_t and ϵ_{2t} .

If we define $A \equiv \left(\sigma_1^2 - \frac{\sigma_{12}^2}{\sigma_2^2} \right)$ and $b \equiv \left(x'_{1t}\beta_1 + \frac{\sigma_{12}}{\sigma_2^2}(IRI_t - x'_{2t}\beta_2) \right)$, then the maximum likelihood can be constructed in two stages:

- Stage 1: When $FXI_t > 0$ ($FXI_t = FXI_t^*$)

$$\begin{aligned} f(FXI_t, IRI_t) &= f(FXI_t^* | IRI_t, x_{1t}, x_{2t}) f(IRI_t | x_{1t}, x_{2t}) \\ &= \frac{1}{A^{1/2}} \phi\left(\frac{FXI_t^* - b}{A^{1/2}}\right) \frac{1}{\sigma_2} \phi\left(\frac{IRI_t - x'_{2t}\beta_2}{\sigma_2}\right) \end{aligned} \quad (8)$$

- Stage 2: When $FXI_t = 0$ ($FXI_t^* \leq 0$)

$$\begin{aligned} f(FXI_t, IRI_t) &= \Pr(FXI_t^* \leq 0 | IRI_t, x_{1t}, x_{2t}) f(IRI_t | x_{1t}, x_{2t}) \\ &= \left(1 - \Phi\left(\frac{b}{A^{1/2}}\right)\right) \frac{1}{\sigma_2} \phi\left(\frac{IRI_t - x'_{2t}\beta_2}{\sigma_2}\right) \end{aligned} \quad (9)$$

The resulting Maximum Likelihood function, shown in equation (10), is then fully characterized by combining equations (8) and (9) for both censored and uncensored observations:

$$\begin{aligned} L_n(\theta) &= \prod_{FXI_t^* \leq 0} f(FXI_t, IRI_t | x_{1t}, x_{2t}) \prod_{FXI_t^* > 0} f(FXI_t, IRI_t | x_{1t}, x_{2t}) \\ &= \left[\prod_{FXI_t^* \leq 0} 1 - \Phi\left(\frac{b}{A^{1/2}}\right) \prod_{FXI_t^* > 0} \frac{1}{A^{1/2}} \phi\left(\frac{FXI_t^* - b}{A^{1/2}}\right) \right] \left[\prod \frac{1}{\sigma_2} \phi\left(\frac{IRI_t - x'_{2t}\beta_2}{\sigma_2}\right) \right] \end{aligned} \quad (10)$$

Finally, under significant dependence between policy instruments, monetary shocks can be computed in vector form as shown in equation (11):

$$\begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{bmatrix} = \begin{bmatrix} FXI_t \\ IRI_t \end{bmatrix} - \begin{bmatrix} E(E[FXI_t | IRI_t, x_{1t}, x_{2t}] | x_{1t}, x_{2t}) \\ E(IRI_t | x_{1t}, x_{2t}) \end{bmatrix} \quad (11)$$

Where the last term can be expressed as:

$$\begin{aligned} & \begin{bmatrix} E(E[FXI_t | IRI_t, x_{1t}, x_{2t}] | x_{1t}, x_{2t}) \\ E(IRI_t | x_{1t}, x_{2t}) \end{bmatrix} = \\ & \Pr(FXI_t^* > 0 | x_{1t}) E \begin{bmatrix} FXI_t | FXI_t^* > 0, x_{1t}, x_{2t} \\ IRI_t | FXI_t^* > 0, x_{1t}, x_{2t} \end{bmatrix} + \Pr(FXI_t^* \leq 0 | x_{1t}) E \begin{bmatrix} FXI_t | FXI_t^* \leq 0, x_{1t}, x_{2t} \\ IRI_t | FXI_t^* \leq 0, x_{1t}, x_{2t} \end{bmatrix} \\ & = \Phi\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) \begin{bmatrix} x'_{1t}\beta_1 + \sigma_1\lambda\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) \\ x'_{2t}\beta_2 + \frac{\sigma_{12}}{\sigma_1}\lambda\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) \end{bmatrix} + \left(1 - \Phi\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right)\right) \begin{bmatrix} 0 \\ x'_{2t}\beta_2 + \frac{\sigma_{12}}{\sigma_1}\lambda\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) \end{bmatrix} \end{aligned}$$

Note that some steps are based on the fact that if (v_t, ϵ_{2t}) are jointly normal, then $\epsilon_{2t} = \frac{\sigma_{12}}{\sigma_1}v_t + \varsigma$, where the random variable ς is independent of v_t .²⁰ The resulting monetary shocks, $(\epsilon_{1t}, \epsilon_{2t})$, should be free of endogenous and anticipatory movements and should contain only the random component of monetary policy. In the related literature, this exogenous variation has been mostly interpreted as exogenous shocks to how policymakers value different targets or how their views are aggregated. Other interpretations include the pursuit of additional (temporary) objectives, changes in beliefs, operating procedures, strategic considerations on private agents' expectations, measurement error and technical factors.²¹

4.2 Explanatory Variables in X_t

An important part of this paper consisted of correctly specifying the relevant variables in X_t . The main challenge was to model the undertakings of monetary authorities as closely as possible so as to avoid a potential omitted variable bias. As such, the internal forecasts of the central bank were

²⁰See Cameron and Trivedi (2005).

²¹See Hamilton (1997), Christiano et al. (1999), Romer and Romer (1994), Bernanke and Mihov (1998), Ball (1995) and Chari et al. (1997).

ideal candidates since they fed into the board’s discussions whenever they met to decide over FXI or IRI.

In addition to the internal forecasts, the board of directors could have examined other variables. To account for some of these responses, a set of control variables was also included in X_t based on the official reports of the CBoC that were presented to the Colombian Congress (*Informes de la Junta Directiva al Congreso de la Republica*) and the minutes of the board of director’s meetings.²² Table 3 shows three specifications of x_{1t} : $x_{1t}(1)$, $x_{1t}(2)$, $x_{1t}(3)$, and four specifications of x_{2t} : $x_{2t}(1)$, $x_{2t}(2)$, $x_{2t}(3)$, $x_{2t}(4)$, that were used in order to purge the corresponding instruments of their deterministic component. Section 5.3 proposes a heuristic exercise to determine which of these specifications is subject to misspecification. Also, lagged policy instruments (FXI_{t-1} and IRI_{t-1}) were considered in order to capture persistence effects, a common feature of intervention clusters.

All variables were included in either levels or changes based on the stationarity properties of the Elliot-Rothenberg-Stock test for a unit root, presented in Table 2. For example, IRI_t was included in changes (ΔIRI_t) due to a significant time trend in IRI_t . Since all variables used in the estimations were stationary, conventional asymptotics were implied. Finally, all control variables in period “ t ” contained information up until the close-of-business day previous to the policy change. Otherwise, interventions and explanatory variables would simultaneously determine each other, creating a bias in the policy estimates.²³

4.3 Impact of Policy on Outcome Variables

The second step of the methodology consisted of estimating the effects of ϵ_{1t} and ϵ_{2t} on the different outcome variables in Y_t . This was achieved by estimating either equation (12), which follows Romer and Romer’s (2004) methodology, or equation (13), which follows Jorda’s (2005) methodology. Both equations should be interpreted as being different representations of the same object, provided that shocks are independent. This result is corroborated in the next section.

$$Y_{it} = \gamma_0 + \sum_{j=0}^h \gamma_j \epsilon_{1t-j} + \sum_{k=0}^h \gamma_k \epsilon_{2t-k} + S_{it} \quad (12)$$

²²These reports include macroeconomic results, different targets set by the board of directors, and explicit monetary procedures and regulations that the CBoC followed for different periods.

²³This postulation is entirely reasonable given that board meetings were generally held before noon (very little information could be gained from the time markets closed until the next day’s meeting).

$$Y_{it+s} = \eta_0^s + \eta_1^s \epsilon_{1t} + \eta_2^s \epsilon_{2t} + \vartheta_{it+s} \quad \text{for } s = 0, 1, \dots, h \quad (13)$$

While Romer and Romer’s proposed regression is conceptually straightforward, the resulting standard errors are subject to misspecification (and thus a need for bootstrapping). Jorda’s method of local projections avoids this problem by estimating sequential regressions in which the endogenous variable is shifted at each forecasting period. The tradeoff, however, is that Jorda’s approach does not control for the possible correlation between the different lags of the policy shock.

For this reason, I estimated impulse response functions (**IRFs**) for variables with a monthly frequency according to Jorda’s methodology (equation 13). In this case, the correlation between lags disappears since shocks are summed up into monthly observations. Conversely, I estimated IRFs for variables with a daily frequency according to Romer and Romer’s methodology (equation 12).²⁴ Coefficients and standard errors (bootstrapped) were summed up every period in order to obtain the cumulative effect across time.²⁵ Finally, equations (12) and (13) were also estimated with only one monetary shock at a time (ϵ_{1t} or ϵ_{2t}). The inclusion of one or two shocks yielded almost identical results which suggest that policy instruments were, in fact, conditionally independent (the next section specifically addressed this issue).

5 Estimation and Results

5.1 Parametric Dependence of Monetary Shocks

Estimation results for the Maximum Likelihood function of equation (10) are reported in Table 4. Values correspond to the covariance between v_t and ϵ_{2t} for the different specifications of X_t (see Table 3). As can be observed, none of the covariances are statistically significant. This finding indicates that, under the assumptions of the model, the board’s decisions about one instrument did not alter the probability distribution of the other. This is mostly due to the inclusion of internal forecasts as control variables. Additional estimations (not reported) suggest that the covariance is significant when these forecasts are not included.

As such, this finding justifies the estimation of independent processes described in equations

²⁴Monte Carlo methods consisted of 500 draws from a multivariate normal distribution with mean and variance-covariance matrix given by the regression’s point estimates.

²⁵The number of lags varied depending on the frequency of the outcome variable (h=24 if monthly, h=45 if daily).

(3) and (4) in order to derive the monetary shocks ϵ_{1t} and ϵ_{2t} . Additional evidence is shown in Table 10 (Appendix 3) where the cross-correlogram of the shocks is always close to zero. However, this result does not mean that policies did not react to similar targets. In fact, many control variables that were included in x_{1t} were also included in x_{2t} .²⁶ Independence, in this case, is conditional on the set of control variables.

5.2 Policy Functions

5.2.1 FXI_t Policy Function

The FXI_t policy function of equation (3) was estimated by using a censored regression (Tobit) model and results are reported in Table 5. Estimates show that the impact of FXI_{t-1} is significant and less than unity for all specifications. Also, the effects of internal forecasts of both exchange rate misalignments ($e_{t-1} - Forecast(e_{t-1})$) and GDP gap ($y_{t-1} - Forecast(y_{t-1})$) are significant and have the expected sign. That is, the CBoC tried to depreciate domestic currency by purchasing USD whenever the exchange rate appreciated (or was below the forecasted equilibrium value) and whenever the GDP gap decreased. On the other hand, inflation forecasts ($Forecast(p_{t-1}) - Target(p_{t-1})$) and the Net position of the CBoC ($D_{NetP_{t-1}}$) were not statistically significant, probably because most interventions were fully sterilized.²⁷

Other variables that significantly affected FXI_t include: exchange rate volatility (VOL_{t-1}), Brazil's exchange rate changes Brazil (Δe_{t-1}),²⁸ meeting dates of the board of directors ($BoardMeet_{t-1}$), biweekly exchange rate changes ($\Delta e_{t-1,10}$), industrial production growth (ΔInd_{t-1}) and periods in which capital controls were enforced by the CBoC (D_{tax}). The negative sign of D_{tax} suggests that capital controls acted as substitutes for FXI_t (rather than complements) as they significantly restrained inflows of foreign assets.

5.2.2 IRI_t Policy Function

The IRI_t policy function of equation (4) was estimated using OLS (around meeting dates of the board of directors) and results are reported in Table 6.²⁹ Lagged interventions (IRI_{t-1}) were included in

²⁶An example is lagged interest rate interventions (IRI_{t-1}), which were included in specification x_{1t} (3) as part of the FXI policy rule.

²⁷Only in few occasion did the board announce that sterilized purchases would correspond to up to 50% of total purchases (see Appendix 2).

²⁸Brazil's exchange rate was included to capture similarities within the region, as suggested in Loaiza and Melo (2012).

²⁹Board meetings of the CBoC were pre-established at the beginning of each year and therefore the board conducted policy on IRI only over the assigned dates. This setting is similar to Romer and Romer (2004).

both levels and first differences in order to capture tendencies toward mean reversion in the board's behavior.³⁰ Also, this setting (like in Romer and Romer 2004) assumes that unemployment acts through the measure of GDP gap (Okun's Law).

Coefficients of IRI_{t-1} are significant but close to zero which is evidence that the board conducted gradual changes in policy rather than an immediate one-time adjustment. Estimates also show that all internal forecasts have a significant impact and the expected sign (except for exchange rate misalignments in specification 10a). Namely, the board conducted expansionary policy whenever the GDP gap decreased and whenever the exchange rate appreciated. Conversely, the board conducted contractionary policy whenever forecasted inflation was higher than the yearly target. Other variables that prompted policy adjustments through IRI_t include: inflation surprises ($\pi_{t-1} - \pi_{t-1}^e$), biweekly exchange rate changes ($\Delta e_{t-1,10}$), 1-day yield spreads between Colombia and the United States ($i_{t-1}^{1day} - i_{t-1}^{*1day}$), 1-year Treasury bond yield changes (Δi_{t-1}^{1year}) and industrial production growth (ΔInd_{t-1}).

Finally, the 1-year Treasury bond's yield had a negative effect on IRI_t when considering the sub-sample of 2006-2008 ($D_{\Delta i_{t-1}^{1year}}$). In normal circumstances, different maturity yields tend to move in the same direction, almost as if exhibiting a parallel shift. For this particular period, however, the board of directors seemed to have expected the yield curve to flatten out (probably in anticipation of the economic downturn or deflation episodes that followed).

5.3 Policy Shocks

Figure 5 depicts the resulting monetary shocks ($\epsilon_{1t}, \epsilon_{2t}$) compared to the observed policy instruments (FXI_t, IRI_t). Note that, to improve readability, data points were summed into quarterly observations. The deterministic component of policy can be interpreted as the difference between the green (solid) line and each specific residual. As can be inferred from Figure 5a, the CBoC would have intervened less in the foreign exchange market had it not been for exchange rate misalignments, GDP gap and, to a lesser extent, the remaining variables presented in Table 5. In fact, explanatory variables were able to explain most interventions conducted in 2004-2006 and 2008. Also, specifications $x_{1t}(1)$, $x_{1t}(2)$ and $x_{1t}(3)$ were able to explain 39%, 76% and 78% of the pronounced intervention peak of 2007, respectively.

Policy residuals depicted in Figure 5b also differ from what occurred with the observed IRI_t . The most marked difference occurred in 1999, where monetary shocks were in fact positive as opposed to the negative sign of the observed intervention. This is mainly due to the economic crisis

³⁰The inclusion of IRI_{t-1} (levels) in specifications $x_{2t}(2)$ and $x_{2t}(4)$ was motivated by Romer and Romer's (2004) methodology, as presented in equation (1) of their paper.

of 1998-1999 and the urgency to lower inflation down to a one-digit level, which is captured in the deterministic component of policy. Other noticeable discrepancies can be observed in 2001-2002, 2006-2007 and 2009.

One important characteristic of correctly specified policy shocks is their unpredictability. In other words, information prior to the policy change should not have any predicting power over the estimated residuals. A heuristic exercise to test for this orthogonality condition can be expressed as $\epsilon_{it} \perp \Omega_{t-1}$, where Ω_{t-1} represents the information set available before the policy change took place. Results of this test are presented in Table 7 where policy shocks are individually regressed against 16 variables, some of which are different from those specified in Table 3.³¹ All gaps in Table 7 imply that the variable (row) was used under that specification (column) and the shock is, by construction, orthogonal to that variable. Results show that $x_{1t}(2)$, $x_{2t}(1)$, $x_{2t}(3)$ and $x_{2t}(4)$ (columns 3, 5, 7 and 8) are the only correct specifications since they are not correlated with any variable in Ω_{t-1} .

5.4 Impact on Outcome Variables

The contemporaneous exchange rate (e_t), exchange rate volatility (Vol_t) and inflation (π_t) are obvious candidates to test for the effectiveness of Central Bank intervention as they are explicit objectives of the CBoC. Nonetheless, the 1-year Treasury bond's yield (Δi_t^{1year}), industrial production growth (ΔInd_t) and aggregate demand ($\Delta AggregateDemand$) also shed some light on salient features of the Colombian monetary transmission mechanism. The Treasury bond's yield, for instance, can explain the behavior of a medium to long-term maturity yield (1-year) after a policy change takes place. On the other hand, industrial production and aggregate demand are key variables that will ultimately determine if monetary shocks have an effect on real output.

In all cases, the effects of both the estimated residuals (ϵ_{1t} , ϵ_{2t}) and the observed policy instruments (FXI_t , IRI_t) were computed.³² While the former consist of correctly specified monetary surprises, the latter are most likely biased by anticipatory movements in the economy. The comparison of both measures is thus useful in order to get a better sense of the direction and magnitude of the bias driven by observed interventions (FXI_t and IRI_t).

³¹Residuals were individually regressed in order to avoid cases in which correlation amongst covariates would yield insignificant estimates.

³²Specifications $x_{1t}(2)$ and $x_{2t}(3)$ were considered for all IRFs. $x_{1t}(2)$ was the only correct specification of x_1 . $x_{2t}(3)$ was *i*) correctly specified, *ii*) had interest rate changes instead of levels (ΔIRI_t) and *iii*) had relevant control variables that were mentioned in CBoC reports.

5.4.1 Inflation

Figure 6 depicts the implied IRF of inflation minus yearly targets. While panel (a) shows that FXI_t has a significant albeit small effect on $\pi_t - target(\pi)$, panel (b) shows that ϵ_{1t} has no significant effect at all, which is consistent with the fact that almost all interventions were fully sterilized. Panel (c) shows that an increase of 1% in ΔIRI_t has a strong positive effect on inflation (of up to 1.5%) that lasts for one year (12 periods) before the effect subsides. Taken at face value, this result is straightforward evidence of the “price puzzle” in which prices and interest rates are positively correlated. However, panel (d) shows that this result no longer holds. On the contrary, an increase of 1% in ϵ_{2t} lowers inflation by the same amount. Results are significant after the first year (and remain significant for up to 2 years), which is consistent with most of the empirical findings for developed economies.³³

5.4.2 Industrial Production and Aggregate Demand

Figure 7 depicts the implied IRF of industrial production growth. The main findings are seen in panels (c) and (d) where the effect on industrial output changes considerably. An increase of 1% in ΔIRI_t has an immediate positive impact on ΔInd_t of more than 6%, a strange result considering that the board is conducting monetary tightening. This result, however, is completely reversed in Panel (d) where a 1% increment of the policy shock ϵ_{2t} precedes a 2% reduction in ΔInd_t (significant after the 10th month). This finding is similar to that of Romer and Romer (2004) and is evidence that interest rate incrementals, when properly controlled for, have a negative impact on output. Panels (a) and (b) show that neither FXI_t nor ϵ_{1t} have significant effects on ΔInd_t .

Results are very similar when considering changes in aggregate demand. While panel (c) of Figure 8 shows that a 1% increase in ΔIRI_t raises aggregate demand by 4%, panel (d) shows that a 1% increase in ϵ_{2t} reduces aggregate demand by up to 2%.

5.4.3 Exchange Rate Changes and Volatility

Panels (a) and (b) of Figure 9 show that neither FXI_t nor ϵ_{1t} had a significant impact on exchange rate changes. This means that foreign exchange interventions are not well equipped to modify the value of the Peso vis-à-vis the USD. On the other hand, while Panel (c) shows that ΔIRI_t does not have a significant effect on the exchange rate, Panel (d) shows that a 1% increase in ϵ_{2t} appreciates domestic currency by 0.5% and its effects last for approximately 3 weeks (16 periods).

³³See for example Romer and Romer (2004), Angrist and Kuersteiner (2011) or Wasserfallen and Kuersteiner (1994) for evidence of the lag-delay that interest rates have on inflation.

Figure 10 depicts the implied IRF of exchange rate volatility. Panel (a) shows that observed purchases of foreign currency (FXI_t) have no significant effect on Vol_t . On the other hand, panels (c) and (d) show that, while ΔIRI_t has no significant impact over Vol_t , an increase of 1% in ϵ_{2t} raises volatility by up to 2% (the effects subside after the first week). Finally, panel (b) shows that a 1 million USD purchase in ϵ_{1t} reduces Vol_t by up to 0.005% and its effect lasts for approximately 3 weeks. This confirms that foreign exchange interventions have a significant, albeit small, effect on reducing exchange rate volatility.

5.4.4 1-year Treasury bond's yield

Figure 11 depicts the implied IRF of the 1-year Treasury bond's yield only as a response to IRI_t and ϵ_{2t} . Panels (a) and (b) show that a 1% increase in either ΔIRI_t or ϵ_{2t} raises the Δi_t^{1year} by up to 0.2% and its effects last for approximately 6 weeks (30 periods).

Table 8 summarizes the effects of observed policy instruments (FXI_t , IRI_t) and monetary policy shocks (ϵ_{1t} , ϵ_{2t}) on all outcome variables.

5.5 Counterfactual Experiments

It might be of interest to know what would have occurred if monetary authorities had not intervened, given that they did. In other words, to be able to compare the behavior of outcome variables with the alternative (passive) policy in which the central bank had chosen not to intervene. A caveat however, is that if monetary authorities had strayed from their *modus operandi*, different estimates would be obtained and policy effects would vary. Alternative policy paths are thus compared assuming that estimates are held constant.

As such, it is important to capture the effects of policy shocks turning off all other variation in the economy. This can be achieved without any further estimation. Coefficients from IRFs can be used to compute the cumulative effect of policy after every period. Formally, let η_i^h be the impulse response coefficient “h” periods after the shock “i” takes place, like in equation (13). Similarly, $\eta_i^h = \sum_{t=0}^h \gamma_{it}$ in the context of equation (12). The response of an outcome variable y_t , attributed exclusively to a monetary shock, is then computed as shown in equation (14):

$$\sum_{h=1}^t \epsilon_{(i)(t-h+1)} \eta_i^h = y_t \quad \text{for } i = 1, 2 \quad (14)$$

Where $\eta_i^h = 0$ when $h > 24$ or $h > 45$ for variables with monthly or daily frequency, respectively (see footnote 24). Also, $t = 1$ denotes the first observation of y_t .

Figure 12a depicts industrial production growth compared to what would have happened in the event of no intervention. The CBoC expanded industrial output by up to 4% during Nov 01-Jun 03, Feb 06-Jun 08 and Aug 09-Jun 10 as a result of expansionary policies. Nonetheless, the 2008-2009 crisis would have been 3% less severe if the CBoC had not conducted contractionary policies to control for inflation.

Figure 12b shows that the CBoC was able to effectively lower inflation by almost 2% during Feb 04-Aug 06, Feb 09-Feb 10, and Jan 11-Nov 11. However, it is possible that the CBoC could have avoided missing several of its targets had it decided to act sooner.

Figure 12c depicts exchange rate volatility compared to counterfactual outcomes in which the CBoC a) had not conducted *FXI* and b) had not conducted *IRI*. The figure shows that, for a few but highly marked episodes, volatility would have been higher without *FXI*. In particular, the average monthly volatility would have been 3.3% higher in May 2006 if the CBoC had not intervened in the exchange market. Alternatively, if the CBoC had not intervened through *IRI*, volatility would have behaved only marginally differently. The same applies for the effect of *IRI* on exchange rate changes, as shown in Figure 12d.

Finally, Figure 12e shows how the 1-year Treasury bond's yield responded to IRI_t . Namely, if the CBoC had not intervened, the 1-year yield would have been higher during Apr 05-Jul 07, and Nov 08-May 09 and lower during Nov 02-Mar 05, Aug 07-Oct 08 and Feb 11-Jul 11.

6 Conclusions

Many questions, critical to the design of effective policy regimes in emerging economies, have remained almost entirely unanswered. Some of these include: What are the effects of monetary policy when central banks have multiple instruments at their disposal? Are decisions about policy instruments independent? What alternative policy regimes can central banks adopt to better achieve their targets?

This paper addresses these questions within a non-standard framework of causal effects in a dynamic setting. The main findings indicate that:

- Empirical anomalies that are found using actual intervention data, such as the price puzzle or the co-movement between output and interest rates, are completely eliminated when properly accounting for the systematic responses of policy.
- Foreign exchange interventions are not effective for the purposes of depreciating domestic currency, nor do they have a significant impact on industrial production or aggregate demand.

They do have a significant, albeit small, effect on reducing exchange rate volatility, but most of the evidence presented in this paper suggests that exchange rate interventions have very limited effects.

- A 1% increase in the intervention interest rate raises the 1-year Treasury bond's yield by up to 0.25%, confirming that policy has a positive impact on different maturity rates.
- There is a 10-12 month lag-delay regarding the effects of interest rate policy on inflation and industrial production growth.
- Conditional on a set of control variables, decisions about interest rate interventions did not alter the probability distribution of foreign exchange interventions.

In light of this new evidence, monetary authorities should conduct most of their policy through the intervention interest rate. They should limit exchange rate interventions (if any) to scenarios of high exchange rate volatility.

7 References

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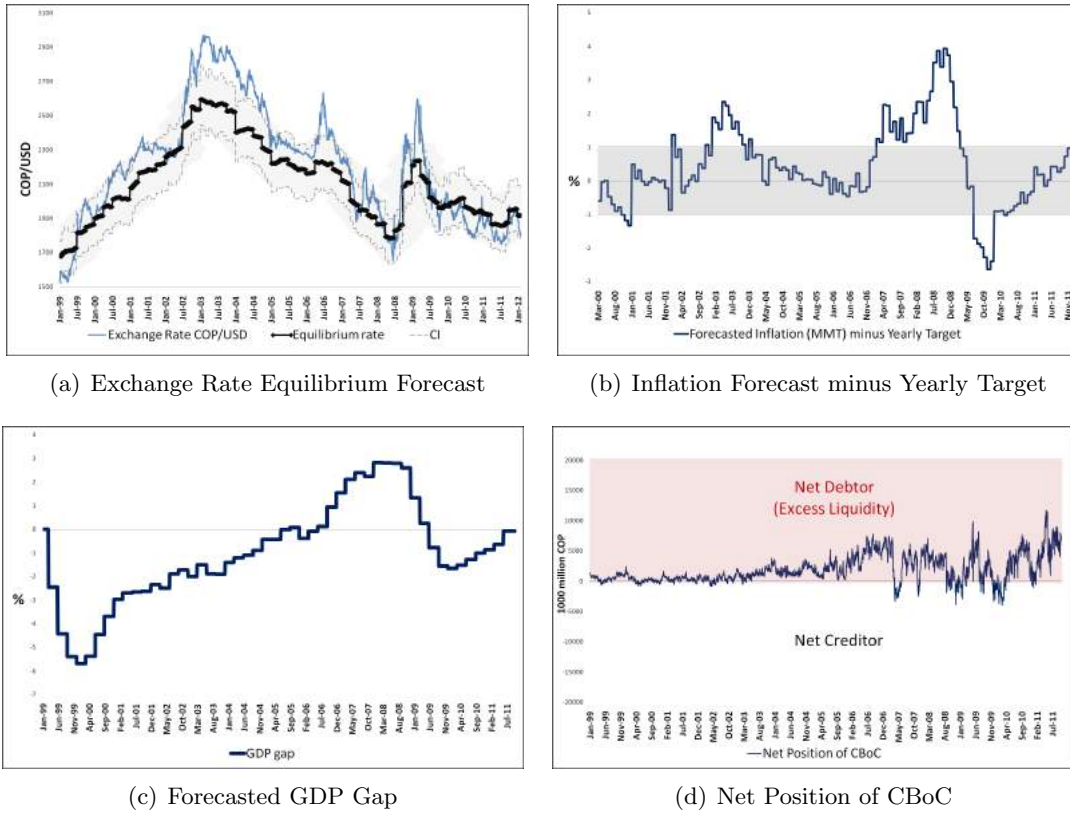


Figure 1: Internal Forecasts (a-c) and Net Position (d) of Central Bank: 1999-2012

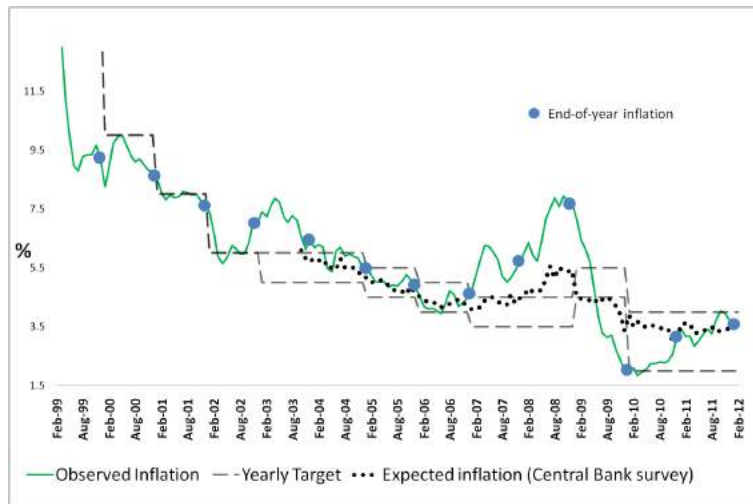


Figure 2: Inflation, Expected Inflation, and Inflation Target: 1999-2012

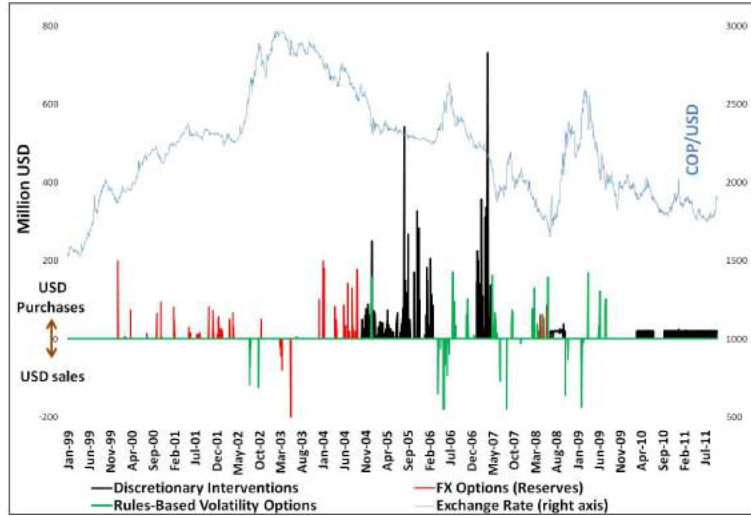


Figure 3: Different Mechanisms of Foreign Exchange Intervention: 1999-2012

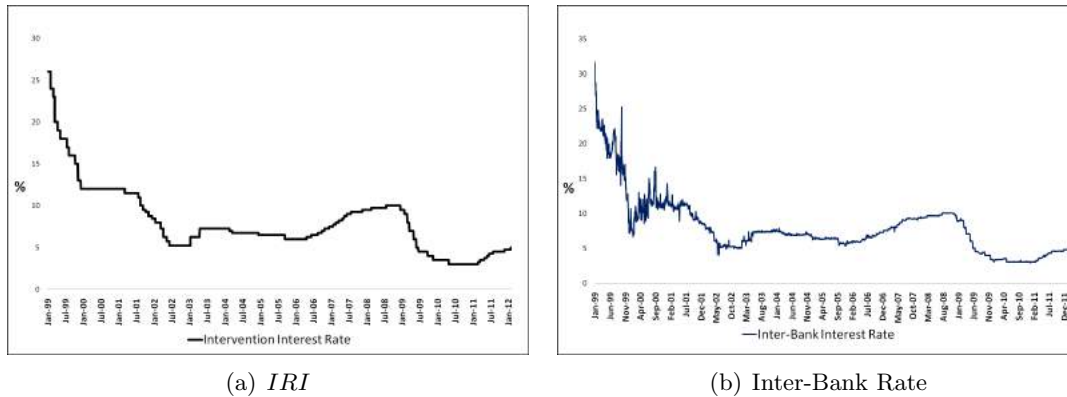
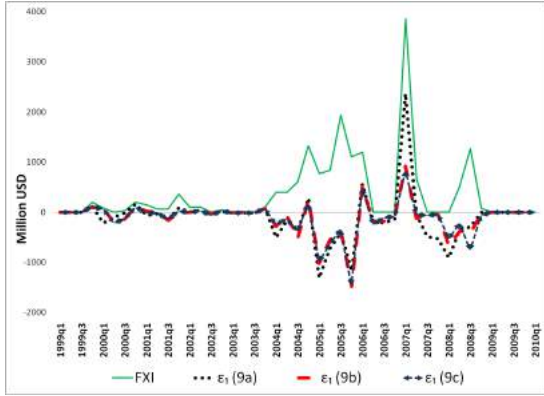
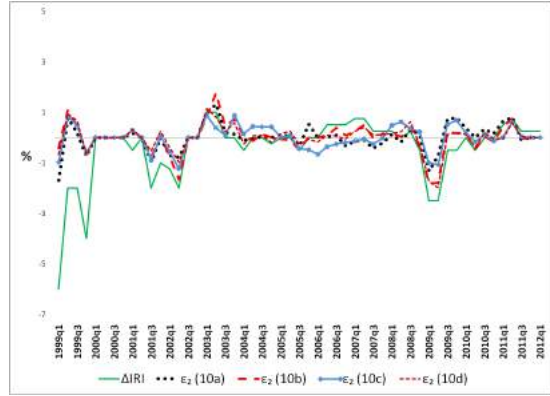


Figure 4: Intervention Interest Rate (a) and Inter-Bank Rate (b) of Central Bank: 1999-2012

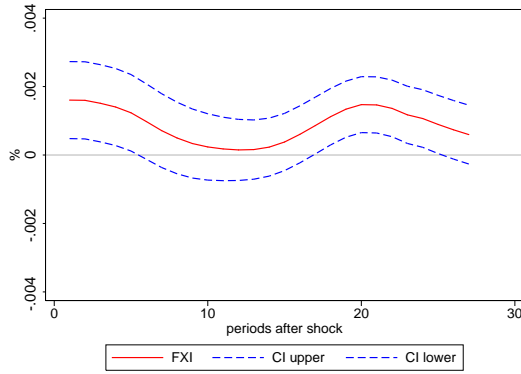


(a) FXI vs Tobit Residuals ϵ_{1t}

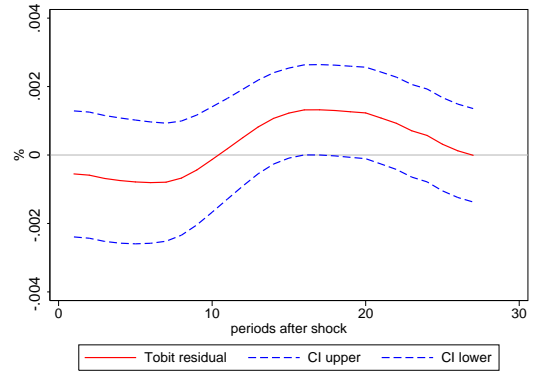


(b) ΔIRI vs OLS Residuals ϵ_{2t}

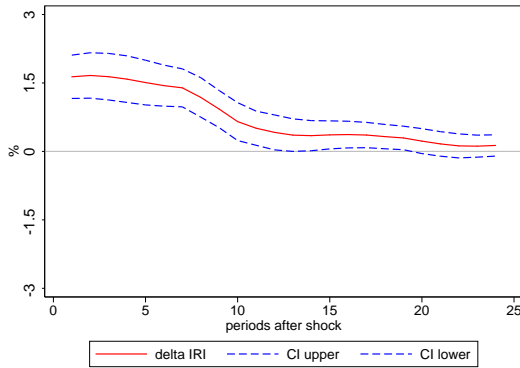
Figure 5: Observed Policy Instruments vs New Measures (Policy Shocks): 1999-2012



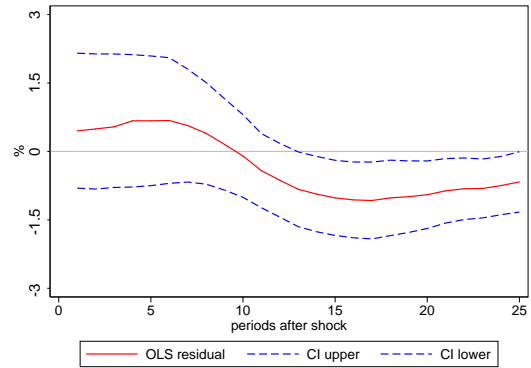
(a) Response to a 1 million USD purchase in FXI



(b) Response to a 1 million USD purchase in ϵ_{1t}

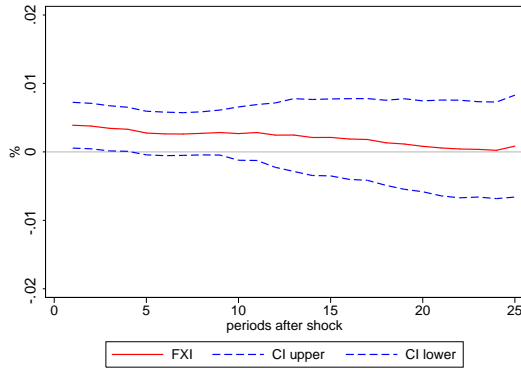


(c) Response to a 1% change in ΔIRI

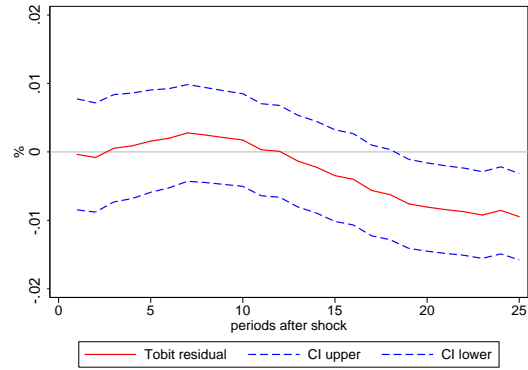


(d) Response to a 1% change in ϵ_{2t}

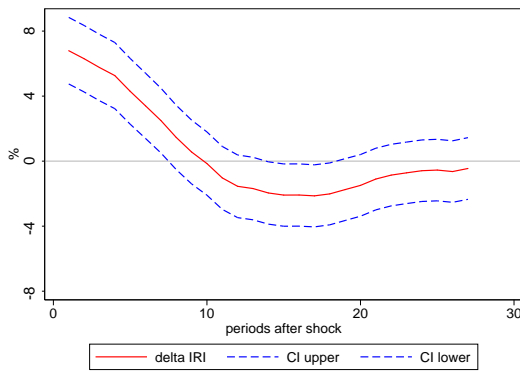
Figure 6: Implied IRFs of Inflation ($\pi_t - target(\pi_t)$)



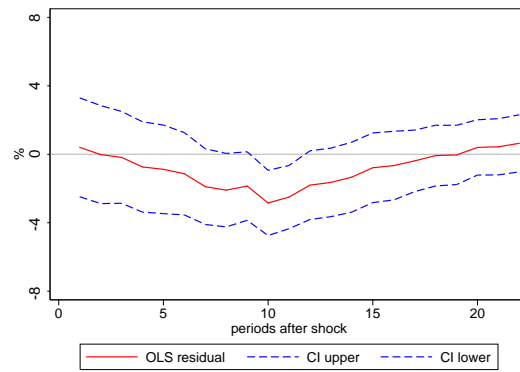
(a) Response to a 1 million USD purchase in FXI



(b) Response to a 1 million USD purchase in $€1t$

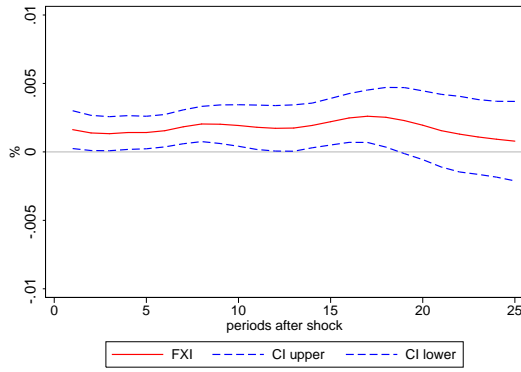


(c) Response to a 1% change in ΔIRI

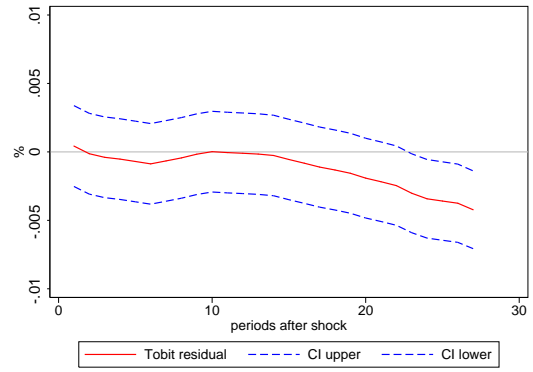


(d) Response to a 1% change in $€2t$

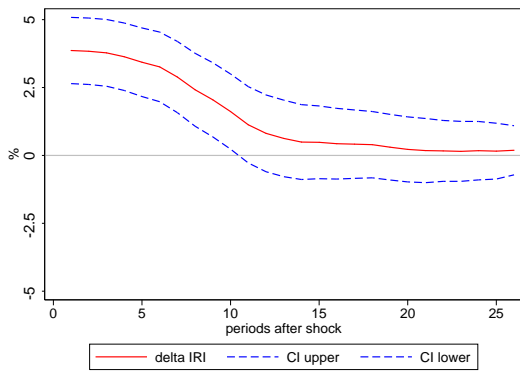
Figure 7: Implied IRFs of Industrial Production (ΔIND_t)



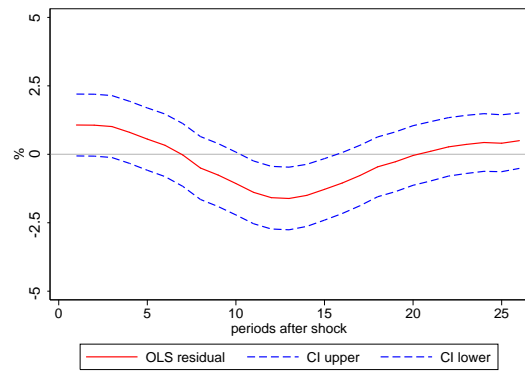
(a) Response to a 1 million USD purchase in FXI



(b) Response to a 1 million USD purchase in $\text{€}1t$

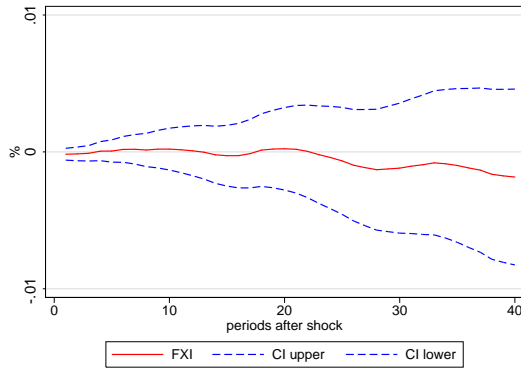


(c) Response to a 1% change in ΔIRI

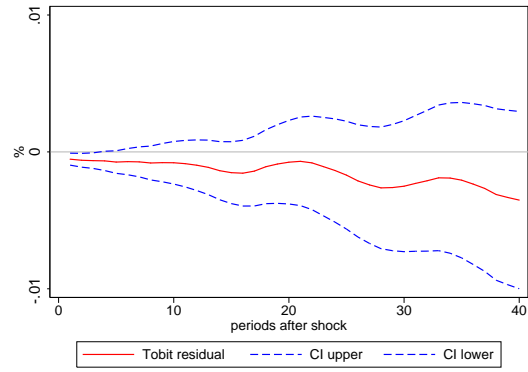


(d) Response to a 1% change in $\text{€}2t$

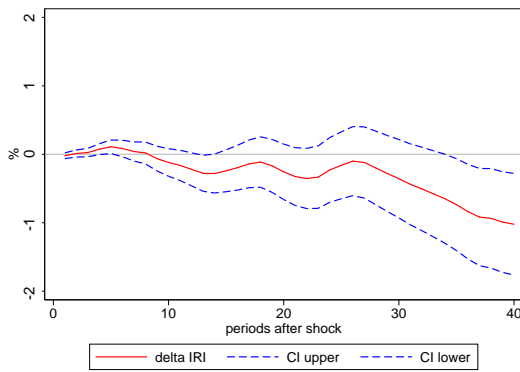
Figure 8: Implied IRFs of Δ Aggregate Demand



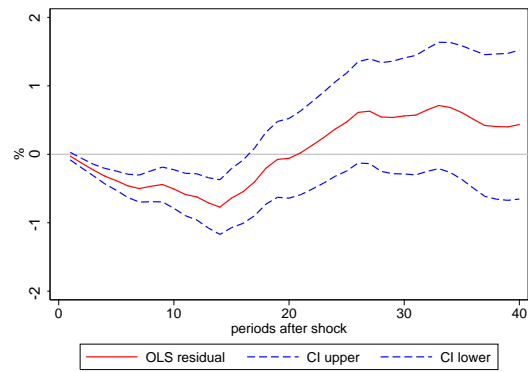
(a) Response to a 1 million USD purchase in FXI



(b) Response to a 1 million USD purchase in $€1t$

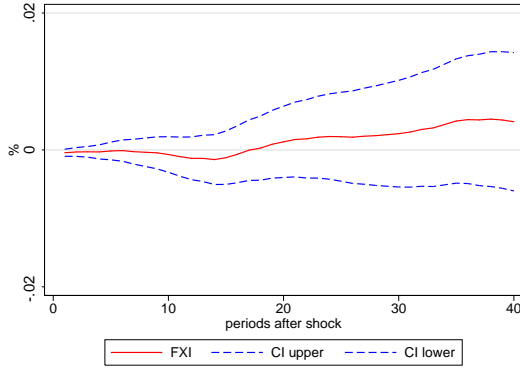


(c) Response to a 1% change in ΔIRI

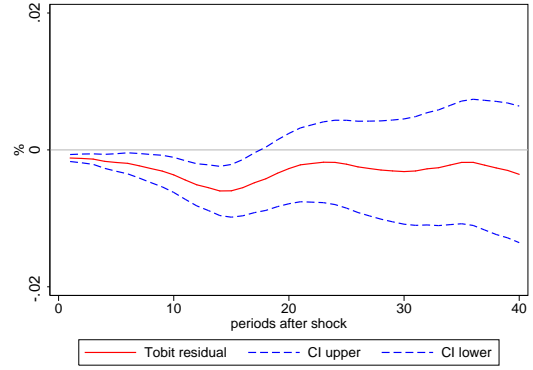


(d) Response to a 1% change in $€2t$

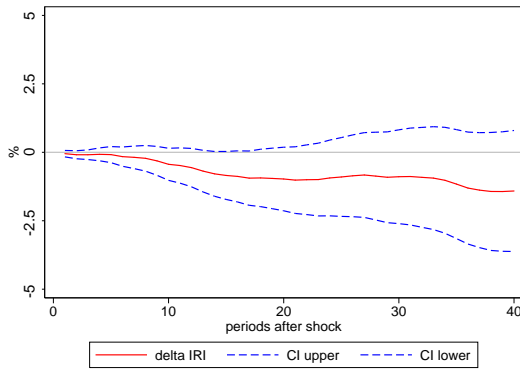
Figure 9: Implied IRFs of Exchange Rate Changes (Δe_t)



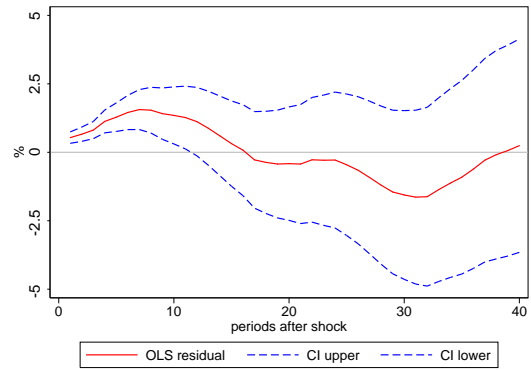
(a) Response to a 1 million USD purchase in FXI



(b) Response to a 1 million USD purchase in $€1t$

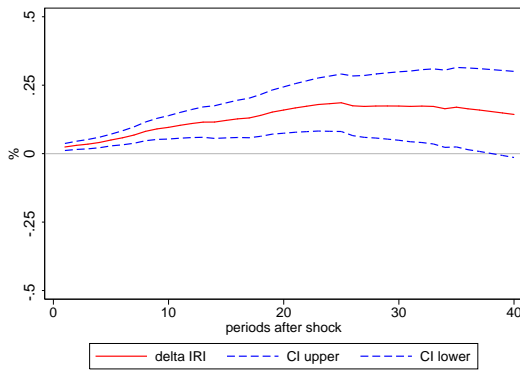


(c) Response to a 1% change in ΔIRI

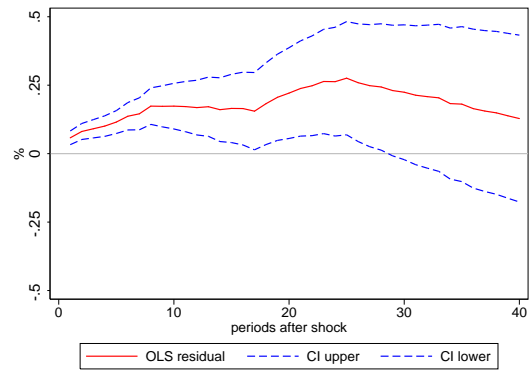


(d) Response to a 1% change in $€2t$

Figure 10: Implied IRFs of Exchange Rate Volatility (VOL_t)

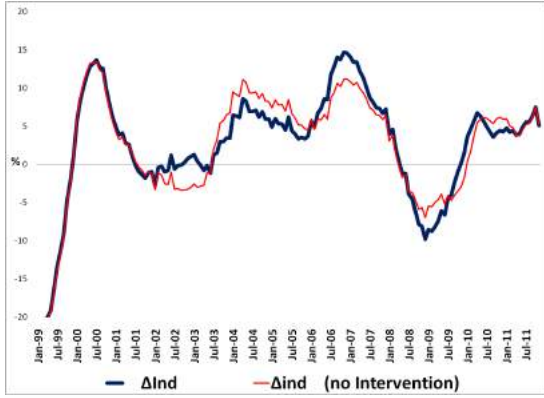


(a) Response to a 1% change in ΔIRI

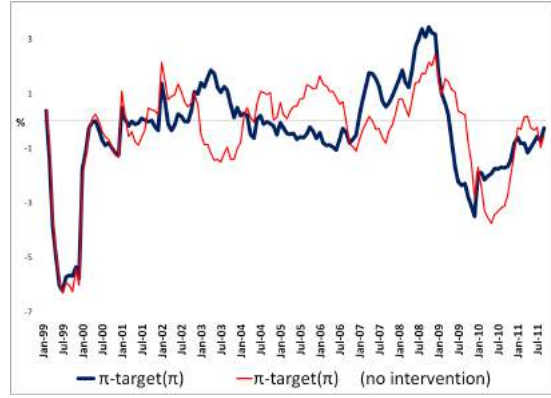


(b) Response to a 1% change in $€2t$

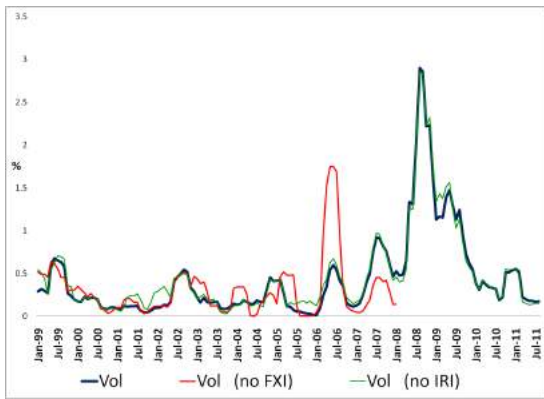
Figure 11: Implied IRFs of 1-year Treasury Bond's Yield (Δi_t^{1year})



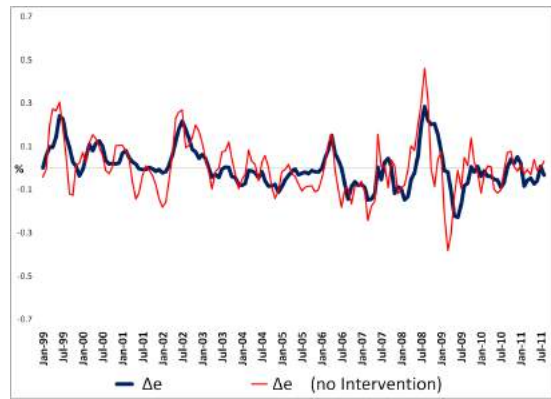
(a) Response of ΔInd_t



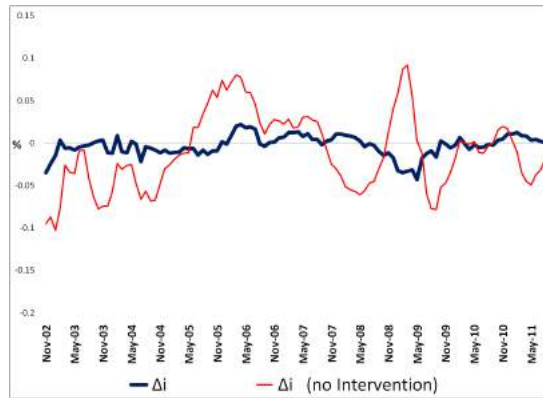
(b) Response of $\pi_t - target(\pi_t)$



(c) Response of Vol_t



(d) Response of Δe_t



(e) Response of $\Delta i_t^{.1year}$

Figure 12: Counterfactual Outcomes. Figures (c-e) correspond to smoothed monthly averages

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Table 1: Foreign Exchange Interventions 1999-2012 (Billion USD purchases)

USD Purchases	Total	99-03	04	05	06	07	08-09	10	11	12
SPOT MARKET	19.9	0.0	1.3	4.6	1.2	4.5	1.4	3.0	3.7	3.0
OPTIONS MARKET	3.3	1.5	1.4	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Intervention days (% of total trading days)		5%	32%	70%	13%	18%	18%	62%	75%	83%

SOURCE: Central Bank Data and author's calculations

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

Variable (up to 28 lags)	t-statistic	1% critical value	10% critical value
FXI_t	-5.517	-3.480	-2.570
ΔIRI_t	-6.157	-3.480	-2.570
Vol_t	-8.413	-3.480	-2.570
Δe_t	-7.756	-3.480	-2.570
$e_t - Forecast(e_t)$	-2.812	-3.480	-2.570
$Forecast(\pi_t) - Target(\pi_t)$	-3.520	-3.480	-2.570
$\pi_t - \pi^e$	-2.696	-3.480	-2.570
D_{NetP}_t	-6.131	-3.480	-2.570
$y_t - Forecast(y_t)$	-4.069	-3.480	-2.570
ΔInd_t	-3.887	-3.480	-2.570
$Brazil(\Delta e_t)$	-11.398	-3.480	-2.570
Δi_t^{1year}	-12.244	-3.480	-2.570
Δi_t^*	-3.827	-3.480	-2.570
ΔRes_t	-7.092	-3.480	-2.570

The minimum lag is determined using the modified akaike's information criterion (MAIC). All variables reject the null hypothesis of a unit root at the 1% level (except for the exchange rate deviation from the equilibrium forecast and deviations from expected inflation, which reject the null at the 10% level).

Table 3: Different Specifications for X_t

Variables Included (In addition to the Central Bank's Internal Forecasts)	
Variables in X_1	
$x_{1t}(1)$:	Exchange rate Volatility (VOL_{t-1})
$x_{1t}(2)$:	Net Position of Central Bank ($D_{NetP_{t-1}}$), Brazil's Exchange rate ($Brazil(\Delta e_{t-1})$), Board Meetings ($BoardMeet_{t-1}$), Industrial Production (ΔInd_{t-1}), Capital Controls (D_{tax})
$x_{1t}(3)$:	All in $x_{1t}(2)$ + Exchange rate Volatility (VOL_{t-1}), Biweekly Exchange rate ($\Delta e_{t-1,10}$), International Reserves (ΔRes_{t-1}), 1-Year Yield Spreads ($i_{t-1}^{1year} - i_{t-1}^{*1year}$), Lagged Interest rate Interventions (ΔIRI_{t-1})

Variables in X_2	
$x_{2t}(1)$:	Inflation Surprises ($\pi_{t-1} - \pi_{t-1}^e$), Biweekly Exchange rate ($\Delta e_{t-1,10}$), Industrial Production (ΔIRI_{t-1})
$x_{2t}(2)$:	All in $x_{2t}(1)$ + EMBI ($EMBI_{t-1}$)
$x_{2t}(3)$:	All in $x_{2t}(1)$ + Biweekly Exchange rate ($\Delta e_{t-1,10}$), 1-Day Yield Spreads ($i_{t-1}^{1day} - i_{t-1}^{*1day}$)
$x_{2t}(4)$:	1-Year Yield Δi_{t-1}^{1year} , Dummy (2006-2008) for 1-Year Yield ($D_{\Delta i_{t-1}^{1year}}$), Industrial Production (ΔIRI_{t-1})

See Appendix 1 for a detailed description of each variable.

Table 4: Covariances of Bivariate Process

Specification	$x_{1t}(1)$	$x_{1t}(2)$	$x_{1t}(3)$
$x_{2t}(1)$	-0.04 (0.058)	-0.04 (0.061)	-0.03 (0.128)
Log-Likelihood	67.06	110.69	122.26
$x_{2t}(2)$	-0.02 (0.054)	-0.04 (0.058)	-0.09 (0.215)
Log-Likelihood	-172.51	-128.99	-117.23
$x_{2t}(3)$	-0.04 (0.058)	-0.03 (0.061)	-0.04 (0.125)
Log-Likelihood	61.94	105.35	117.11
$x_{2t}(4)$	-0.03 (0.053)	-0.05 (0.055)	-0.11 (0.177)
Log-Likelihood	-339.41	-295.87	-283.78

Specifications $x_{1t}(1-3)$ and $x_{2t}(1-4)$ correspond to the different combinations of covariates presented in Table 2. All models consisted of 2,108 observations. *, **, *** indicate significance at the 10%, 5% and 1% level, respectively. Standard errors are reported in parentheses.

Table 5: Tobit Estimation: $FXI_t = \max[0, x'_{1t}\beta_1 + v_t] + \epsilon_{1t}$

Specification ($x'_{1t}\beta_1$)	$x_{1t}(1)$	$x_{1t}(2)$	$x_{1t}(3)$
FXI_{t-1}	0.51*** (0.058)	0.36*** (0.056)	0.35*** (0.058)
$e_{t-1} - Forecast(\bar{e}_{t-1})$	-2.36** (1.017)	-4.63*** (1.078)	-6.69*** (1.410)
$Forecast(\pi_{t-1}) - Target(\pi_{t-1})$	-7.41 (7.965)	-4.45 (8.121)	-5.81 (8.045)
$y_{t-1} - Forecast(\bar{y}_{t-1})$	-40.8*** (11.901)	-66.0*** (12.322)	-47.4*** (13.390)
D_{NetP}_{t-1}		4.17 (11.563)	3.48 (11.580)
VOL_{t-1}	1.96 (1.502)		2.54* (1.498)
$Brazil(\Delta e_{t-1})$		-8.43*** (3.222)	-8.08** (3.169)
$BoardMeet_{t-1}$		-19.6*** (12.084)	-20.5* (12.244)
ΔInd_{t-1}		-1.25* (0.706)	-0.87 (0.715)
D_{tax}		-164.8*** (19.140)	-164.6*** (20.192)
$\Delta e_{t-1,10}$			-4.68** (2.249)
ΔRes_{t-1}			-0.33 (2.644)
$i_{t-1}^{1year} - i_{t-1}^{*1year}$			-1.97 (3.869)
ΔIRI_{t-1}			-43.1 (51.000)

Specifications $x_{1t}(1-3)$ correspond to the different combinations of covariates presented in Table 2. All models consisted of 2,108 observations. Pseudo $R^2=0.08, 0.10$ and 0.11 for Tobit specifications 1-3. *, **, *** indicate significance at the 10%, 5% and 1% level, respectively. Standard errors are reported in parentheses. Constant and time dummies are not reported (estimations without dummies yield similar results).

Table 6: OLS Estimation: $\Delta IRI_t = x'_{2t}\beta_2 + \epsilon_{2t}$

Specification ($x'_{2t}\beta_2$)	$x_{2t}(1)$	$x_{2t}(2)$	$x_{2t}(3)$	$x_{2t}(4)$
ΔIRI_{t-1}	0.36*** (0.093)		0.19* (0.110)	
IRI_{t-1}		-0.06*** (0.015)		-0.07*** (0.012)
$e_{t-1} - Forecast(\bar{e}_{t-1})$	0.00 (0.006)			0.01*** (0.005)
$Forecast(\pi_{t-1}) - Target(\pi_{t-1})$			0.07*** (0.023)	
$y_{t-1} - Forecast(\bar{y}_{t-1})$		0.08*** (0.025)		0.08*** (0.015)
$EMBI_{t-1}$		0.04* (0.021)		
$\pi_{t-1} - \pi_{t-1}^e$	0.05** (0.024)	0.02 (0.031)		
$\Delta e_{t-1,10}$	0.02** (0.010)	0.02** (0.011)	0.02** (0.008)	
$i_{t-1}^{1day} - i_{t-1}^{*1day}$			-0.07*** (0.025)	
Δi_{t-1}^{1year}			0.63*** (0.217)	0.76*** (0.229)
$D_{\Delta i_{t-1}^{1year}}$			-0.33 (0.427)	-0.62* (0.360)
ΔInd_{t-1}	0.020*** (0.007)	0.014*** (0.004)	0.004 (0.005)	0.008* (0.004)

Specifications $x_{2t}(1-4)$ correspond to the different combinations of covariates presented in Table 2. All models consisted of 161 observations. $R^2=0.54, 0.64, 0.64$ and 0.67 for OLS specifications 1-4. *, **, *** indicate significance at the 10%, 5% and 1% level, respectively. Robust standard errors are reported in parentheses. Constant is not reported. Time dummies were not included.

Table 7: Policy Shocks' Orthogonality Condition ($\epsilon_{it} \perp \Omega_{t-1}$)

Policy Shock Specification	ϵ_{1t}			ϵ_{2t}			
	$x_{1t}(1)$	$x_{1t}(2)$	$x_{1t}(3)$	$x_{2t}(1)$	$x_{2t}(2)$	$x_{2t}(3)$	$x_{2t}(4)$
ΔInd_{t-1}	0.3*** (0.129)						
$BoardMeet_{t-1}$	-5.7*** (1.451)						
D_{NetP}_{t-1}	2.5* (1.261)			0.002 (0.067)	-0.05 (0.079)	0.001 (0.064)	-0.03 (0.067)
$Brazil(\Delta e_{t-1})$	-1.6** (0.787)			0.000 (0.015)	0.016 (0.019)	0.006 (0.016)	0.008 (0.018)
D_{tax}	-5.6*** (1.145)			-0.08 (0.079)	0.06 (0.063)	0.031 (0.070)	0.07 (0.064)
ΔRes_{t-1}	-0.61 (0.902)	-0.43 (0.779)		-0.003 (0.016)	-0.006 (0.014)	-0.005 (0.014)	-0.01 (0.013)
$i_{t-1}^{1year} - i_{t-1}^{*1year}$	-0.24* (0.127)	-0.07 (0.125)		0.007 (0.011)	0.000 (0.009)	0.014 (0.010)	0.001 (0.009)
$\pi_{t-1} - \pi_{t-1}^e$	-0.02 (0.872)	-0.50 (0.839)	-0.58 (0.841)			-0.003 (0.019)	-0.005 (0.019)
$EMBI_{t-1}$	0.002 (0.003)	0.004 (0.003)	0.004 (0.003)	0.000 (0.000)		0.000 (0.000)	0.000 (0.000)
$\Delta e_{t-1,20}$	-0.04 (0.183)	-0.005 (0.176)	-0.33* (0.180)	-0.02 (0.127)	-0.004 (0.139)	0.02 (0.112)	0.19 (0.145)
$\Delta \pi_{t-1}$	3.58 (2.505)	0.21 (2.391)	0.47 (2.382)	0.13 (0.129)	0.12 (0.106)	0.010 (0.110)	0.11 (0.104)
Δi_{t-1}^{*1day}	-6.4 (5.306)	-5.7 (5.316)	-4.8 (5.382)	0.08 (0.188)	0.05 (0.152)	0.09 (0.161)	0.07 (0.141)
$\Delta GDP_{t-1}^{Tradables}$	-0.23 (0.355)	-0.37 (0.334)	-0.040 (0.332)	0.01 (0.012)	0.02* (0.011)	0.008 (0.010)	0.017 (0.010)

Specifications $x_{1t}(1-3)$ and $x_{2t}(1-4)$ correspond to the different combinations of covariates presented in Table 2. All models consisted of 2,108 observations. *, **, *** indicate significance at the 10%, 5% and 1% level, respectively. Standard errors (robust for OLS) are reported in parentheses.

Table 8: Effects of Observed Instruments (FXI_t , IRI_t) and Policy Shocks (ϵ_{1t} , ϵ_{2t})

Outcome Variable	FXI_t	IRI_t	ϵ_{1t}	ϵ_{2t}
Inflation	+	+	0	-
	(≤ 5 months)	(≤ 1 year)		(≥ 1 year)
Industrial Production	0	+	0	-
		(≤ 7 months)		(months: 10-12)
Aggregate Demand	0	+	0	-
		(≤ 10 months)		(months: 11-15)
Exchange Rate	0	0	0	-
				(≤ 15 days)
Exchange Rate Volatility	0	0	-	+
			(≤ 16 days)	(≤ 11 days)
1-year Treasury bond's yield		+		+
		(≤ 40 days)		(≤ 27 days)

SOURCE: Author's calculations based on Impulse Response Functions

8 Appendix 1: Data Description

- Policy instruments of the CBoC (D_{1t} and D_{2t})
 - FXI_t : Discretionary purchases of foreign currency (USD) conducted in the spot market and through foreign exchange rate options. (Daily frequency)
 - IRI_t : Minimum overnight lending interest rate set by the CBoC. This variable is analogous to the US *intended* Federal Funds rate. (Daily frequency)
- Variables in X_t
 - Net position of the CBoC ($NetP_t$): Total net credit/debit with respect to the financial system. D_{NetP_t} is a dummy variable that is switched on whenever the CBoC is a net debtor. The board usually considered this variable in order to avoid episodes of excess liquidity. (Daily frequency)
 - Board Meetings ($BoardMeet_t$): Board meeting dates are analogous to the meetings of the US Federal Open Market Committee (FOMC). Information on when monetary authorities met and whether they decided to loosen, tighten or leave monetary policy unchanged is critical to remove possible endogenous relationships between the intervention interest rate and economic conditions. (Daily frequency)
 - EMBI ($EMBI_t$): 1 year yield spreads between the US and Colombia. (Daily frequency)
 - Expected Inflation (π_t^e): Mean expected yearly inflation based on the Central Bank Expectations Survey. Interviewees include commercial banks, stockbrokers and pension funds. (Monthly frequency)
 - Brazil's Exchange rate ($Brazil(\Delta e_t)$): Nominal exchange rate changes between Brazil and the US (Real/USD). (Daily frequency)
 - Capital Controls (Tax_t): Capital controls were implemented between May 2007 and October 2008. They correspond to a tax (%) imposed on capital inflows. Series corresponds to the one presented in Rincon and Toro (2011). (Daily frequency)
 - International Reserves (Res_t): International Reserves of the CBoC. (Daily frequency)
 - Exchange rate Misalignments forecasts ($e_t - Forecast(e_t)$): Seven structural models are estimated by the Observatorio de Tasa de Cambio Real (CBoC division). Specifically, two models are based on the purchasing power parity condition (PPP), two models are

based on SVEC methodologies, two models are based on the current account equilibrium and one model simply uses Hodrick and Prescott filters. Exchange rate misalignments are measured as the log-difference of the exchange rate minus the average forecasted equilibrium value. (Daily frequency)

- Inflation forecasts minus yearly target rate ($Forecast(\pi_t) - Target(\pi_t)$): forecasts are estimated by the Departamento de Modelos Macroeconomicos (CBoC department). Since 2001, the CBoC adopted a model proposed by Gomez and Julio (2001) to forecast future inflation. This model includes 9 equations that govern prices, aggregate demand, wages, an interest rate rule, the uncovered interest rate parity condition, foreign real interest rates, risk premium, terms of trade and policy rates. (Daily frequency)
- GDP gap forecasts ($y_t - Forecast(y_t)$): forecasts are estimated by the Departamento de Modelos Macroeconomicos (CBoC department). This DSGE model (PATACON) incorporates nominal and real rigidities and uses 5 main equations: cascade of Calvo pricing, staggered wages, endogenous depreciation, external habits in consumption, and investment costs. (Monthly frequency)
- US Fed Funds Rate (i_t^*): Self explanatory. (Daily frequency)

- Outcome variables in Y_t

- Exchange rate (e_t): Nominal Exchange rate between Colombia and the US (Pesos/USD). (Daily frequency)
- Exchange rate volatility (Vol_t): Squared daily returns $(e_t - e_{t-1})^2$. (Daily frequency)
- 1-year Treasury bond's yield (i_t^{1year}): Self explanatory. (Daily frequency)
- Industrial production growth (ΔInd_t): Self explanatory. (Monthly frequency)
- Inflation (π_t): Yearly changes for the Colombian Consumer's Price Index (IPI). (Monthly frequency)

Source: Central Bank of Colombia (Banco de la Republica de Colombia)

9 Appendix 2: Central Bank Policies and Regulations

Table 9: Selected Fragments of Reports that were presented to the Colombian Congress

Date	Informe de la Junta Directiva del Banco de la Republica al Congreso
Mar-00	“Aun cuando se permita que la tasa de cambio flote, es necesario evitar volatilidades extremas por los efectos perversos que esto podria tener sobre la estabilidad economica”
Mar-04	“En vista de la persistencia de las presiones revaluacionistas del tipo de cambio durante 2004, las cuales se considera pueden ser transitorias, la JDDBR estimo prudente convocar a subastas de acumulacion de reservas internacionales para enfrentar en el mediano y largo plazo posibles reversiones de los flujos de capital y ajustes en la tasa de cambio que pueden afectar el comportamiento futuro de la inflacion las compras de reservas seran esterilizadas hasta en un 50%”
Mar-05	“En periodos en los que se requiere una estrategia monetaria expansiva, la compra de divisas puede actuar como complemento de reducciones en las tasas de interes de intervencion Este tipo de politica monetaria...resulta superior a la que se concentra de manera exclusiva en el manejo de la tasas de interes”
Jul-06	“La estrategia de inflacion objetivo se ha combinado con intervenciones en el mercado cambiario por parte del Banco de la Republica, como mecanismo complementario para evitar volatilidad en el crecimiento economico y en la tasa de cambio real.”
Jul-07	“En la medida en que se perciba alguna contradiccion en el logro simultaneo de ambos objetivos, la credibilidad de los mismos quedara en entredicho, y la efectividad de la intervencion en el mercado cambiario puede verse reducida.”
Jul-08	“En junio 20 de 2008 el Emisor anuncio un nuevo mecanismo de intervencion en el mercado cambiario al determinar una acumulacion diaria de US\$20 m a traves de subastas diarias de compra directa.”

10 Appendix 3: Correlogram and Cross-Correlogram of shocks

Table 10: Autocorrelations and Cross-Correlogram

LAG	AC of ϵ_{1t}	AC of ϵ_{2t}	Cross-Correlogram
1	0.03	0.00	0.01
2	-0.01	0.00	0.00
3	-0.04	0.00	0.00
4	0.06	0.00	-0.01
5	0.01	0.00	0.01
6	0.02	0.00	0.00
7	0.05	-0.01	0.03
8	0.07	0.00	0.02
9	0.10	0.00	-0.01
10	0.03	0.00	0.00
11	0.00	0.01	0.01
12	-0.04	0.00	-0.01
13	0.01	0.00	-0.02
14	0.02	-0.07	0.01
15	0.06	0.00	0.00
16	-0.03	0.00	0.01
17	0.03	0.00	0.00
18	-0.03	0.00	-0.01
19	0.00	0.00	0.02
20	-0.04	0.00	0.01

Author's calculations.