Price Discovery in Brazilian FX Markets

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Abstract
We study price discovery in the Brazilian Foreign Exchange (FX) markets and indicate which market (spot or futures) adjusts more quickly to the arrival of new information. We find that the futures market dominates price discovery since it accounts for 66.2% of the variation in the fundamental price shock and 97.4% of the fundamental price composition. This corroborates results from previous studies that, in a unique world example, the exchange rate is formed in the futures market. In a dynamic perspective, the futures market is also more efficient since equilibrium is more quickly restored when markets are subjected to a shock in the fundamental price. By computing price discovery according to calendar semesters, we find evidence of the correlation between price discovery metrics and market factors, such as spot market supply-demand disequilibrium, central bank interventions, and institutional investors’ pressure.

Keywords: Price discovery, Exchange rate, Efficiency, Arbitrage, Derivatives.

JEL Codes: C58, F31, G14, G28.

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1. Introduction

Price discovery is the process through which information is timely incorporated into prices in the search for a new equilibrium. The related literature focuses on fragmented markets where similar assets are traded in multiple venues. A natural question that arises is: Which venue impounds new information changes in the price of a security? In other words, where does price discovery take place? The case may be that investors recognize a trading venue as preferable and recent empirical studies on price discovery (Caporale and Girardi, 2013, Fernandes and Scherrer, 2013, among others) have not only concentrated on determining the dominant market, but have also focused on identifying the characteristics of the trading environment that leads to a given outcome.

When applied to Brazilian foreign exchange (FX) markets, this concern is of particular interest in that we will be able to not only determine the dominant market to set the exchange rate (spot or futures), but also discuss the role of institutions in the price discovery process. Brazil has a long history of exchange rate crises that have originated different forms of capital controls. This process created an atypical FX market structure where, contrary to common international practice, most of the liquidity is concentrated in the first-to-mature futures contract, as is documented by Garcia and Ventura (2012). The aim of this paper is to indicate which market (spot or futures) adjusts more quickly to the arrival of new information and to provide a measure of efficiency that considers the dynamic response of each market to a new equilibrium.

We use two datasets comprising high-frequency data from the spot and futures Brazilian FX markets that cover the period between January 2008 and June 2013. Bloomberg provided the spot FX market database, while BVMF\(^1\) supplied the futures database. Both include prices at a sampling frequency of five minutes.

The contribution of the present study to the literature is twofold. This is the first paper to conduct a formal analysis with high-frequency data of Brazilian FX markets, corroborating the result noted in previous studies (Garcia and Urban, 2005, Garcia and Ventura, 2012) that, in a unique world example, the exchange rate is formed in the futures market. Institutional and market instability entails a complementary analysis of sub-samples in order to check for potential differences in the results. Hence, by checking for dominance switching over the course of each semester of the sample, it will be possible to explore the results with regard to financial indicators and policy actions. Moreover, the methodology is also applied to an emerging country with a highly regulated FX environment, which broadens the scope of the research and contributes to the literature on the effectiveness of macroprudential tools. Also, note that a Brazilian FX market investigation that

\(^1\)BVMF is the acronym for BM&FBOVESPA S.A. – Securities, Commodities & Futures Exchange, which is the main Brazilian exchange. BVMF is one of the largest exchanges in the world by market capitalization and the leader in Latin America (http://ir.bmfbovespa.com.br/static/enu/perfil-historico.asp?idioma=enu).
applies price discovery methodology combined with high frequency data has not
yet been carried out. Thus, even if previous results are validated in the light of
price discovery methodology, this study represents a significant contribution to the
literature. Our more recent sample also allows us to infer a few results regarding
the use of high-frequency trading (HFT) in Brazilian FX markets.

We find that the futures market dominates FX price discovery in Brazil. It
accounts for 66.2% of the variation in the fundamental price shock and for 97.4% of
the fundamental price composition. In a dynamic perspective, the futures market
is also more efficient since it more quickly recovers to a state of equilibrium when
markets are subjected to a shock in the fundamental price. We attribute this
finding to superior levels of liquidity and transparency in this market. In fact,
transaction restrictions in the spot market curb operations from key agents in
special high frequency trading (HFT).\textsuperscript{2} An extensive body of literature treats this
as an important driver of price efficiency (see Brogaard et al., 2013, Hasbrouck
and Saar, 2013). Besides, our findings are in accordance with those of Garcia and
Ventura (2012), where the same conclusions were reached through the application
of an order flow approach.

We also investigated whether results are robust in sub-samples. When we break
up sub-samples by semester, price discovery figures show non-trivial variations.
Despite the fact that futures market dominance still holds in all sub-samples,
results do not follow an easily identifiable pattern. Spot market supply-demand
disequilibrium, central bank interventions, and institutional investors’ pressure in
the futures market emerge as potential explanatory factors. We also identified a
capital control that restricted futures transactions as a potential price discovery
driver. Finally, futures dominance in high volatility regimes provides additional
evidence that prices are formed in this market and then transmitted to the spot
market through arbitrage.

This paper is structured as follows. In Section 2, we briefly address the main
references on the subject. In Section 3, the institutional details of the Brazilian
FX market are presented. Section 4 documents the data sources and discusses
potential limitations. Section 5 features the empirical framework and discusses
the price discovery metrics that will be used in the study. In Sections 6 and 7, the
results for the whole sample and sub-samples are reviewed, respectively. Finally,
we offer concluding remarks in Section 8.

2. Related Work

Price discovery literature takes advantage of the fact that prices are linked by
a no-arbitrage condition in order to construct a common or fundamental price in
a situation where an asset is traded in more than one market. The search for an
equilibrium price is not new, dating back to Schreiber and Schwartz (1986). This

\textsuperscript{2}HFT refers to the use of sophisticated technological tools and computer algorithms in order
to trade securities and change positions as fast as possible when faced with potential price shocks.
process has received special attention with the availability of high frequency\cite{3} data and the development of the Information Share (IS), a direct measure of price discovery formulated by Hasbrouck (1995), which measures the relative contribution of each market being studied to the variance of the efficient price. Under the same framework, the Component Share (CS).\cite{4} an alternative price discovery metric, has been proposed based on Gonzalo & Granger’s (1995) separation between transitory and permanent components. More recently, Yan and Zivot (2010) recommended a combination of both measures to form the Information Leadership Share (ILS). The ILS is a dynamic measure of relative market efficiency, based on a structural model of Yan and Zivot (2007) that addresses two main drawbacks of the previous two measures: they are based on reduced-form representations, and they are static in nature.

The use of price discovery measures was initially driven by the effort to examine price leadership in fragmented markets. Hasbrouck (1995, 2003) compared IS values for assets traded domestically in U.S. markets, while Grammig et al. (2005) studied three German stocks traded in U.S. and German markets and found that price discovery happened domestically. Caporale and Girardi (2013) also uncovered a special role for the domestic market in a highly fragmented environment: the euro-denominated bonds. On the other hand, Fernandes and Scherrer (2013) found evidence of international dominance by comparing prices from Vale and Petrobras, the main companies of the Brazilian stock market, which are traded both domestically and abroad.

Although the leadership contest between futures and spot FX markets has been the subject of various studies in the literature, this interplay is rather unsettled. While Cabrera et al. (2009) have shown that the spot\cite{5} market dominates, Rosenberg and Traub (2009) stated that this conclusion does not hold in all periods. Chen and Gau (2010) compared IS and CS measures in sub-samples and found that the futures market gains importance surrounding macroeconomic announcements for the EUR/USD and JPY/USD. With respect to emerging markets, Boyrie et al. (2012) analyzed the Brazilian real (BRL), Russian ruble (RUB) and South African rand (ZAR) using daily data. Whereas the spot market dominates in Russia, the futures market prevails in Brazil, and results were inconclusive in regards to South Africa. For Brazil, there is additional evidence of futures market dominance. Garcia and Urban (2005) accounted for the temporal precedence of futures FX prices by means of Granger causality tests. Later, Garcia and Ventura (2012) reached the same conclusion by comparing the informational content in the order flow of each market and the relative speed of adjustment of its cointegrated series.

\cite{3}Daily studies are able to provide evidence on price linkages across markets, but they cannot circumvent the problem of non-synchronous closing prices.

\cite{4}Many authors were involved in the early use of CS to measure price discovery (e.g., Booth et al. (1999), Chu et al. (1999) and Harris et al. (2002).

\cite{5}EUR/USD and JPY/USD.
Recent applied studies also analyzed the relationship between futures and spot prices in different markets. Schultz and Swieringa (2013), for instance, showed that UK natural gas futures are the main venue for price discovery when compared to physical trading hubs. In contrast, Muravyev et al. (2013) found no economically significant price discovery in the U.S. option market. Using a database that included 39 U.S. stocks and options from April 2003 to October 2006, the authors concluded that stock prices are insensitive to put-call parity deviations and that option prices resolved this misalignment.

3. FX Markets in Brazil

The Central Bank of Brazil (BCB) executes the FX policy established by the National Monetary Council (CMN), which is composed of the President of the BCB and the Ministers of Finance and Planning. The BCB holds all of the authority in determining the institutions that can directly participate in the FX spot market and also performs a regulatory role. Since 1999, Brazil has adopted a de facto administered floating FX regime where the BCB has intervened to avoid excess volatility and build FX reserves.\(^6\)

The term spot market refers to FX contracts with a financial settlement period of up to two days and is divided into two main segments: primary and secondary. The primary market is where the balance of payment transactions occur between resident and non-resident agents, including the public sector, with authorized financial institutions acting as intermediaries. Outflows from the primary market bifurcate into both a commercial and financial flux. In the commercial segment, the major players are non-financial institutions with FX obligations as only importers and exporters of goods are allowed in this segment. Services and capital flows are registered in the financial segment. Only banks that are duly chartered may act as counterparties in the spot market, and they link the two segments.

Transactions in the primary market naturally affect FX balances of the banks allowed to participate in the primary market. To restore the equilibrium and reduce risk, they resort to the secondary market, also called the interbank (IB) market, where transactions are mainly denominated in dollars as the external currency. Finally, all FX transactions, either in the primary or in the secondary market, are closed through specific contracts which are registered in a consolidated system, the Sistema Cambio, administered by the BCB. In 2014, there were 198 institutions authorized to operate in the FX market, 86 of which are multiple and commercial banks. Also in 2014, 85% of the total volume in both segments of the

\(^6\)According to the IMF’s Annual Report on Exchange Arrangements and Exchange Restrictions (2013), Brazil has a floating exchange rate (that is not free floating) which restricts the Central Bank to a maximum of three interventions for every six months. Examples of countries adopting a free floating exchange rate are Chile, Mexico, Canada, Israel, Japan, Norway, Sweden, United Kingdom, United States, and the Euro Zone countries.
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spot market was concentrated in 16 banks. But Brazil is not alone in this subject.\textsuperscript{7}

In the IB market, transactions can be booked over the counter (OTC) or through the Foreign Exchange Clearinghouse (BMC), operated by BVMF since the restructuring of the Brazilian payments system in April 2002. Today, the vast majority (approximately 95\%) of the gross volume of the interbank spot FX market is settled through the BMC. This turned out to represent important progress in terms of risk management as transactions are, by regulatory enforcement, registered without delay. In February 2006, BVMF introduced the Spot Dollar Pit, an Electronic Brokering System, in an attempt to centralize trading platforms and increase transparency in the FX market. In spite of this effort, Table 3.1 shows that the Spot Dollar Pit is losing its relative importance over time and the vast majority of operations are spread among various dealers. Some even provide access to proprietary electronic systems to facilitate and concentrate operations.

The derivatives market, in turn, performs operations of longer maturity aimed at transferring risk between investors. The most liquid contract, however, is the first-to-mature. Whereas forwards are usually traded OTC, futures contracts are highly standardized, publicly traded on organized exchanges, and transmitted to a clearing house.\textsuperscript{8} Trading is facilitated by the use of identical contracts and margin requirements are reduced by the netting of long and short positions. BVMF acts as a central counterparty, thereby greatly reducing counterparty risk. As the transactions are referenced in dollars but settlement is in domestic currency, they are not as restricted as the spot market, which also includes non-financial institutions, external investors, and individuals. The access of different participants generates more liquidity and market depth,\textsuperscript{9} thus making the impact of transactions less pronounced in the futures than in the spot market. The result is greater trading volume and market liquidity which, in turn, potentially improves the information transmission of relevant market information to market prices. According to Table 3.1, from 2006 to 2012, the proportion of trades in the futures market relative to the IB market increased from five to nine, i.e., for each dollar traded in the IB market, nine dollars were traded in the form of futures contracts.

However, in Brazil, the futures market assumes a much broader role than it was primarily designed for. Due to regulatory restrictions, some operations that should be done in the spot market are synthetically reproduced in the futures market, as described by Garcia and Urban (2005).\textsuperscript{10} This evidence becomes clear

\textsuperscript{7}The BIS (2010) Triennial Survey on FX markets points out that the declining trend of financial institutions participating in the global interbank FX market is due to a concentration in the banking industry. In the U.S., for instance, 20 banks were responsible for 75\% of the FX turnover in 1998, while only seven banks were responsible for the same amount in 2010. Most countries follow a similar trend.

\textsuperscript{8}In Brazil, BVMF and its clearing house concentrate all of the FX futures contracts.

\textsuperscript{9}Garcia and Ventura (2012) concluded that the impact of transactions in the futures market is smaller than in the spot.

\textsuperscript{10}Due to liquidity constraints in the spot market, banks usually prefer to perform FX trans-
Table 3.1 – Total trading volume in each market per year (in billions of dollars)

<table>
<thead>
<tr>
<th>Year</th>
<th>IB Spot market</th>
<th>Futures market</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spot Dollar Pit</td>
<td>Total</td>
</tr>
<tr>
<td>2006</td>
<td>55.4 (11.8%)</td>
<td>471.4</td>
</tr>
<tr>
<td>2007</td>
<td>123.4 (15.0%)</td>
<td>822.1</td>
</tr>
<tr>
<td>2008</td>
<td>122.5 (16.8%)</td>
<td>730.5</td>
</tr>
<tr>
<td>2009</td>
<td>152.4 (26.1%)</td>
<td>582.9</td>
</tr>
<tr>
<td>2010</td>
<td>57.4 (8.6%)</td>
<td>668.4</td>
</tr>
<tr>
<td>2011</td>
<td>66.6 (13.0%)</td>
<td>512.4</td>
</tr>
<tr>
<td>2012</td>
<td>28.7 (6.1%)</td>
<td>467.5</td>
</tr>
</tbody>
</table>

Source: BCB and BVMF.

Note: The numbers in parentheses represent the share of the BVMF relative to the IB market.

when we find that the futures market concentrates over 90% of its volume on the first-to-mature contract, with maturity of one month or less. Taking this into consideration, it is fair to say that the Brazilian FX market has an unusual configuration as opposed to central FX markets in which the spot concentrates liquidity and the futures are mainly used for longer term transactions.

The main argument in favor of futures market dominance is that prices are formed in the most liquid market and then transmitted via arbitrage to the less liquid one. In the Brazilian case, this would be the futures and spot, respectively. When a bank must offset a position originated by a transaction in the primary market, it may, and generally prefers, to resort to the futures market, via the first-to-mature contract, with a remaining maturity never longer than a month. Accordingly, private information via order flow from the primary market is directed to the futures market, not to the spot one. Whereas this practice creates simplicity, it also generates an interest rate risk due to the misalignment between spot and futures positions that makes it necessary to transfer positions throughout the day. The constant demand for this operation motivated the emergence of a specific market: the “casado” (married). Under this OTC contract, an instantaneous forward premium is traded, which allows both markets to be linked. Under this operational framework, we aim to determine where price discovery occurs using a unique database that consists of pairs of futures and spot market prices, as is actions in the futures market. During the day, they are able to transmit by means of synthetic operations that match positions between the markets: the so-called “casado” or “diferencial”. For details, see Garcia and Urban (2005). It is also true that price disequilibrium is not the only factor triggering “casado” transactions. Spot and hedging demands and BCB interventions are additional factors that must be taken into account.
described in the following section.

4. Database

Our database consists of regularly-spaced data on futures and spot market prices between January 2008 and June 2013, or 1,346 trading days. As far as futures transaction prices are concerned, we can say that the whole market is contemplated in that all relevant operations are necessarily conducted at BVMF, our data source, with the support of its clearinghouse. However, spot market transactions are spread among various dealers and the spot price traded at the Spot Dollar Pit corresponds to no more than 10% of the total IB market in the sampling period. Actually, FX spot market decentralization represents a challenge in terms of data collection, but Bloomberg provides a good indication, named Bloomberg BGN, which is a simple average price that includes both indicative prices and executed ones from various sources.

Hasbrouck (1995) proposes using the highest possible frequency in order to reduce a correlation between VECM residuals. At the same time, in regards to the microstructure issues usually found in high frequency studies, we must add that microstructure noise in the spot market is a mixture of different noises, originated in each data supplier’s transaction environment. In this scenario, high frequency data can give light to a noise structure that we cannot assess without additional information. This makes it reasonable to consider a five-minute frequency, which is the higher version at our disposal for the spot market, as our reference case and further decrease the frequency to 10 and 30 minutes to assess the robustness of the results.

We face what Hasbrouck (2002) calls data thinning, where a market that posts frequently is forced to follow the pattern of the less frequent one. Indeed, handling data from multiple sources with different trading frequencies requires assumptions that are not innocuous when it comes to price discovery analysis. Specifically, we had to define price intervals according to the less liquid market as the data on FX futures prices are more frequent. As Hasbrouck (2002) points out, to obtain a multivariate series, prices are adjusted to guarantee synchronization and that they are determined more or less contemporaneously. Thinning the data reduces the information set, just like any censoring procedure. Thus, how can IS be misleading when trading frequencies differ? Suppose, for instance, that the satellite market only trades after the dominant market settles down in reaction to the arrival of new information. In this case, trading is endogenous to the information process and informational leadership can be obscured by data frequency.

Evidence provided by FX traders indicates that the transfer between futures and spot positions is not a continuous process. “Casado” transactions are concen-

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11 We had futures market prices for every one minute interval.
12 To obtain a regularly-spaced series, we first identify the transaction prices nearest to each 5-min grid. Then, we consider that this price remains valid until the end of a given 5-min grid.
trated in the morning due to higher demand from corporate customers and to the formation of “Ptax”.\textsuperscript{13} They are also positively related to trading volume and, as a result, negatively related to volatility. Due to microstructure considerations, we cannot rule out the “thinning the data” effect thus introducing an element of doubt that will only be elucidated as far as the above data frequency collection issues are solved.

The BVMF futures market opens at 09:00 AM and remains active until 06:00 PM (local time) and the most liquid contract is always the first-to-mature, with the maturity date on the first day of the following month. Two days before expiration, we switch to the one maturing in the following month, which corresponds to the rollover conducted by players, as liquidity disappears. The opening hour of Bloomberg’s spot market prices is the same, but the closing time varies throughout the period of the database. As such, the joint database will consider only the periods in which both markets are open, which totals 140,153 five-minute observations. Also, price discovery measures do not include the overnight return and are estimated only during the daily continuous trading sessions.

Brazil’s very restrictive FX regulations forbid deposits in foreign currencies. The way to bypass this legal constraint was through the derivatives market. The onshore dollar rate in Brazil is obtained through a derivative that pays the equivalent of an investment in the Brazilian interest rate (also a futures contract, DI x PRÉ) and the purchase of FX (USD) futures. The covered interest rate parity (CIP) would equate the onshore dollar rate to the USD libor of the same maturity. But Brazil has both a history of defaults and a non-convertible currency, which may cause a divergence between the two types of investments in terms of risk, especially for longer maturities and during market stress. Also, continuous sterilized interventions are shown to create a positive wedge between the short-maturity onshore dollar rate and the short-maturity libor (Garcia and Volpon, 2014). The onshore dollar rate, the “Cupom cambial”, is the interest rate in dollars for an investment in Brazil and is traded as a futures contract at the BVMF. Taking country risk\textsuperscript{14} into account, “Cupom cambial” allows the relationship between futures and spot prices to take the following form:

\begin{equation}
F_t = S_t e^{(i_t - i^*_t)(T - t)}
\end{equation}

where \(F_t\) is the futures price, \(S_t\) is the spot price, \(i^*_t\) is the “cupom cambial”, \(i_t\) is the domestic interest rate for the same maturity and \((T - t)\) is the remaining time until maturity.\textsuperscript{15}

\textsuperscript{13}“Ptax” is Brazil’s benchmark rate that is used to settle currency futures contracts, among other FX transactions. Ptax is short for “Programa de Taxas”, the Brazilian Central BankBCB’s computer program that originally computed the exchange rate’s daily average.
\textsuperscript{14}See Didier et al. (2003), for information on the determinants of FX and country risk.
\textsuperscript{15}“Cupom cambial” is expressed in calendar days, while domestic interest rates are indicated in business days.
Although the underlying asset for the futures contract is the spot one and, hence, they share a common price, its relationship includes time-variant variables that are incompatible with a linear cointegration structure, which is the baseline for the “one security, many markets” approach. Before calculating price discovery measures, we must correct the futures price according to (4.1) for every five-minute observation. Due to data availability, we will perform this correction with two approximations. The first is related to the fact that we do not possess intraday data on both interest rates and we will approximate the futures price by the daily data, assuming that the correction factor is rather insensitive to small changes in interest rates.\footnote{The standard deviation of the daily percentage variation of the 30-day interest rate swap is 0.47\% and 22.78\% for the first-to-mature “cupom cambial”. To compute the potential impact of interest rate changes on the correction factors, we take the average value of each contract and time to maturity of 22 business days for the domestic interest rate and 30 calendar days for “cupom cambial”. In such circumstances, a one standard deviation change in each interest rate will modify the correction factors by 0.038\% and 0.039\%, respectively.} Also, the interest rate values should be taken from each term structure that observes the futures contract’s maturity. This is true for “Cupom Cambial” futures data that exactly matches the one for dollar futures. On the other hand, since short-term interest rate futures have low liquidity parameters, the 30-day interest rate swap is the best choice, as negligible differences are expected in terms of a risk premium.

Table 4.1 shows that while average futures prices are superior, the comparison between daily average standard deviation suggests a close pattern. In fact, futures and spot prices are highly correlated at the daily frequency and the first converges downward to meet the latter in the last day of the contract. This is a situation described as contango. As is often reported for high-frequency data, there is some evidence of negative serial correlation for low lags in both five-minute returns, possibly due to microstructure effects,\footnote{According to microstructure theory, the use of mid-spreads instead of transactions prices could minimize negative serial correlation.} but higher lags have no significant correlations.

Table 4.1 – Descriptive statistics for futures and spot prices between January 2008 and June 2013

<table>
<thead>
<tr>
<th></th>
<th>Spot</th>
<th>Futures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Five-minute mean</td>
<td>1.865</td>
<td>1.871</td>
</tr>
<tr>
<td>Daily average of five-minute standard deviation</td>
<td>0.0064</td>
<td>0.0065</td>
</tr>
<tr>
<td>First-order serial autocorrelation returns</td>
<td>-0.015</td>
<td>-0.025</td>
</tr>
</tbody>
</table>

Source: BVMF (futures market) and Bloomberg (spot market).

From Figure 4.1, it is clear that both return series display similar intraday volatility patterns. In the beginning of the trading day, volatility reaches its peak and slowly decreases until the fifth trading hour, which corresponds to the end
of lunch time in Brazil. In the following two trading hours, volatility increases, a reaction potentially linked to the market activity peak in the U.S. financial centers. At the end of the day there is another decline.

Figure 4.1 – Daily average of five-minute standard deviation prices per trading hour

![Figure 4.1](image)

We have already discussed factors that affect the microstructure of each market, which translates not only into large differences in terms of liquidity, but can also affect the relative efficiency of the markets. Indeed, this joint movement still holds when we increase the sampling frequency, but price divergences may be present in some moments depending on each market’s speed of adjustment to new information, as Figure 4.2 shows.

5. Methodology

Although the seminal paper from Hasbrouck (1995) has originated a series of developments over the recent years, all have departed from the same principle: the identification of the efficient or fundamental price, common to all the markets where the asset is traded. According to this notion, prices for the same asset can deviate from one another in the short run due to trading frictions, but both are connected to its fundamental value and will ultimately converge in the long run.

Consider that an asset trades in two venues with potentially different prices \((p_{1t}, p_{2t})\). Since securities are identical, they must share a fundamental price which, by assumption, follows a random walk process. Price differences are assumed to be transitory and covariance is stationary, arising from the fact that securities are
subjected to different sources of microstructure noise such as a bid-ask bounce and discreteness of price changes.

On these assumptions, prices are integrated at order one ($I(1)$) and the following VMA (Vector Moving-Average) representation exists:

$$\Delta p_t = \Psi(L) e_t \tag{5.1}$$

where $p_t = (p_{1t}, p_{2t})$ is a $2 \times 1$ column vector of prices and $\Delta p_t$, its first difference.

Despite the fact that prices are non-stationary, the first difference is stationary, i.e., $\beta = (1; -1)$ is a cointegration vector up to a scale factor. Defining $\Psi(1)$ as the sum of all VMA coefficients or a long-run impact matrix, the value of $\beta$ implies not only that $\beta^* \Psi(1) = 0$, but also that the rows of $\Psi(1)$ are identical. Denoting $\psi$ as the common row, Beveridge & Nelson’s (1981) decomposition$^{18}$ yields the following representations in terms of price levels:

$$p_t = p_0 + \psi \left( \sum_{s=1}^{t} e_s \right) + \psi^* (L) e_t \tag{5.2}$$

where $p_0$ is a vector of initial values and $\psi^* (L)$ is a matrix polynomial in the lag operator.

$^{18}$Applying Beveridge and Nelson’s decomposition, we can decompose matrix $\Psi(L)$ as follows: $\Psi(L) = \Psi(1) + (1 - L) \psi^* (L)$. 

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Figure 4.2 – Futures and spot daily intraday five-minute prices on December 1, 2008
The first term of (5.2) represents non-stochastic differences between prices (average spread, for instance). The middle term is the efficient or common price that we wish to estimate and the last term accounts for the zero mean residuals.

The VMA parameters of (5.1) can be recovered from the estimation of the following Vector Error Correction Model (VECM) (see Hamilton, 1994):

$$\Delta p_t = \alpha(p_{1,t-1} - \beta p_{2,t-1} + e) + \Gamma_1 \Delta p_{t-1} + \Gamma_2 \Delta p_{t-2} + \cdots + \Gamma_k \Delta p_{t-k+1} + e_t$$  \hspace{1cm} (5.3)

This is the basic reduced-form framework and we will now turn our attention to the particularities of each price discovery measure. Based on Hasbrouck (1995), the first price discovery metric used in the study is called information share (IS), which measures each market’s contribution to the variance in the innovation of the efficient price and can be written as:

$$IS_i = \frac{\psi_i^2 \Omega_{ii}}{\psi \Omega \psi'}$$  \hspace{1cm} (5.4)

where the index $i$ refers to the individual markets and $\psi \Omega \psi'$ is the variance of the efficient price innovation $\psi e_t$. $\Omega$ is the residual’s $e_t$ covariance matrix. IS indicates the proportion of the efficient price variance that is explained by each market and, accordingly, can be used to define who moves first in the price discovery process. However, being a contemporaneous measure, it does not aim to measure the total amount of information impounded on prices. It is also important to emphasize that this interpretation rests on the assumption that the VMA residuals are not correlated. When residuals are correlated, Hasbrouck proposes that the system be calculated under different orderings which have the effect of maximizing the informational content of the market at the top of the hierarchy.

The main drawback of this approach is that the residuals are not orthogonal, which makes it difficult to interpret the results. Choleski bounds can be far from tight, as is noted by Grammig and Peter (2010), especially when residuals are highly correlated. With that in mind, Fernandes and Scherrer (2013) proposed a modified IS measure based on a spectral decomposition of the covariance matrix, $\Omega$, which outperforms both Hasbrouck’s IS and Lien & Shrestha’s (2009) modified IS metric.\(^{19}\) In the eigenvector’s space, residuals are orthogonal, turning it into a unique measure defined by the following equation:

$$IS_i = \frac{([\psi S]^2)}{([\psi \Omega \psi'])}$$  \hspace{1cm} (5.5)

where $S = V \wedge (1/2) V'$, with $V$ being the matrix composed of the eigenvectors in columns and $\wedge$ a diagonal matrix of eigenvalues.

Gonzalo and Granger (1995) proposed a decomposition of a co-integrated series into permanent and transitory components that is the basis for a price discovery

\(^{19}\)Lien and Shrestha (2009) based their spectral decomposition on the correlation matrix.
measure called Component Share (CS). The permanent component must have two properties:

1) it is a linear combination of contemporaneous prices and
2) it is not Granger-caused in the long run by any transitory component.

These assumptions can be used to identify the weights as a function of the speed of adjustment coefficients from the VECM model. Baillie et al. (2002) and De Jong (2002) were able to associate the weights with the long run impact matrix \( \Psi(1) \).

If we consider an asset trading in two markets \((i, j)\), the CS measure is defined as:

\[
CS_i = \frac{\alpha_{i,i}^\perp}{\alpha_{i,i}^\perp + \alpha_{i,j}^\perp}, \quad \text{or equivalently,} \quad CS_i = \frac{\psi_i}{\psi_i + \psi_j} \tag{5.6}
\]

where \((\psi_i, \psi_j)\) refers to each market’s long run impact matrix derived from matrix \( \Psi(1) \) and the vector \((\alpha_{i,i}^\perp, \alpha_{i,j}^\perp)\) is orthogonal to the speed of adjustment vector \(\alpha\).

For a given market, a low value of the coefficient of adjustment indicates that its contemporaneous price change has a low response to the lagged disequilibrium error: \(\beta(p_i(t-1) - p_j(t-1))\). Since the quantity \(\frac{\alpha_{i,i}^\perp}{\alpha_{i,i}^\perp + \alpha_{i,j}^\perp}\) is also the weight of market price \(i\) on the efficient price, it turns out that the lower the adjustment speed, the higher the weight of a given market to the formation of the efficient price.

Despite the fact that the difference between IS and CS measures lies in the differential use of the long-run impact matrix which is applied to residuals in the former as opposed to prices in the latter, simulation-based results from Hasbrouck (2002), Lehmann (2002) and Baillie et al. (2002) show that they are compatible in a number of situations. Note, however, that both IS and CS measures originated from a reduced-form representation. Hence, as Lehmann (2002) pointed out, the shocks \(e_t\) can be a mixture of information and non-information related frictions. Putnins (2013), by means of simulated data, also concludes that IS and CS methods provide accurate measures of price discovery only when price series exhibit similar noise patterns.

Instead of a reduced form representation, Yan and Zivot (2010) recovered a Structural Moving Average (SMA) model from VECM (5.3) that can also provide a measure of relative efficiency. Their structural model is primarily aimed at analyzing structural impulse response functions as opposed to the static nature of IS and CS methods, that only account for the contemporaneous response to the arrival of new information. Consider a function that computes a measure of deviation of each market on its path to the equilibrium price when a unit shock in the common price is applied to the structural system.

\[
PDEL_i(K^*) = \sum_{k=0}^{K^*} L(f_{i,k} - 1) \tag{5.7}
\]
where \( f \) is the structural impulse response coefficient, \( i \) is the index for each market and \( K^* \) is some truncated lag period, such as \( f \) is close to zero.

The function \( L \) is arbitrary and the quadratic version will be used throughout. Its interpretation is straightforward, indicating the relative efficiency in terms of price formation. Markets with a high PDEL are slower to recover to equilibrium after a shock in the fundamental price.

6. Price Discovery in the Whole Sample

In this Section, we explore the price discovery metrics described in Section 4 for different lag structures and data frequencies. From now on, we will refer to the vector of prices as \( p_t = (s_t, f_t) \), where \( s_t \) is the spot market price and \( f_t \), is the futures price corrected as in (4.1).

Remember that the IS metric reports the contribution of each market to the variance of the common price and is calculated departing from a reduced-form representation. The VMA system could be identified by applying the Choleski decomposition to the covariance matrix, as proposed by Hasbrouck (1995), which would allow us to calculate lower and upper bounds depending on the variable ordering. However, under this identification procedure, determining these bounds is not helpful as they are not tight enough. Although such wide intervals are well documented in the literature (see Hasbrouck, 2003, Grammig and Peter, 2010), what is remarkable is the high level of correlations (0.90) among residuals. Hasbrouck’s proposition to increase sampling frequency to avoid residual correlation is not possible in our study due to the reasons outlined in Section 4. Thus, for the remainder of the paper, IS values will refer to spectral decomposition as described in Section 5.

Working with higher than usual lag lengths is recommended in intraday analysis to account for the high frequency dependencies between prices. Although standard criteria provided divergent recommended values, coefficients are stable irrespective of the lag length we employ. As a result, our reference case will consider a lag length equal to 10.\(^{20}\)

The results in Table 6.1 show that the futures market dominates the exchange rate price discovery in all perspectives, even when taking the confidence interval into account. The futures market accounts for 66.2% of the variation in the permanent shock and for 97.4% of the efficient price composition. But why are CS values considerably higher than IS ones? We can attribute this to the fact that CS is not dependent on residual correlation, suggesting that the decomposition procedure yields an underestimated IS value. Also, the higher value of PDEL indicates a greater efficiency loss in the spot market and thus a lower contribution to the price discovery process. Our results are in agreement with the order flow

\(^{20}\)Our results are robust to changes in the lag structure (1, 5, 30 lags) and to the sampling frequency (daily, 10 minutes and 30 minutes).
findings of Garcia and Ventura (2012). In fact, Rosenberg and Traub (2009) already accounted for the compatibility between the order flow approach and price discovery.

Table 6.1 – Price discovery metrics between January 2008 and June 2013

<table>
<thead>
<tr>
<th>Measure</th>
<th>Spot</th>
<th>Futures</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS</td>
<td>33.8%</td>
<td>66.2%</td>
</tr>
<tr>
<td></td>
<td>[33.0%-34.7%]</td>
<td>[65.3%-67.0%]</td>
</tr>
<tr>
<td>CS</td>
<td>2.6%</td>
<td>97.4%</td>
</tr>
<tr>
<td></td>
<td>[0.7%-4.4%]</td>
<td>[95.6%-99.3%]</td>
</tr>
<tr>
<td>PDEL</td>
<td>0.0120</td>
<td>0.0050</td>
</tr>
<tr>
<td></td>
<td>[0.0095;0.0137]</td>
<td>[0.0047;0.0055]</td>
</tr>
</tbody>
</table>

Note: Lag length = 10. Frequency = 5 minutes. 5% IS, CS, and PDEL confidence intervals in brackets.

Moving to the structural representation, dynamic behavior can be analyzed through the impulse response functions in Figure 6.1, which shows each market’s response to a unity fundamental price innovation. The immediate effect, up to 30 minutes after the shock, is the under reaction of both markets, but the futures one is closer to the fundamental price in the first 15 minutes and, from that point, prices move together. Although the PDEL indicator suggests that the futures market is more efficient, the convergence of both markets is obtained almost simultaneously, approximately 55 minutes after the fundamental price innovation.

Even prior to the evidence presented in Table 6.1, our intuition based on the relative market size would direct us to point out the futures market as the dominant one. But the market share is far from being the factor that uniquely defines the dominant market. Based on daily data, Rosenberg and Traub (2009) analyzed price discovery in the U.S. spot and futures currency markets in two sample periods: 1996 and 2006. In 1996, futures market dominance has been confirmed by both IS and CS metrics within a range of 80-90%, depending on the foreign currency. In 2006, there is a complete reversal given that the spot market played the dominant role. In both periods, the spot market had, by far, higher volume shares. An issue that immediately arises is to determine which factors could drive price discovery to the lower share trading venue and, more importantly, discuss the reasons why it did not apply to the Brazilian FX market.

The first potential factor is the incidence of informed trading. In theory, there are no a priori restrictions for consideration in the satellite market. According to Rosenberg and Traub (2009), the literature lists two main reasons why informed traders could prefer a satellite market: greater anonymity or higher speed of transaction execution. In regards to the Brazilian market, anonymity should be greater in the futures market since noisy trading in high liquid markets should help to
obscure informed trading. In a study of the German stock market, Grammig et al. (2001) found that the probability of informed trading is significantly lower in environments with lower degrees of anonymity. The spot market’s highly decentralized environment also does not favor the transaction execution motivation. Even if we totally agree that informed trading takes place predominantly in the futures market, it is far from consensual to what degree larger shares of informed trading are proportional to price discovery figures. This controversy can be illustrated by the study of Easley et al. (1998) for the 50 most liquid U.S. stocks. The authors showed that trading in the options’ market, the satellite market, contained price relevant information, which leads us to conclude that a non-zero share of informed trading suffices to influence prices.

Transparency is a second factor that could be a determinant in the price discovery process. In 1996, although the U.S. spot FX market had a higher volume share, it lacked transparency. In 2006, higher transparency levels allowed the positive association between liquidity and price discovery to emerge, as reported by Rosenberg and Traub (2009). In Brazil, while futures transactions are all electronically made and instantaneously subjected to the clearinghouse, spot activities are not shared by all investors and traded in multiple decentralized platforms.

Recent papers on the relationship between HFT and price discovery can offer an additional explanation for this result. According to this point of view, HFT can anticipate subsequent price movements, enhancing price discovery and efficiency.
This is Brogaard et al.’s (2013) conclusion, which finds that high frequency traders trade in the direction of permanent prices and in the opposite direction of transitory ones. Hasbrouck and Saar (2013) also develop empirical evidence that market quality can benefit from HFT by reducing spreads and volatility and increasing market depth.

Although most of the literature is based on stock market databases, estimates point to the presence of HFT\footnote{Based on BVMF information, Nakashima (2012) estimates a 16% contribution of the HFT to the total traded volume in the FX futures market.} in the FX market. It is also realistic to infer that high frequency traders are likely to be more actively trading in the futures market, where all transactions are electronically-based and surely the most organized and less restricted. The futures market better protects anonymity and enhances the use of private information. Taking the benefits of HFT into account, together with its higher levels of transparency, it is only natural to conclude that the futures market is dominant both in terms of speed and efficiency.

7. Price Discovery in Sub-Samples

Although our results point to futures market dominance, it will be particularly interesting to investigate this market’s dynamics over sub-samples. To begin with, it is fair to conjecture that the price discovery process might be influenced by market volatility. Uncertainty potentially triggers investors to search for an equilibrium price and the actions of informed traders eventually drive prices to equilibrium. Our assumption is that, in higher volatility periods, markets are subjected to more fundamental shocks and, thus, the price discovery process is more active and the most informative market will play a leading role. From the third quarter of 2008 to the beginning of 2009 (post-Lehman crisis), realized volatility\footnote{Realized volatility has been calculated as the sum of five-minute squared returns with no correction for microstructure. Graph is available upon request.} takes extreme values. In the remaining sample, despite periods dominated by low and stable volatility levels, we can see recurrent short periods of volatility bursts.

Taking this into account, we split the database into two sub-samples according to the realized volatility. Since each sub-sample series is restricted by convergence\footnote{We identified a convergence problem associated with the price discovery methodology. When the eigenvalues’ sum of the VECM parameters’ matrix is above unity, markets do not converge when facing a permanent shock.} issues, a low (high) volatility regime has been constructed with five-minute prices from the 160 least (most) volatile days. Price discovery metrics, presented in Table 7.1, show that futures market dominance is more evident in the high volatility regime which, according to our assumption, means that it is the most informative one.

In Table 7.2, price discovery metrics are calculated by semester.\footnote{We tried to split the sample on a monthly basis in order to match financial reports. We} Since futures...
Table 7.1 – Price discovery metrics from January 2008 to June 2013

<table>
<thead>
<tr>
<th>Measure</th>
<th>Low volatility</th>
<th>High volatility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spot</td>
<td>Futures</td>
</tr>
<tr>
<td>IS</td>
<td>47.4%</td>
<td>52.6%</td>
</tr>
<tr>
<td></td>
<td>[45.4%; 49.4%]</td>
<td>[50.6%; 54.6%]</td>
</tr>
<tr>
<td>CS</td>
<td>31.7%</td>
<td>69.3%</td>
</tr>
<tr>
<td></td>
<td>[29.0%; 34.3%]</td>
<td>[65.7%; 71.0%]</td>
</tr>
<tr>
<td>PDEL</td>
<td>0.000100</td>
<td>0.000039</td>
</tr>
<tr>
<td></td>
<td>[0.000045; 0.000170]</td>
<td>[0.000017; 0.000059]</td>
</tr>
</tbody>
</table>

Note: Lag length according to Schwarz’s criteria.
Frequency = 5 minutes. 5% IS, CS, and PDEL confidence intervals in brackets.
metrics are above 50% in all periods, results support the general conclusion that the futures market is the first to move in the price discovery process. Despite level differences between IS and CS metrics, both are rather compatible if we take into account the joint upward and downward shifts. However, it is important to note that price discovery dynamics are more volatile than the market share evolution would imply. While we observed a progressively larger proportion of futures market shares, there are periods where the spot market contribution was very close to 50%, probably due to institutional and market factors. This phenomenon will be further discussed.

In Boyrie et al. (2012), the authors found an IS value of 77% for the Brazilian futures market. When broken into sub-samples, they found that the spot market IS was above 55% between October 2007 and October 2008, i.e., around the epicenter of the financial crisis. Since this finding is at odds with Table 7.2, it is important to state the differences. First, Boyrie et al. (2012) used a daily sampling frequency, significantly increasing the “data thinning” issue reported by Hasbrouck (2002). In addition, we are not able to attest for its validity provided that the authors did not report CS weights.

Concerning the efficiency dimension, we shall analyze impulse response functions (IRF) under extreme scenarios. In Figure 7.1, we report the IRF for the first semester of 2008, during which time we obtained the highest CS futures value, as well as for the second semester of 2011, when we saw the lowest value. In the first case, we can see that the behavior of each market presents a clearer superior pattern when compared to Figure 6.1. Currently, the futures market reaction is not only superior, but convergence to the equilibrium is quickly obtained 15 minutes after the permanent shock, while the spot market takes more than two hours to converge. In the latter case, where price discovery is almost evenly divided, a puzzling relative response is generated and no clear sign of dominance can be identified.

As we have seen, results are not uniform across the sub-samples. In other words, there is a sufficient indication that price discovery is not a stable process. But what factors could determine the relative contribution to price discovery? From a practical point of view, there are situations where demand imbalances in one market could interfere in price discovery metrics. Take the example of spot demand as inferred by Brazilian current account (CC) figures. Since 2008, there has been a significant rise in the CC deficit that, until the end of our sample, has been covered by the financial account. However, how has the BCB dealt with transitory spot demand imbalances? Since the institution has the acknowledged goal of preserving
<table>
<thead>
<tr>
<th>Semester</th>
<th>IS</th>
<th>Futures</th>
<th>CS</th>
<th>Futures</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.2008</td>
<td>29.7%</td>
<td>70.3%</td>
<td>[28.6%;30.9%]</td>
<td>[69.1%;71.4%]</td>
</tr>
<tr>
<td>II.2008</td>
<td>33.7%</td>
<td>66.3%</td>
<td>[32.5%;35.0%]</td>
<td>[65.0%;67.5%]</td>
</tr>
<tr>
<td>I.2009</td>
<td>36.7%</td>
<td>63.3%</td>
<td>[35.6%;37.8%]</td>
<td>[62.2%;64.4%]</td>
</tr>
<tr>
<td>II.2009</td>
<td>23.0%</td>
<td>77.0%</td>
<td>[22.0%;24.0%]</td>
<td>[76.0%;78.0%]</td>
</tr>
<tr>
<td>I.2010</td>
<td>45.7%</td>
<td>54.3%</td>
<td>[44.4%;47.1%]</td>
<td>[52.9%;55.6%]</td>
</tr>
<tr>
<td>II.2010</td>
<td>39.0%</td>
<td>61.0%</td>
<td>[37.9%;40.1%]</td>
<td>[59.9%;62.1%]</td>
</tr>
<tr>
<td>I.2011</td>
<td>11.8%</td>
<td>88.2%</td>
<td>[10.9%;12.7%]</td>
<td>[87.3%;89.1%]</td>
</tr>
<tr>
<td>II.2011</td>
<td>44.6%</td>
<td>55.4%</td>
<td>[43.4%;45.9%]</td>
<td>[54.1%;56.6%]</td>
</tr>
<tr>
<td>I.2012</td>
<td>40.0%</td>
<td>60.0%</td>
<td>[38.9%;41.1%]</td>
<td>[58.9%;61.1%]</td>
</tr>
<tr>
<td>II.2012</td>
<td>37.4%</td>
<td>62.6%</td>
<td>[36.5%;38.2%]</td>
<td>[61.8%;63.5%]</td>
</tr>
<tr>
<td>I.2013</td>
<td>33.3%</td>
<td>66.7%</td>
<td>[32.5%;34.1%]</td>
<td>[65.9%;67.5%]</td>
</tr>
</tbody>
</table>

Note: Lag length was calculated for each sub-sample according to Schwarz's criteria. 5% IS and CS confidence intervals in brackets.
international reserves, the BCB usually resorted to swap\textsuperscript{27} interventions. When it intervenes through the derivatives market, the BCB offers a FX hedge to private agents. By doing this, the BCB postpones spot demand and expects a better financial scenario will help this imbalance to recover. Along this line of thinking, a proper way to measure such spot market pressure is to compare BCB interventions with the inflow from the primary market.

Understanding the role of each participant\textsuperscript{28} is also vital to infer the price pressures that originated in the futures market. First, FX bank positions are altered by the demand for foreign currency in the primary market. Due to regulation restrictions, the exposure to FX risk is offset in the derivatives market. Hence, we will usually see banks holding opposite positions in the futures and spot markets of a similar magnitude. Non-financial investors assess the market to hedge for FX risks in the primary market, holding matched positions in long term futures.

\textsuperscript{27} Swap is a forward contract where BCB assumes a short position in FX futures and a long position in floating domestic interest rates. For an analysis of the effects of these interventions, see Garcia and Volpon (2014).

\textsuperscript{28} BVMF breakdowns market participants according to its operational characteristics. Financial institutions are banks, brokers, and dealers, which are classified as such by the BCB. Institutional investors are domestic or external entities that organize and pool investments from individuals and corporations. In Brazil, pension funds, insurance companies, and hedge funds are the most important representatives of institutional investors. Corporations are non-financial institutions and, finally, individual investors are also considered.
Institutional investors, whether domestic or external, are the ones we must look at carefully. Since futures contracts are liquidated in the domestic currency, speculative demand does not directly affect spot market demand, but it does interfere with the exchange rate determination through arbitrage (Garcia and Volpon, 2014).

From now on, we identify each calendar semester by a two-part code, where its first part can take the value of “I”, if it is the first semester, and “II”, for the second semester, followed by the year. In I.2008, a period of high CS for the futures market, total capital inflow from the FX primary market\textsuperscript{29} totaled US$ 14.9 billion. This exactly matched the BCB’s spot intervention amount. In addition, the BCB heavily intervened through reverse swaps\textsuperscript{30} amounting to US$ 13.2 billion. Institutional investors were almost neutral, holding a monthly average short position of US$ 600 million. In II.2008, spot and swap interventions were executed in the wake of the lack of liquidity in financial markets. However, the volume of swap interventions was 10 times higher than the spot, with IS and CS values indicating clear futures dominance. In both semesters of 2010, where price discovery results were mixed, the BCB did not intervene in the futures market through swaps, but did intervene in the spot market. In I.2010, the futures position from institutional investors was neutral and spot interventions totaled US$ 14.1 billion, while total FX inflows were significantly lower (US$ 3.4 billion). In II.2010, spot interventions were again superior to capital inflow (US$ 27.5 billion compared to US$ 21.0 billion) and short positions in the futures market averaged US$ 10.7 billion on a monthly basis. Up to this point, we can figure out two possible price discovery factors. The first is the misalignment between capital flows and spot interventions that exerts a potential demand pressure on the spot market, which raising its causes IS and CS values to rise. The second factor refers to the level of futures market interventions (swap or reverse swaps), which can act upon the direction of higher futures IS and CS values.

By adding more semesters to the analysis, the impact of the above factors is reinforced. In I.2011, spot interventions were again matched with capital inflows in a pattern similar to the one verified in I.2008. The BCB resorted heavily to reverse swap interventions (US$ 14.7 billion), resulting in higher CS and IS futures values. In II.2011, the misalignment between spot interventions and capital flows had been once again introduced, but this time the interaction occurred in the opposite direction, i.e., a high capital flows (US$ 25.4 billion) as opposed to a low spot intervention volume (US$ 11.1 billion). As a result, almost half of the price discovery has been credited to the spot market.

The effect of interventions in the FX market has been extensively studied in the literature. It is well known that non-sterilized interventions impact FX rates by the interest rate channel. The effects of sterilized interventions are less consensual.

\textsuperscript{29}BCB releases the FX flow from the primary market on a monthly basis.

\textsuperscript{30}When offering a reverse swap, BCB assumes a long position in FX and a long one in floating domestic interest rates. Therefore, BCB aims at devaluing the domestic currency.
although recent studies have been able to find a significant impact. Using intra-
day data, Lahura and Vega (2013) report an asymmetric effect of Central Bank
interventions in Peru, but only when selling foreign currency. When the Central
Bank is on the buy side, market participants do not adjust their permanent price
expectations because the intervention goal is aimed at increasing reserves, not to
influence prices. Echavarría et al. (428) also report a significant price effect of
pre-announced interventions and capital controls on the Colombian spot exchange
rate. However, the intervention effect is not limited to first order impacts, as Chari
(2007) finds. According to the author, central bank interventions lead, on average,
to widening spreads and increasing levels of volatility.

Kohlscheen and Andrade (2013) reported the presence of short-term effects of
swap interventions on the spot FX market in Brazil. In a related study, Wu (2012)
showed that the daily cumulative central bank flows are correlated to short-run
deviations of the exchange rate to its fundamental value in Brazil. Note that, due
to the singular configuration of the Brazilian FX market, this result should be
put in perspective as a general policy recommendation. Since the futures market
is for the most part responsible for price discovery in Brazil, the fundamental
price will incorporate a high share of the intervention shock and the spot market
will adjust accordingly. In addition, by directly interfering in the futures market
equilibrium, the BCB signals its private information through this market, thus
increasing IS and CS futures shares endogenously. When markets operate in the
usual configuration, to be precise, when the spot market responds for most of the
variation in the fundamental price, the case may be that a futures intervention
will be interpreted as noise rather than a signal to market participants.

It is also worth providing an analysis of FX public policies over the sample
period. Until August 2008, FX policy was directed towards avoiding excessive
capital flows and, consequently, the domestic currency appreciation trend. Mas-
sive FX sterilized purchases were conducted. Around September/October 2008,
as the financial crisis reached its peak, capital outflow induced a complete reversal
in FX policies. The BCB sold some reserves and intervened by selling currency
swaps. Among other measures (Garcia, 2011) a swap agreement with the Fed-
eral Reserve (FED) allowed the market to return to normality. In 2009 and 2010,
monetary expansion and the prevalence of low interest rates in central economies
induced international portfolio rebalancing towards a greater share of emerging
countries’ assets. Thus, the increasing capital inflow inaugurated a period of con-
trols on capital inflows (Chamon and Garcia, 2013) where (Tobin) taxes varied
according to the investment-holding period, which was aimed at reducing the in-
flows of speculative capital.

In 2011, FX policy makers concentrated their efforts so as to avoid domestic
currency appreciation, but there was one regulatory decision of special interest to

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31In order to provide market liquidity in dollars, the FED and BCB set up a swap operation
of up to US$ 30 billion.
our study. In July 2011, the BCB introduced a 1% tax on the notional amount of invested currency derivatives. Note that while all previous measures shared the intention of avoiding speculative capital inflows, the tools employed had an indirect and even effect on both FX markets: spot and futures. This is the only measure that directly affects only one of the markets and, more importantly, it impacted a potential price discovery driving force: the position of institutional investors in the futures market. With a six-month sub-sample, it is difficult to measure and directly associate this policy to the lowest futures market price discovery value in H.2011. However, the alleged “coincidence” allows us to suspect that its impact has not been negligible. Besides, as Table 3.1 shows, the fall in futures trading volume between 2011 and 2012 is a corroborating evidence of the impact of this policy measure on the FX market. As capital started to flow back to central economies in mid-2012, controls on capital inflows have been progressively phased out.

To sum up, the undisputed futures market dominance over sub-samples comes from the fact that it is the most transparent and liquid one. However, we found that the ups and downs in the relative price discovery figures can be associated with some specific factors that put the spot market in a greater position than its market share would indicate. Spot market disequilibrium, measured as the difference between capital inflow and BCB interventions, might play a major role. When there is no spot market disequilibrium and the BCB still intervenes in the futures market through swaps, it is correlated to futures market dominance. Policy actions, such as the introduction of a tax on currency derivatives in July 2011, whose impact is asymmetric, might also be important. Far from being exhaustive, this section aimed at providing insights on the possible price discovery drivers. Besides, the fact that we are not able to compute smaller sub-samples restricts our analysis to a great extent.

8. Conclusion

This paper examines where the exchange rate is determined in the Brazilian FX market. In order to perform this investigation, we applied price discovery methodology based on a high-frequency database covering the period from January 2008 to June 2013. Through a variety of metrics well established in the literature, we provide robust evidence that the futures market dominates the price discovery process. Since prices are linked by arbitrage conditions, the results enable us to conclude that prices are formed in the futures and, then, the spot market adjusts to restore equilibrium and eliminate short-run deviations.

There are reasons why this result naturally arises from microstructure considerations. Spot market transactions are highly decentralized and distributed among several intermediaries. Besides, government regulations limit the spot market’s access to a few authorized financial institutions with a direct impact on relative liquidity, which is nine times higher in the futures market. The futures market, in
turn, is characterized by publicly-traded prices and broad access to financial and non-financial institutions. These features result in higher transparency levels and stimulate HFT, which are both key market efficiency drivers. The futures market has progressively incurred changes to its planned design in order to satisfy the high demand for FX transactions from economic agents. This has resulted in a high proportion of short-term futures contracts being traded with a month or less until maturity. With this background, our findings bring together the empirical methodology with overall market intuition. The IS metric, for instance, points out that 66.2% of the variation in the fundamental price shock originates in the futures market. When it comes to price composition, the CS value indicates that it accounts for 97.4% of the fundamental price. It is also more efficient. In other words, it is faster to recover to equilibrium.

We also investigated whether results are robust to sub-samples. First, we show that the futures market yet dominates in high volatility regimes, where markets are supposedly subject to more frequent shocks and the price discovery process is allegedly more active. When we break into sub-samples by semester, IS and CS figures show non-trivial variations. We have seen that, during the database period, the Brazilian FX market suffered various degrees of interventions and capital controls and its currency (BRL) experienced periods of appreciation and depreciation. We are able to identify spot market offer and demand disequilibrium, central bank interventions, and institutional investors’ pressure on the futures market as potential explanatory factors. We can also attribute variation to a huge regulatory measure that restricted futures transactions in the second semester of 2011.

Future research should investigate the relationship between central bank intervention and price discovery. With the current work, we are able to offer general evidence on this subject, but an analysis of high frequency prices surrounding interventions should shed light on the determinants of this relationship, its intensity, and uncover its transmission mechanism. Conditional on data availability, increasing the sampling frequency can improve efficiency of price discovery estimates and minimize data thinning. Finally, there is room to improve theoretical models and overcome convergence problems in order to allow price discovery metrics in smaller sub-samples.
References


