

# Price Discovery in Brazilian FX Markets

Márcio Garcia, Marcelo Medeiros and Francisco Santos<sup>1</sup>

June 3<sup>rd</sup>, 2014

## Abstract:

Brazilian Foreign Exchange (FX) markets have a unique structure: most trades are conducted in the derivatives (futures) market. We study price discovery in the FX markets in Brazil and indicate which market (spot or futures) adjusts more quickly to the arrival of new information. The contribution of the present study to the literature is twofold. It is the first paper to conduct formal analysis with high-frequency data of Brazilian FX markets, corroborating the result provided in previous studies 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 each semester of the sample, it will be possible to explore the results with regard to financial indicators and policy actions (Brazilian Central Bank sterilized FX interventions and controls on capital inflows). Moreover, the methodology is also applied to an emerging country with a highly regulated FX environment, broadening the scope of the research and contributing to the literature on the effectiveness of macroprudential tools. We find that futures market dominates price discovery since it responds 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, when markets are subjected to a shock in the fundamental price, it is faster to recover to equilibrium. 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.

**Key Words:** price discovery, exchange rate, efficiency, arbitrage, derivatives, Brazilian economy.

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<sup>1</sup> Garcia is Associate Professor, Vinci Chair, at the Economics Department, PUC-Rio; Medeiros is Associate Professor at the Economics Department, PUC-Rio; and Santos is researcher of the Macroeconomic Studies Division at IPEA-RJ. Garcia and Medeiros acknowledge financial support from CNPq. Garcia also acknowledges financial support from FAPERJ. Send correspondence to [mgarcia@econ.puc-rio.br](mailto:mgarcia@econ.puc-rio.br).

We thank Marcelo Fernandes, Alan De Genaro, Marco Cavalcanti and Tiago Berriel for much helpful comments.

## 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 in which of them new information impounds changes in the price of a security, that is, in which market does price discovery take place. It may be the case that investors recognize a trading venue as preferable and recent empirical works on price discovery (Caporale&Girardi (2013), Fernandes&Scherrer (2011), among others) have concentrated not only on determining the dominant market but also on identifying the characteristics of the trading environment that leads to a given outcome.

When applied to the 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 gave rise to different degrees of capital controls, creating an atypical structure of its FX market where, contrary to the international common practice, the first-to-mature futures contract concentrates most part of the liquidity as 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. The spot FX market database has been provided by Bloomberg while the futures one by BVMF<sup>2</sup>, both including prices at a sampling frequency of five minutes.

The contribution of the present study to the literature is twofold. It is the first paper to conduct formal analysis with high-frequency data of Brazilian FX markets, corroborating the result provided 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 each semester of the sample, it will be possible to explore the results with regard to financial indicators and policy actions (Brazilian Central Bank sterilized FX interventions and controls on capital inflows). Moreover, the methodology is also applied to an emerging country with a highly regulated FX environment, broadening the scope of the research and contributing to the literature on the effectiveness of macroprudential tools. Also, note that a Brazilian FX market investigation that applies price discovery methodology combined with high frequency data has not been yet carried out. Thus, even if previous results are validated in the light of the price discovery methodology, this 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 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, futures market is also more efficient since, when markets are subjected to a shock in the fundamental price, it is faster in recovering to equilibrium. We attribute this finding to superior levels of liquidity and transparency in this market. In fact, transaction restrictions in the spot market refrain operations from key agents, in special high frequency trading (HFT)<sup>3</sup> that an extensive literature treat as an important driver of price efficiency (see Brogaard et al (2013), Hasbrouck & Saar (2013)). Besides, our findings are in accordance with those of Garcia

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<sup>2</sup>BVMF is the acronym for BM&FBOVESPA S.A. — Securities, Commodities & Futures Exchange, which is the main Brazilian exchange, and one of the largest in the world by market capitalization and the leader in Latin America (<http://ir.bmfbovespa.com.br/static/enu/perfil-historico.asp?idioma=enu>).

<sup>3</sup>HFT refers to the use of sophisticated technological tools and computer algorithms in order to trade securities and change positions as fast as possible in face of potentially price shocks.

and Ventura (2012), where the same conclusions were reached through the application of an order flow approach.

We also investigated whether results are robust to sub-samples. When we break in 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 regulatory measure 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 list the main references on the subject. In Section 3, the main figures and features of the Brazilian FX market are presented. Next, in Section 4, we document the data sources and discuss its potential limitations. Section 5 presents 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 discussed, 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 the no-arbitrage condition 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 & Schwartz (1986). It has been given special attention with the availability of high frequency<sup>4</sup> data and the development of a direct measure of price discovery in Hasbrouck (1995), the Information Share (IS), which measures the relative contribution of each market under study to the variance of the efficient price. Under the same framework, the Component Share (CS)<sup>5</sup>, an alternative price discovery metric, has been proposed based on Gonzalo & Granger's (1995) separation between transitory and permanent components. More recently, Yan & Zivot (2010) proposed 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 & 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 US markets while Grammig, Melvin & Schlag (2005) studied three German stocks traded in US and German markets and found that price discovery happened domestically. Caporale & Girardi (2013) also revealed a special role for the domestic market in a highly fragmented environment: the euro-denominated bonds. On the other hand, Fernandes & Scherrer (2011) found evidence of the international dominance by comparing prices from Vale and Petrobras, the main companies of the Brazilian stock market, which are negotiated domestically and abroad.

Although it has been the subject of various studies in the literature, the leadership contest between futures and spot FX markets is rather unsettled. While Cabrera, Wang & Yang (2009) shown that the spot<sup>6</sup> market leads, Rosenberg & Traub (2009) stated that their conclusion does not hold in all periods. Chen & 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, Pavlova & Parhizgari (2012) analyzed Brazilian real (BRL), Russian ruble (RUB) and South African rand (ZAR) using daily data. Whereas in Russia, the spot market dominates, in Brazil it is the futures one and the

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<sup>4</sup> Daily studies are able to provide evidence on price linkages across markets, but they cannot circumvent the problem of non-synchronous closing prices.

<sup>5</sup> 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).

<sup>6</sup> EUR/USD and JPY/USD

results were inconclusive about South Africa. In Brazil, there is additional evidence of the futures market dominance. Garcia & Urban (2005) accounted for the temporal precedence of futures FX prices by means of Granger causality tests. Later, Garcia & 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.

Recent applied studies also analyzed the relationship between futures and spot prices in different markets. Schultz & Swieringa (2013), for instance, show that UK natural gas futures is the main venue for price discovery when comparing to physical trading hubs. In contrast, Muravyev et al (2013) find no economically significant price discovery in the US option market. Using a database that included 39 US stocks and options from April 2003 to October 2006, the authors conclude that stock prices are insensitive to put-call parity deviations and that option prices resolve the misalignment.

### 3. FX markets in Brazil

The Central Bank of Brazil executes the FX policy established by the National Monetary Council (CMN), which is composed by the President of the Central Bank and the Ministers of Finance and Planning. It holds all the authority in determining the institutions that can directly participate in the FX spot market and also performs the role of regulation. Since 1999, Brazil has adopted a de facto administered floating FX regime where the Central Bank has intervened to avoid excess volatility and build FX reserves.<sup>7</sup>

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. It is in the primary market where 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 a commercial flux and a financial one. 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 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 interbank (IB) market, where transactions are mainly denominated in dollars as the external currency. The scope of operations in the IB market includes not only those meant to satisfy the restrictions to the net positions imposed by the Central Bank but also directional ones. At last, 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 Central Bank. In 2014, there were 198 institutions authorized to operate in the FX market, 86 of which are multiple and commercial banks. Also in 2014, 16 banks concentrated 85% of the total volume in both segments of the spot market. But Brazil is not alone in this subject.<sup>8</sup>

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 Brazilian payment 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, which 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,

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<sup>7</sup> According to the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (2013), Brazil has a floating exchange rate, not a free floating, which restricts central bank interventions to a maximum of three for every six months. Examples countries adopting a free floating exchange rate are Chile, Mexico, Canada, Israel, Japan, Norway, Sweden, United Kingdom, United States and the Euro countries.

<sup>8</sup> 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 concentration in the banking industry. In the US, for instance, 20 banks were responsible for 75% of the FX turnover in 1998, while only 7 banks were responsible for the same amount in 2010. Most countries follow similar trend.

an Electronic Brokering System, an attempt to centralize trading platforms and increase transparency in the FX market. In spite of this effort, it remains clear from Table 3.1 that the Spot Dollar Pit is losing its relative importance over time and the vast majority of operations are spread among various dealers, some of them even providing 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 cleared through a clearing house<sup>9</sup>. 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, including also non-financial institutions, external investors and individuals. The access of different participants generates more liquidity and market depth<sup>10</sup>, making the impact of transactions less pronounced in the futures than in the spot. The result is greater trading volume and market liquidity which, in turn, potentially improves 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 at the IB market, nine dollars were traded in the form of futures contracts.

Table 3.1 – Total trading volume in each market per year (in billion dollars)

	IB Spot market		Futures market
	Spot Dollar Pit	Total	
2006	55.4 (11,8%)	471.4	2315.2
2007	123.4 (15,0%)	822.1	4235.2
2008	122.5 (16,8%)	730.5	4370.0
2009	152.4 (26,1%)	582.9	3338.8
2010	57.4 (8,6%)	668.4	4122.7
2011	66.6 (13,0%)	512.4	4308.4
2012	28.7 (6,1%)	467.5	4202.5

Source: Central Bank of Brazil and BVMF

Note: In parenthesis the share of BVMF Market relative to the IB market

However, in Brazil, the futures market assumes a much broader role, more than it was primarily designed to. Due to regulatory restrictions, some operations that should be done in the spot market are synthetically reproduced in the futures one, as described by Garcia & Urban (2005)<sup>11</sup>. This evidence becomes clear when we find that futures 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 preserves its role in long 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, futures and spot respectively in the Brazilian case. 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 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

<sup>9</sup> In Brazil, BVMF and its clearing house concentrates all FX futures contracts.

<sup>10</sup> Garcia and Ventura (2012) concluded that the impact of transactions in the futures market is smaller than in the spot one.

<sup>11</sup> Due to liquidity constraints in the spot market, banks usually prefer to perform FX transactions 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.

due to the misalignment between spot and futures positions making it necessary to transfer positions along 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 allowing 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 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 1346 trading days. As far as future 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 including both indicative prices or executed ones from various sources.

Hasbrouck (1995) proposes to use the highest possible frequency in order to reduce correlation between VECM residuals. At the same time, 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 making it reasonable to consider a five-minute frequency, which is the higher one at our disposal for the spot market<sup>12</sup>, as our reference case and further decrease the frequency to ten and thirty 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 and 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<sup>13</sup> to guarantee synchronization and 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 that case, trading is endogenous to the information process and the 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 concentrated in the morning due to higher demand from corporate customers and to the formation of “Ptax”<sup>14</sup>. 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 maturity date at 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

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<sup>12</sup> We had futures market prices for every one minute interval.

<sup>13</sup> To obtain a regularly-spaced series, we first identify the transaction prices nearest to each 5-min grid. We, then, consider that this price remains valid until the end of a given 5-min grid.

<sup>14</sup> “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 Bank computer program that originally computed the exchange rate daily average.

opening hour of Bloomberg spot market prices is the same, but the closing time varies along the database period. As such, the joint database will consider only the periods in which both markets are open totaling 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.

Brazilian very restrictive FX regulations forbid deposits in foreign currencies. The way to bypass this legal constraint was through 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. 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 investment 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 BVMF. Taking country risk<sup>15</sup> into account, “cupom cambial” allows the relationship between futures and spot prices to take the following form:

$$F_t = S_t \cdot e^{(i_t - i_t^*)(T-t)} \quad (4.1)$$

Where  $F_t$  is the futures price,  $S_t$  is the spot one,  $i_t^*$  is the “cupom cambial”,  $i_t$  is the domestic interest rate for the same maturity and  $(T-t)$  the remaining time to maturity.<sup>16</sup>

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 one is related to the fact that we do not possess intraday data on both interest rates and we will approximate it by the daily data assuming that the correction factor is rather insensitive to small changes in interest rates<sup>17</sup>. Also, the interest rate values should be taken from each term structure observing the futures contract’s maturity. This is true for “Cupom Cambial” futures data that exactly matches the dollar futures one. 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 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 daily frequency and the first converge downward to meet the latter in the last day of the contract, a situation described as contango. As 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<sup>18</sup>, but higher lags have no significant correlations.

<sup>15</sup> See Didier, Garcia & Urban (2003), for an exposure of the determinants of FX and country risk.

<sup>16</sup> Cupom cambial is expressed in calendar days while domestic interest rates, in business days.

<sup>17</sup> The standard deviation of the daily percentage variation of the 30-day interest rate swap is 0.47%, and of the first-to-maturity “cupom cambial” is 22.78%. 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.

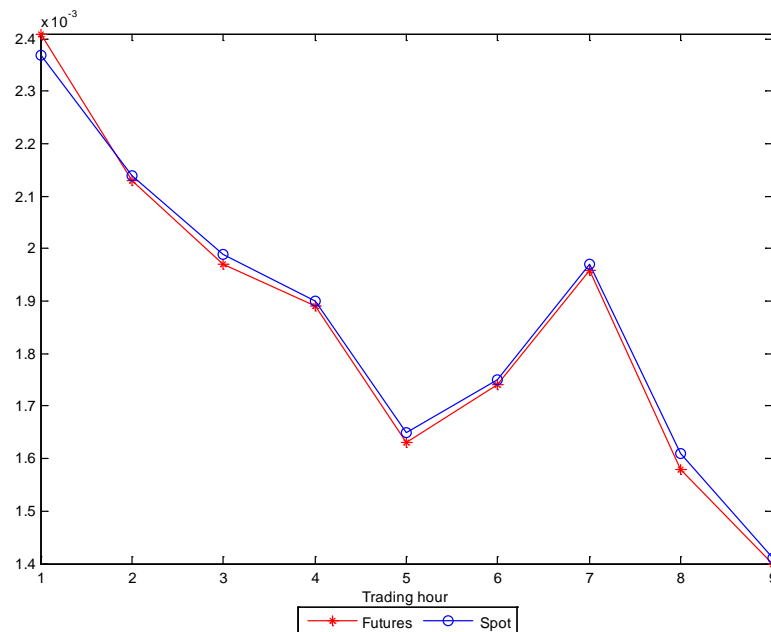
<sup>18</sup> According to microstructure theory, the use of mid-spreads instead of transactions prices could minimize negative serial correlation.

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

	Spot	Futures
Five-minute mean	1.865	1.871
Daily average of five-minute standard deviation	0.0064	0.0065
First-order serial autocorrelation returns	-0.015	-0.025

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 5<sup>th</sup> trading hour, what corresponds to end of lunch time in Brazil. In the following two trading hours, volatility increases possibly linked to market activity peak in the U.S. financial centers and, finally, there is another decline in the end of the day.

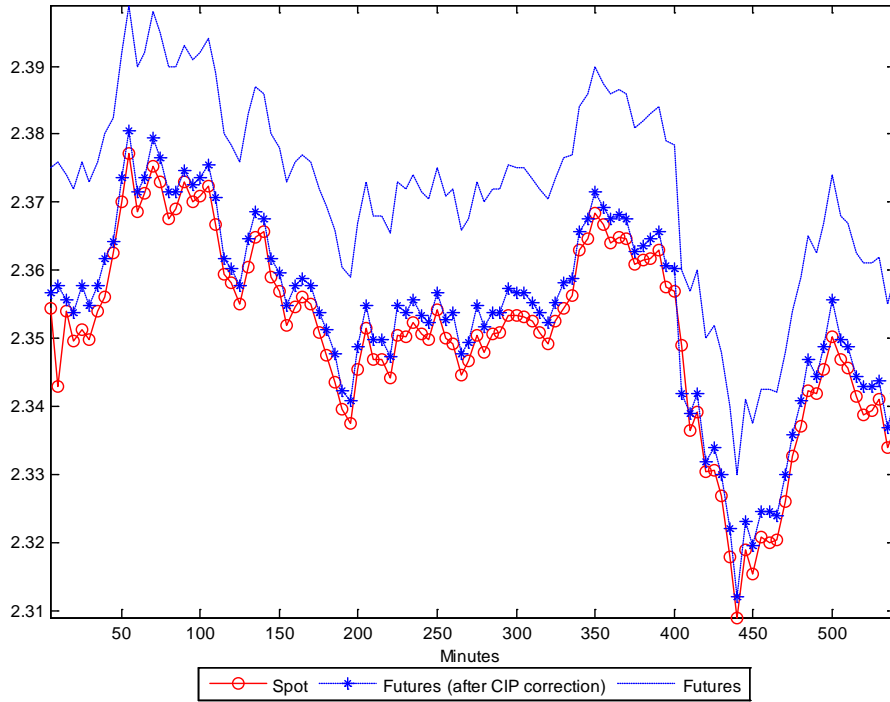
Figure 4.1: Daily average of five-minute standard deviation prices per trading hour



We have already discussed factors that affect the microstructure of each market which translates not only in large differences in terms of liquidity but also can 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 the each market's speed of adjustment to new information, as Figure 4.2 shows.



Figure 4.2: Futures and spot daily intraday five-minute prices at 1<sup>st</sup> December, 2008



## 5. Methodology

Although the seminal paper from Hasbrouck (1995) has raised a series of developments over the recent years, all of them 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 on two venues with potentially different prices ( $p_{1t}$ ,  $p_{2t}$ ). Since securities are identical, they must share a fundamental price  $m_t$  which, by assumption, follow a random walk process. On these assumptions, prices are integrated of order one ( $I(1)$ ) and there exists a VMA (Vector Moving-Average) representation as follows:

$$\Delta p_t = \Psi(L)e_t \quad (5.1)$$

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 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 (1981) decomposition yields the following representations in terms of price levels:

$$\Psi(L) = \Psi(1) + (1 - L)\Psi^*(L)$$

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

The first term is a vector of initial value that 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)):

$$\Delta p_t = \alpha(p_{1,t-1} - \beta \cdot p_{2,t-1} + c) + \Gamma_1 \Delta p_{t-1} + \Gamma_2 \Delta p_{t-2} + \dots + \Gamma_{k-1} \Delta p_{t-k+1} + e_t \quad (5.3)$$

This is the basic reduced-form framework and we will now turn our attention to the particularities of each price discovery measure. According to Hasbrouck (1995), the term  $\psi e_t$  is the efficient price innovation whose variance is given by  $\psi \Omega \psi'$ , where  $\Omega$  is the residual's  $e_t$  covariance. Our first price discovery metric, called *information share* (IS), can be written as:

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

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 it fails, Hasbrouck proposes that the system should be calculated under different orderings which have the effect of maximizing the information content of the market in the top of the hierarchy. The main drawback of this approach is that the residuals are not orthogonal making it difficult to interpret the results. Choleski bounds can be far from tight, as noted by Grammig & Peter (2010), especially when residuals are highly correlated. With that in mind, Fernandes & Scherrer (2013) proposed a modified IS measure based on a spectral decomposition of the covariance matrix,  $\Omega$ , which outperforms both Hasbrouck IS and Lien & Shrestha (2009) modified IS metric<sup>19</sup>. In the eigenvector's space, residuals are orthogonal turning it into a unique measure defined in the following equation:

$$IS_i = \frac{([\psi S]_i)^2}{(\psi \Omega \psi')} \quad (5.5)$$

Where  $S = V \Lambda^{1/2} V'$ , with  $V$  the matrix composed of the eigenvectors in columns and  $\Lambda$  a diagonal matrix of eigenvalues.

Gonzalo & Granger (1995) proposed a decomposition of a cointegrated series into permanent and transitory components that is the basis for a price discovery 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 the transitory component. These assumptions can be used to identify the weights as a function of the speed of adjustment coefficients from the VECM model. Later on, 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 at two markets (i,j), the CS measure is defined as:

$$CS_i = \frac{\alpha_{\perp i}}{\alpha_{\perp i} + \alpha_{\perp j}}, \text{ or equivalently, } CS_i = \frac{\psi_i}{\psi_j + \psi_i} \quad (5.6)$$

Where  $(\psi_i, \psi_j)$  refers to the each market's long run impact matrix derived from matrix  $\Psi(1)$  and the vector  $(\alpha_{\perp i}, \alpha_{\perp j})$  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

<sup>19</sup>Lien and Shrestha (2009) based their spectral decomposition on the correlation matrix.

error:  $\beta(p_{i,(t-1)} - p_{j,(t-1)})$ . Since the quantity  $\frac{\alpha_{\perp,i}}{\alpha_{\perp,i} + \alpha_{\perp,j}}$  is also the weight of market price 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. Note 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. In fact, simulation-based results from Hasbrouck (2002), Lehmann (2002) and Baillie et al (2002) show that they are compatible in a number of situations. However, weights on the efficient price are equal to the long-run multipliers only up to a scale. So, CS fails to provide accurate efficient price estimates which should be based on the Stock-Watson common trend representation. Besides, Gonzalo-Granger decomposition imposes that the permanent component to be I(1), not necessarily a random-walk what is behind Hasbrouck (2002) critique to the economic interest in such a measure. Note that both IS and CS measures are 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.

Instead of a reduced form representation, Yan & Zivot (2010) recovered a Structural Moving Average (SMA) model from VECM (5.3) that can also provide a measure of relative efficiency (see Appendix A for details). Their structural model is primarily aimed at analyzing structural impulse response functions as opposed to the static nature of IS and CS methods, that accounts only for the contemporaneous response to the arrival of new information. However, it is convenient to compute a measure of deviation of each market on its path to the equilibrium price. This deviation can be calculated for each time k by accumulating impulse responses taken from  $D_p(L)$  in (A.9) as follows:  $f_{i,k} = \sum_{i=0}^k d_{i,k}^p$ . Consider a function that summarizes such deviations when a unit shock in the common price is applied to system (A.1).

$$PDEL_i(K^*) = \sum_{k=0}^{K^*} L(f_{i,k} - 1) \quad (5.7)$$

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 one will be use 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. Based on the same structural representation, Yan & Zivot (2010) provides examples where IS and CS can be misleading pictures of the price discovery efficiency. They propose a measure to correct for cross-market transitory effects that rests on the assumption that covariance residuals are uncorrelated, but the fact that our covariance residuals are highly correlated constrains its application to our analysis. Putnins (2013), by means of simulated data, also concludes that IS and CS provide accurate measures of price discovery only when price series exhibits similar noise patterns.

There is a lot of confusion and lack of precision in the literature concerning what do one means by price discovery. By stating that it refers to the “efficient and timely incorporation of the information implicit in investor trading into market prices”, Lehmann (2002) gives an indication on the two dimensions that we must take into account in order to get an economic perspective. According to Putnins (2013), the term “efficient” refers to the market’s ability to reach the fundamental price, implying a relative absence of noise, to which we can link PDEL metric due to its dynamic nature while computing the accumulated deviation from a permanent shock. “Timely” refers to the relative speed at which new information is incorporated into prices, being closely related to Hasbrouck’s IS metric as far as it measures the contemporaneous contribution of each market to the permanent component innovation, or “who moves first”. Similar concept applies to CS just by taking permanent price instead of innovation.

## 6 Results

In this Section, we discuss the results. We first analyze the VECM parameters and then provide the price discovery measures for different lag structures and data frequencies.

## 6.1 VECM

We will start our analysis with the VECM results (equation 5.3) for the whole sample period. 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). It is usually recommended to work with higher than usual lag lengths in intraday analysis to account for the high frequency dependencies between prices. Although standard criteria provided divergent recommended values, it is clear from Table 6.1.1 that coefficients are stable irrespective of the lag length we employ. So, our reference case will consider a lag length equal to 10 and we will check results' robustness in Section 6.3.

The speed of adjustment toward equilibrium is determined by the magnitude of  $\alpha$  and, restricting the cointegration coefficient to (1,-1), it measures the adjustment to deviations from CIP<sup>20</sup>. We reject the null hypothesis ( $\alpha=0$ ) for the spot market adjustment coefficient, meaning that it reacts to such deviations. The negative sign means that when facing a negative disequilibrium error, that is, when futures increases above the arbitrage conditions imposed by CIP, spot reacts accordingly by raising its price. The low adjustment value suggests that this correction is slow given that only 3.2% of the disequilibrium is adjusted in one time-period (five minutes). In contrast, we conclude that the futures market does not respond to equilibrium deviations by the fact that the adjustment speed is not significant. It is important to note that, similar to Garcia & Ventura (2012), the speed of adjustment is lower in the futures market what, according to Hasbrouck (2006), indicates a more dominant market. Finally, LR cointegration test for binding restrictions, which tests the null of no cointegration against the known alternative of rank one, supports the existence of a (1,-1) cointegration vector in all cases.

Table 6.1.1: Coefficients for the VECM regression from January/2008 to June/2013

$$(\Delta p_t = \alpha(s_{t-1} - f_{t-1} + c) + \Gamma_1 \Delta p_{t-1} + \Gamma_2 \Delta p_{t-2} + \dots + \Gamma_{k-1} \Delta p_{t-k+1} + e_t)$$

	Lag Length = 5		Lag Length = 10		Lag Length = 30	
	Spot	Futures	Spot	Futures	Spot	Futures
$\alpha$	-0.044 (10.6)	0.001 (0.3)	-0.032 (7.5)	0.001 (0.1)	-0.022 (5.1)	0.001 (0.2)
$\beta$	1	-1	1	-1	1	-1
c	0.0003		0.0003		0.0003	
Residual correlation	0.95		0.95		0.95	
R <sup>2</sup>	0.03	0.01	0.03	0.01	0.03	0.01
Number of observations	140,089		140,084		140,	

Note: Lag coefficients are omitted  
In parenthesis, are the t-statistics.

## 6.2. Price Discovery in the whole sample

We will explore the different price discovery metrics described in Section 4. We will begin with our reference case that employs a VECM with lag length of 23 and five-minute intraday price frequency. 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 on the covariance matrix, as proposed by Hasbrouck (1995), what would allow us to calculate lower and upper bounds depending on the variable ordering. However, under this identification procedure, they are not helpful to identify as bounds are not tight enough. Although such wider intervals are well documented in the literature (see Hasbrouck (2003), Grammig & Peter (2010)), what makes it 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. So, for the remainder of the paper, IS values will refer to spectral decomposition as described in Section 5.

<sup>20</sup> Taking risk country into account by applying "cupom cambial".

The results in Table 6.2.1 show that futures market dominates the exchange rate price discovery in all perspectives and taking confidence interval into account. It responds for 66.2% of the variation in the permanent shock and for 97.4% of the efficient price composition. But why CS values are considerably higher than IS ones? We can attribute 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 findings of Garcia & Ventura (2012). In fact, Rosenberg & Traub (2009) already accounted for the compatibility between the order flow approach and price discovery.

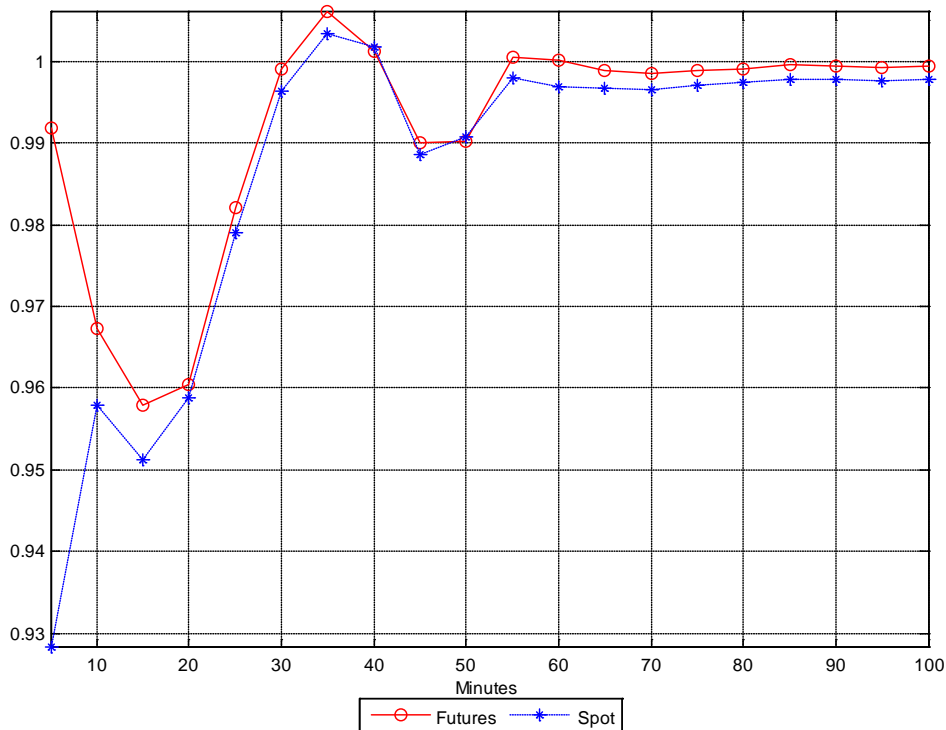
Table 6.2.1: Price discovery metrics between January 2008 to June 2013

Measure	Spot	Futures
IS	33.8%[33.0%;34.7%]	66.2%[65.3%;67.0%]
CS	2.6%	97.4%
PDEL	0.0120[0.0095;0.0137]	0.0050[0.0047;0.0055]

Note: Lag length=10.  
Frequency= 5 minutes.  
5% confidence interval in brackets.

Moving to the structural representation, dynamic behavior can be analyzed through the impulse response functions in Figure 6.2.1, which shows each market's response to a unity fundamental price innovation. The immediate effect, up to 30 minutes after the shock, both markets underreact but 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.

Figure 6.2.1: Impulse response functions from January 2008 to June 2013



Note: Lag length=10  
Frequency= 5 minutes.

Even prior to the evidence presented in Table 6.2.1, our intuition based on the relative market size would direct us to point out the futures market as the dominant one. But market share is far from being the factor that uniquely defines the dominant market. Based on daily data, Rosenberg & Traub (2009) analyzed price discovery in the US 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 one played the dominant role. In both periods, spot market had, by far, higher volume shares. An issue that immediately arises is to find what factors could drive price discovery to the lower share trading venue and, more important, 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 it to be taken in the satellite market. According to Rosenberg & Traub (2009), the literature lists two main reasons why informed traders could prefer a satellite market: greater anonymity or higher speed of transaction execution. Back 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 German stock market study, Grammig et al (2001) found that the probability of informed trading is significantly lower in environments with lower degrees of anonymity. Spot market highly decentralized environment does not favor the transaction execution motivation either. But even if we totally agree that informed trading takes place predominantly at 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 US stocks. The authors showed that trading in the options' market, the satellite market, contained price relevant information what leads us to conclude that a non-zero share of informed trading suffices to influence prices.

Transparency is a second factor that could be determinant in the price discovery process. In 1996, although US spot FX market had 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 & Traub (2009). In Brazil, while futures transactions are all electronically made and instantaneously subjected to the clearinghouse, spot ones 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 to this result. According to this point of view, HFT can anticipate subsequent price movements, enhancing price discovery and efficiency. This is the conclusion of the work of Brogaard et al (2013), which find that they trade in the direction of permanent prices and in the opposite direction of transitory ones. Hasbrouck & Saar (2013) also find empirical evidence that market quality can benefit from HFT by reducing spreads and volatility and increasing market depth.

Although most part of the literature is based on stock market databases, estimates point to the presence of HFT<sup>21</sup> 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 one. It is where it could better protect anonymity and enhance the use of private information. Taking the benefits of HFT into account together with its higher transparency levels, it comes as no surprise to conclude that the futures market is dominant both in terms of speed and efficiency.

### 6.3. Changing the Lag structure

Using a sampling frequency of five minutes and the whole sample, we will assess to what extent changing the lag structure interferes in the results. From Table 6.3.1, we can rule out any misspecification due to the lag length choice. In general, we reinforce the interpretation that futures market dominates the price discovery process with IS point estimates in a tight range [62.9%, 67.3%] as much as CS ones [86.2%, 98.4%]. Moreover, confidence intervals are distant

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<sup>21</sup> Based on BVMF information, Nakashima (2012) estimates in 16% the contribution of HFT to the total traded volume in the FX futures market.

enough to attest for the statistical significance and conclude for the difference in IS and PDEL values. PDEL metric also indicates a futures superior efficiency, except when lag length is equal to 1, when we cannot reject the equality between spot and futures market.

Table 6.3.1: Price discovery metrics between January 2008 to June 2013 for different lag lengths

Lag Length	IS		CS		PDEL	
	Spot	Futures	Spot	Futures	Spot	Futures
1	37.1%[36.3%;38.0%]	62.9%[62.0%;63.7%]	13.8%	86.2%	0.00045[0.00029;0.00067]	0.00042[0.00037;0.00049]
5	33.6%[32.8%;34.3%]	66.4%[65.7%;67.2%]	1.6%	98.4%	0.0185[0.0126;0.0243]	0.0060[0.0053;0.00070]
30	32.7%[31.8%;33.4%]	67.3%[66.6%;68.2%]	6.4%	93.6%	0.0710[0.0695;0.0722]	0.0650[0.0635;0.0683]

Note: Frequency= 5 minutes.  
5% Confidence interval in brackets.

#### 6.4 Changing the frequency of the data

What should be the impact of frequency choice in the analysis? First of all, sampling prices at lower frequencies should alleviate problems associated with the lower liquidity of the spot market such as non-trading and market microstructure. Second, we assumed that any significant difference between OTC and BVMF prices is not sustainable for a long period of time. Apart from the cost of information loss, working with lower frequencies make it possible to the slower market to adjust, suppressing any information advantage from the dominant market.

In this sense, it is clear from Table 6.4.1 that lower frequencies tend to favor spot market both in term of efficiency (PDEL) and contemporaneous variance contribution (IS). Note also that efficiency losses are almost negligible in daily frequency indicating that adjustment towards equilibrium takes less time. Spot market CS values are negative for all sampling frequencies implying that spot and permanent prices moved in opposite directions. Yet, according to Korenok et al (2011), price discovery metrics can lead to erroneous interpretation when CS weights are negative. The results, thus, confirm the adequacy of the five-minute one as our leading scenario.

Table 6.4.1: Price discovery measures between January 2008 to June 2013

Measure	10 minutes		30 minutes		Daily	
	Spot	Futures	Spot	Futures	Spot	Futures
IS	29.6%[28.2%;30.9%]	70.4%[69.1%;71.8%]	34.9%[33.0%;36.9%]	65.1%[63.1%;67.0%]	41.9%[40.2%;43.1%]	58.1%[56.9%;59.3%]
CS	-33.3%	133.3%	-41.6%	141.6%	103.5%	203.5%
PDEL	0.032[0.028;0.043]	0.032[0.030;0.037]	0.013[0.012;0.017]	0.014[0.011;0.016]	0.0014[0.0014;0.0019]	0.0018[0.0016;0.0020]

Note: Lag length= 20 (Frequency= 10 minutes.) and Lag length=5 (Frequency= 30 minutes.) and Lag length=1 (Frequency= 1 day)  
5% Confidence interval in brackets.

#### 7 Price discovery in sub-samples

Although our results point to futures market dominance, it will be particularly interesting to investigate its dynamics over sub-samples. To begin with, it is fair to conjecture that price discovery process might be influenced by market volatility. Uncertainty potentially triggers investors' search for an equilibrium price and action 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, price discovery process is more active and the most informative market will play a leading role. As shown in Figure 1 of the Appendix B, from the 3<sup>rd</sup> quarter of 2008 to the beginning of 2009 (post-Lehman crisis), realized volatility<sup>22</sup> figures take extreme values. In the remaining sample, despite periods of low and stable volatility levels dominate, we can see recurrent short periods of volatility bursts.

Taking this into account, we split the database in two sub-samples according to the realized volatility. Since each sub-sample series is restricted by convergence<sup>23</sup> issues, a low (high) volatility regime has been constructed with five-minute prices from the 160 least (most) volatile

<sup>22</sup> Realized volatility has been calculated as the sum of the five-minute squared returns with no correction for microstructure.

<sup>23</sup> We identified a convergence problem associated with price discovery methodology. When the eigenvalues' sum of the VECM parameters' matrix is above unity, both markets do not converge when facing a permanent shock. We are grateful to Cristina Scherrer and Marcelo Fernandes for this contribution.



days. Price discovery metrics, presented in Table 7.1, show that futures market dominance is more evident in the high volatility regime what, according to our assumption, means that it is the most informative one.

Table 7.1: Price discovery metrics between January 2008 to June 2013

Measure	Low volatility		High volatility	
	Spot	Futures	Spot	Futures
IS	47.4% [45.4%;49.4%]	52.6% [50.6%;54.6%]	37.6% [35.4%;39.8%]	62.4% [60.2%; 64.6%]
CS	31.7%	69.3%	0.2%	98.8%
PDEL	0.000100 [0.000045;0.000170]	0.000039[0.000017;0.000059]	0.000260 [0.000071;0.000510]	0.000070 [0.000049;0.000094]

Note: Lag length according to Schwarz criteria. Frequency= 5 minutes. 5% confidence interval in brackets.

In Table 7.2, where price discovery metrics are calculated by semester<sup>24</sup>. Since futures metrics are above 50% in all periods, results support the general conclusion that the futures market moves first 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. It is important to note, though, that price discovery dynamics is more volatile than the market share evolution would imply. While we observed a progressively larger proportion of futures market share, there are periods where spot market contribution was very close to 50%, probably due to institutional and market factors that will be further discussed.

Table 7.2: Price Discovery metrics by semester

Semester	IS		CS	
	Spot	Futures	Spot	Futures
I.2008	29.7% [28.6%;30.9%]	70.3% [69.1%;71.4%]	10.9%	89.1%
II.2008	33.7% [32.5%;35.0%]	66.3% [65.0%;67.5%]	16.8%	83.2%
I.2009	36.7% [35.6%;37.8%]	63.3% [62.2%;64.4%]	20.1%	79.9%
II.2009	23.0% [22.0%;24.0%]	77.0% [76.0%;78.0%]	22.8%	77.2%
I.2010	45.7% [44.4%;47.1%]	54.3% [52.9%;55.6%]	35.9%	64.1%
II.2010	39.0% [37.9%;40.1%]	61.0% [59.9%;62.1%]	36.3%	63.7%
I.2011	11.8% [10.9%;12.7%]	88.2% [87.3%;89.1%]	21.9%	78.1%
II.2011	44.6% [43.4%;45.9%]	55.4% [54.1%;56.6%]	48.5%	51.5%
I.2012	40.0% [38.9%;41.1%]	60.0% [58.9%;61.1%]	25.9%	74.1%
II.2012	37.4% [36.5%;38,2%]	62.6% [61.8%;63.5%]	37.8%	62.2%
I.2013	33.3% [32.5%;34.1%]	66.7% [65.9%;67.5%]	24.6%	75.4%

Note: Lag length was calculated for each sub-sample according to Schwarz criteria 5% Confidence interval in brackets.

In Boyrie, Pavlova&Parhiagan (2012), the authors found an IS value of 77% for the Brazilian futures market<sup>25</sup>. When they break in sub-samples, they found that spot market IS was above 55% between October 2007 and October 2008, i.e., around the financial crisis epicenter. Since this finding is at odds with Table 7.2, it is important to state its differences. First, Boyrie, Pavlova&Parhiagan (2012) used a daily sampling frequency, much increasing the "data

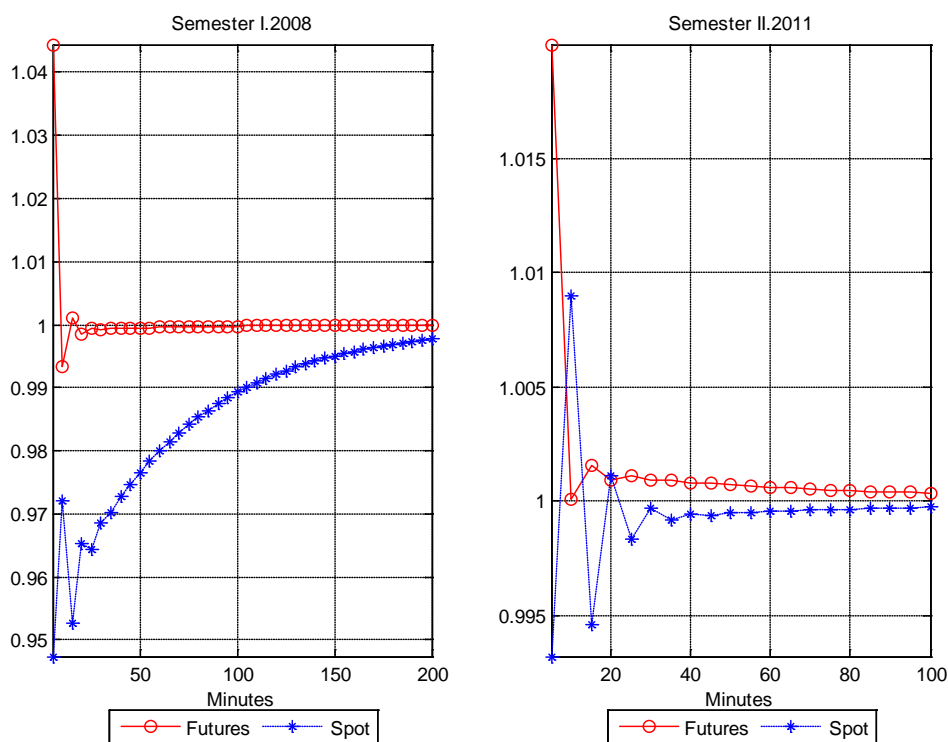
<sup>24</sup>At first, we tried to split the sample on a monthly basis in order to match with financial reports that are released in identical frequency. We only obtained reliable price discovery metrics in sub-samples with at least six-month data, see note 15 for details.

<sup>25</sup>Their sample period ranged from January 2005 to March 2011.

thinning” issue reported by Hasbrouck (2002). In addition, we are not able to attest for its validity<sup>26</sup> 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 where we obtained the highest CS futures value and also the one for second semester of 2011, the lowest one. In the first, we can see that the behavior of each market presents a clear superior pattern when compared to Figure 6.2.1. Now, 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, where price discovery is almost evenly divided, a puzzling relative response is generated and no clear sign of dominance can be identified.

Figure 7.1: Impulse response function for selected semesters



Note: Lag length was calculated for each sub-sample according to Schwarz criteria

As we have seen, results are not uniform across the sub-samples. Stated differently, there is sufficient indication to infer 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 is a significant rise in CC deficit which, until the end of our sample, has been covered by the financial account. However, how BCB has dealt with transitory spot demand imbalances? Since it has the acknowledged goal of preserving international reserves, it usually resorted to swap<sup>27</sup> interventions. When it intervenes through the derivatives market, BCB offers hedge for banks which, in principle, allows them to meet the private agents’ demand. By doing this, it postpones spot demand and expect for a better financial scenario to recover this

<sup>26</sup> Remember, from Section 6.4, that CS weights were negative when we used daily data, making price discovery values difficult to interpret.

<sup>27</sup> 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).

imbalance. In 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.

Understating the role of each participant<sup>28</sup> is also vital to infer price pressures 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 similar magnitude. Non-financial investors assess market to hedge for FX risks in the primary market, holding matched positions in long term futures. Institutional investors, whether domestic or external, are the ones we must take a careful look. Since futures contracts are liquidated in the domestic currency, speculative demand does not directly affect spot market demand, but it does interfere in 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<sup>29</sup> totaled US\$ 14.9 billion, exactly matching BCB spot intervention amount. In addition, BCB heavily intervened through reverse swaps<sup>30</sup> 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. Swap interventions' volume, though, was ten times higher than the spot ones, with IS and CS values indicating clear futures dominance. In both semesters of 2010, where price discovery results were mixed, BCB did not intervene in the futures market through swaps, only in the spot one. In I.2010, futures position from institutional investors were neutral and spot interventions totaled US\$ 14.1 billion while total FX inflow were significant lower (US\$ 3.4 billion). In II.2010, spot interventions were again superior to capital inflow (US\$ 27.5 billion against 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 flow and spot interventions that exerts a potentially demand pressure on the spot market, rising its IS and CS values. The second one refers to the level of futures market interventions (swap or reverse swaps), this one acting in the direction of higher futures IS and CS values.

Adding up more semesters to the analysis, the impact of the above factors is reinforced. In I.2011, spot interventions were again matched with capital inflow and, in a similar pattern to that verified in I.2008. 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 flow had been introduced again, but this time it occurred in the opposite direction, i.e., high capital flow (US\$ 25.4 billion) as opposed to 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 ones impact FX rates by the interest rate channel. As far as sterilized interventions are concerned, its effects are less consensual, although recent studies have been able to find significant effect. Using intraday data, Lahura & Vega (2013) report an asymmetric effect on Central Bank intervention on Peru, only when it sells foreign currency. When Central Bank is at the buy side, market participants do not adjust its permanent price expectations because the intervention goal is aimed at increasing reserves, not to influence prices. Echavarría et al (2013) also report a significant price effect of pre-announced interventions and capital controls on the Colombian spot exchange rate. But intervention effect

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<sup>28</sup> BVMF breakdowns market participants according to its operational characteristics. Financial institutions are banks, brokers and dealers, classified as so 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 its most important representatives. Corporations are non-financial institutions and, finally, individual investors are also considered.

<sup>29</sup> BCB releases the FX flow from the primary market on a monthly basis.

<sup>30</sup> 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.

is not limited to first order effects, as Chari (2007) finds. According to the author, central bank interventions lead, on average, to widening spreads and increasing levels of volatility.

Kohlscheen & 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 Brazilian FX market, this result should be put in perspective as a general policy recommendation. Since the futures market is responsible for the most part of 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 futures market equilibrium, BCB signals its private information through that market, increasing IS and CS futures shares endogenously. When markets operate in the usual configuration, to be precise, when spot market responds for most part of the variation in fundamental price, it may be the case that a futures intervention will be interpreted as noise rather a signal to market participants.

It is also worth to provide 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. Massive 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 CB sold some reserves and intervened selling currency swaps. Among other measures (Garcia, 2011) a swap agreement<sup>31</sup> with FED allowed the market return to normality. In 2009 and 2010, monetary expansion and the prevalence of low interest rates in the central economies induced international portfolio rebalancing towards a greater share of emerging countries assets. Thus, the increasing capital inflow inaugurated a period of controls on capital inflows (Chamon and Garcia, 2013) where (Tobin) taxes varied according to the investment holding period, aimed at reducing the inflows of speculative capital.

In 2011, FX policy makers concentrated its effort so as to avoid domestic currency appreciation, but there was one regulatory decision that attracted special interest to our study. In July 2011, BCB introduced a 1% tax on the notional amount 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 to 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 II.2011. But the alleged "coincidence" allows us to suspect that its impact has not been negligible. Besides, the fall in futures trading volume between 2011 and 2012, as Table 3.1 shows, is a corroborating evidence of the impact of this policy measure in 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 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, still, BCB 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 giving insights on the possible price discovery drivers. Besides, the fact that we are not able to compute smaller sub-samples restricts, to a great extent, our analysis.

## 8 Conclusion

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<sup>31</sup> In order to provide market liquidity in dollars. FED and BCB set up a swap operation up to US\$ 30 billion.

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 that starts at January 2008 to June 2013. Through a variety of metrics well established in the literature, we provide robust evidence that 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, 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, distributed among several intermediaries. Besides, government regulations limit its access to a few authorized financial institutions with direct impact on relative liquidity which are 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, both key market efficiency drivers. It has progressively incurred in a change in its planned design in order to satisfy the high demand for FX transaction from economic agents, resulting in a high proportion of short-term futures contracts traded, with a month or less to maturity. With this background, our findings bring together the empirical methodology with overall market intuition. The IS metric, for instance, point out that 66.2% of the variation in the fundamental price shock is originated in the futures market. When it comes to price composition, the CS value indicates that it responds for 97.4% of the fundamental price. It is also more efficient, that is, it is faster to recover to equilibrium.

We also investigated whether results are robust to sub-samples. First, we show that futures market yet dominates in high volatility regimes, where supposedly markets are subject to more frequent shocks and the price discovery process is supposedly more active. When we break in 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 in 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 shall give light to 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.

## AppendixA: A description of the structural model

Yan and Zivot's (2007) model consists of one permanent and one transitory shock. First, the authors assume that the first difference of the price vector has a SMA representation in which the structural shocks  $\eta_t = (\eta_t^p, \eta_t^t)$  are serially and mutually uncorrelated.

$$\Delta p_t = D(L)\eta_t \quad (\text{B.1})$$

Where the indexes (p,t) stand for the permanent and transitory shocks. The impact of the structural shocks on each market is given by the lag polynomials  $d_i(L)$  as follows:

$$\begin{pmatrix} \Delta p_{1,t} \\ \Delta p_{2,t} \end{pmatrix} = (D_p(L) \quad D_t(L)) \begin{pmatrix} \eta_t^p \\ \eta_t^t \end{pmatrix} = \begin{pmatrix} d_1^p(L) & d_1^t(L) \\ d_2^p(L) & d_2^t(L) \end{pmatrix} \begin{pmatrix} \eta_t^p \\ \eta_t^t \end{pmatrix} \quad (\text{B.2})$$

The permanent innovation will be the one that carries new information and, by construction, will impose a one-to-one long-run impact on market prices. The opposite is true for the transitory innovation which arises in the hands of uninformed and liquidity traders and carries no information. Then, the long-run characteristics of the shocks assume the following representation:

$$\lim_{k \rightarrow \infty} \frac{\partial E_t[p_{t+k}]}{\partial \eta_t^p} = \lim_{k \rightarrow \infty} \sum_{l=0}^k \frac{\partial E_t[\Delta p_{t+l}]}{\partial \eta_t^p} = \lim_{k \rightarrow \infty} \sum_{l=0}^k D_l^p = D^p(1) = 1$$

$$\lim_{k \rightarrow \infty} \frac{\partial E_t[p_{t+k}]}{\partial \eta_t^t} = \lim_{k \rightarrow \infty} \sum_{l=0}^k \frac{\partial E_t[\Delta p_{t+l}]}{\partial \eta_t^t} = \lim_{k \rightarrow \infty} \sum_{l=0}^k D_l^t = D^t(1) = 0 \quad (\text{B.3})$$

Using the BN decomposition, price levels can be written in terms of its long-run impact matrix:

$$p_t = p_0 + \begin{pmatrix} 1 & 0 \\ 1 & 0 \end{pmatrix} \sum_{i=1}^t \eta_i + s_t \quad (\text{B.4})$$

Although B.4 has the same interpretation as (5.2), note that zero mean residuals  $s_t$  are defined in terms of structural residuals. To identify the system, SMA parameters must be uniquely defined by the VMA representation (5.1). For that purpose, we will see that the long-run impacts (B.4) are enough. Applying Johansen (1991) factorization, the long-run impact matrix  $\Psi(1)$  can be represented as a function of the VMA coefficients:

$$\Psi(1) = \beta_{\perp} (\alpha_{\perp}' \Gamma(1) \beta_{\perp})^{-1} \alpha_{\perp}' = \xi \alpha_{\perp}' \quad (\text{B.5})$$

To check for the interpretation of the parameter  $\xi$ , we refer to Gonzalo & Ng (2001), where the authors separate permanent and transitory components  $(\epsilon_t^p, \epsilon_t^t)$  as a function of the reduced-form residuals:

$$\begin{pmatrix} \epsilon_t^p \\ \epsilon_t^t \end{pmatrix} = \begin{pmatrix} \alpha_{\perp}' e_t \\ \beta' e_t \end{pmatrix} = G e_t \quad (\text{B.6})$$

Applying the VECM residuals  $e_t$  to each side of equation (B.6), we see that  $\xi$  is the long-run response of the market prices to a unit permanent shock. From (B.4), we want vector  $\xi$  to be equal to one for both prices. This is true only if we make  $\alpha_{\perp}' = \psi$  and  $\xi$  a 2x1 vector of ones.

Since permanent and transitory innovations  $(\epsilon_t^p, \epsilon_t^t)$  can be correlated, a Choleski triangular factorization allows us to write it as function of the orthogonalized structural shocks:

$$\text{var}(\epsilon_t) = HCH' \quad (\text{B.7})$$

Where the matrix H is a 2x2 lower triangular matrix with ones in the diagonal elements and C is a diagonal matrix with positive elements. Then, using (B.6), structural innovations are defined as:

$$\eta_t = H^{-1}\epsilon_t = H^{-1}Ge_t \quad (\text{B.8})$$

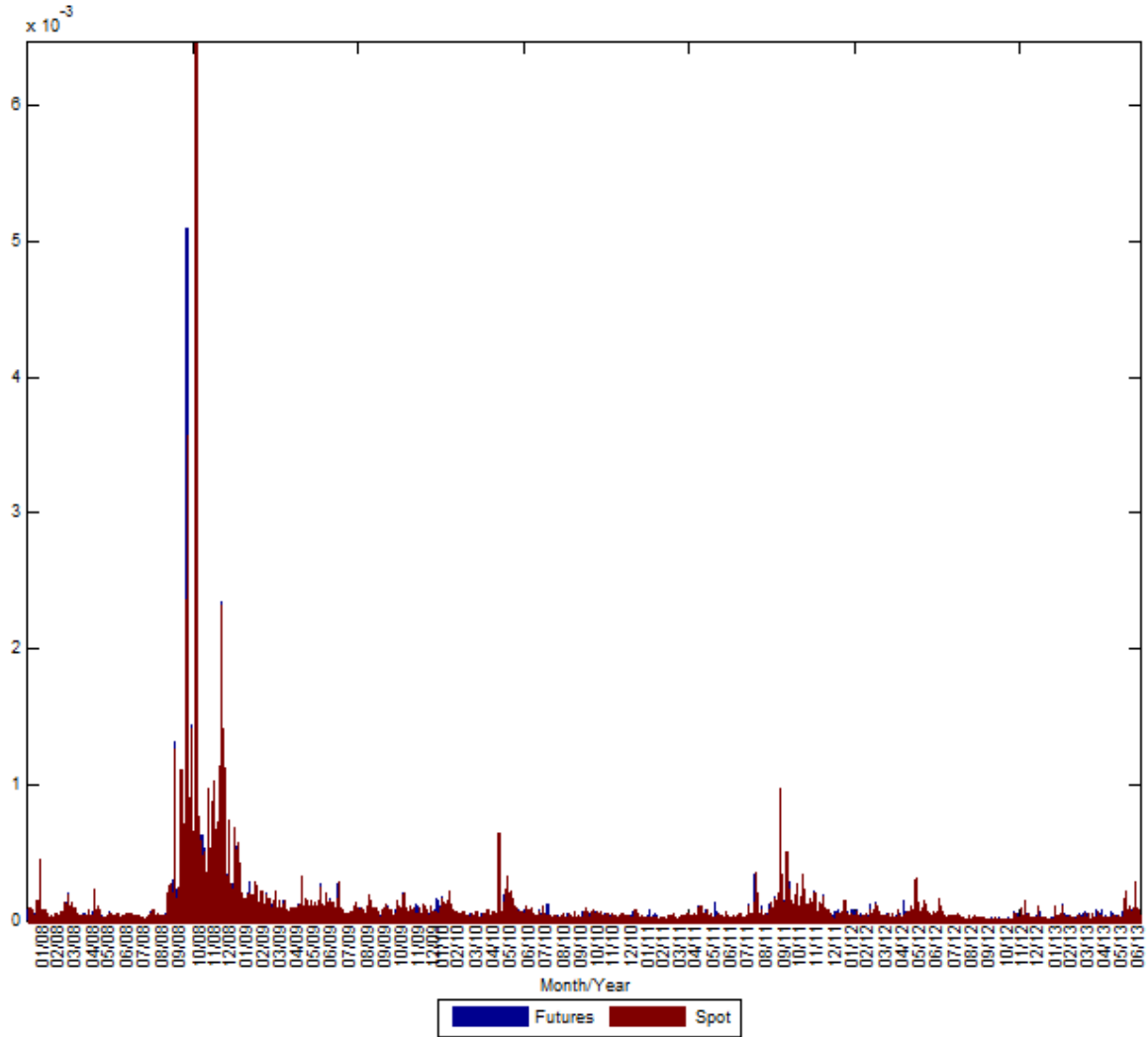
The structural representation is exactly identified and its parameters can be recovered from VMA parameters after applying some transformations:

$$\Delta p_t = \Psi(L)e_t = \Psi(L)G^{-1}HH^{-1}Ge_t = D(L)\eta_t = D_p(L)\eta_t^p + D_t(L)\eta_t^t \quad (\text{B.9})$$

Where  $D_0 = G^{-1}H$ ,  $D(L) = \Psi(L)D_0$  and  $(D_p(L), D_t(L))$  are the columns of  $D(L)$  corresponding to  $(\eta_t^p, \eta_t^t)$ , respectively.

## Appendix B

Figure1: Daily realized volatility estimates for the spot and futures markets between January 2008 and June 2013





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