RBEE

# Cointegration and Causality-in-Mean and Variance Tests: Evidence of Price Discovery for Brazilian Cross-Listed Stocks

Rodrigo Lanna F. Da Silveira*
Leandro Maciel**
Rosangela Ballini***

**Resumo:** O objetivo deste trabalho é analisar o processo de descoberta de preços de 24 ações de empresas brasileiras com dupla listagem, transacionadas simultaneamente na BM&FBOVESPA e na NYSE. Para tanto, foram utilizados testes de cointegração e de causalidade na média e na variância entre os preços dos pares ação-ADR. Os resultados apontaram para a existência de cointegração da maior parte dos pares ações-ADRs. Verificou-se também que ajustes de curto-prazo para existência de equilíbrio de longo-prazo ocorreram nos dois mercados. Adicionalmente, os testes de causalidade na média e na variância mostraram relações de bi-causais.

**Palavras-chave:** mercado de ações; ADR; descoberta de preços; arbitragem; causalidade.

* Departamento de Teoria Econômica, Instituto de Economia, Universidade Estadual de Campinas. Email: rlanna@unicamp.br.

** Departamento de Controle e Automação, Faculdade de Engenharia Elétrica e Computação, Universidade Estadual de Campinas. Email: maciel@dca.fee.unicamp.br.

*** Departamento de Teoria Econômica, Instituto de Economia, Universidade Estadual de Campinas. Email: ballini@eco.unicamp.br.

**Abstract:** The purpose of this study is to investigate the price discovery process of 24 cross-listed stocks of Brazilian companies simultaneously traded on BM&FBOVESPA and NYSE stock exchanges. Cointegration methods and tests for causality-in-mean and causality-in-variance between the prices of stock-ADR pairs were used. Results indicated the existence of cointegration for most stock-ADR pairs. In addition, short-term adjustments occurred in both markets. The causality-in-mean and causality-in-variance tests showed bicausal relationships between the prices.

**Keywords:** stock market; ADR; price discovery; arbitrage; causality.

**JEL Codes: Q14; G13; C12.**

## 1. Introduction

The financing of a company can occur from sources of resources that are internal or external to the company. For internal resources, the reinvestment of profits in operational activity is one alternative. For external resources, this involves the raising of funds from outside the corporation through loans from financial institutions, the issuance of securities (bonds and commercial papers) and the Initial Public Offering (IPO) on stock exchanges. In this latter option, there is the possibility of domestic companies issuing rights represented by their stocks in foreign financial markets, and these stocks are known as Depositary Receipts - DR.

A well-known and traded type of DR is the American Depositary Receipt - ADR, traded exclusively in the U.S. financial market. According to Iyeki (2013), the U.S. market accounts for 80% of the total value of DRs traded in the world and, approximately 83% of this is negotiated on the New York Stock Exchange (NYSE). Of the six ADRs with the highest turnover on the NYSE in 2013, three refer to Brazilian companies: Vale, Petrobrás and Itaú-Unibanco. In these cases, such ADRs constitute depositary receipts issued by a U.S. bank. These are traded in the financial market of that country, with a guarantee of shares in Brazilian corporations. On the side of the companies, the issuance of these stocks is a means of capitalization (in the case of ADR being backed by new issuances) as well as a means to increase the liquidity of the security. Furthermore, it is argued that the issuance of ADRs increases the transparency of a company, as well as decreasing the risk perception of the company by the financial agents, which then in turn reduces the cost of capital. From the perspective of U.S. investors, by conferring economic benefits equal to a share issued in the home market of the corporation, the ADRs enable the inclusion of securities from other countries in their investment portfolios, which avoid carrying out international operations for portfolio diversification (PROCIANOY & KWITKO, 2007).

With the existence of cross-listed stocks on stock exchanges, located in different countries, matters relating to the integration of these markets and the possibility of arbitrage in such securities have been the subjects of research in finance since the late 1970s. The pioneering study conducted by Garbade and Silber in 1979 offered insights into the integration of stocks traded on different U.S. exchanges. More recent studies that have been conducted have given importance to the increased globalization and integration of markets, as well as the predominance of electronic bids on the stock exchanges and the increasing use of robot traders. Examples of these include the studies conducted between the ADRs traded on the NYSE and also the stocks traded on the stock exchanges of: Canada (KEHRLE & PETER, 2013; PHYLAKTIS & KORCZAK, 2010; GRAMMIG et al., 2005), Israel (QADAN & YAGIL, 2012), Argentina and Egypt (ANSOTEGUI et al., 2013), Mexico (FURSTENBERG & TABORA, 2004), Spain (PASCUAL et al., 2006) and China (SU & CHONG, 2007; CHEN et al. 2010). It is also worth noting that these studies addressed other dominant satellite markets in areas such as the evaluation of the stocks listed on exchanges in Hong Kong and London (WANG ET AL., 2002), the stock markets of Taiwan (WAN & KAO, 2009) and stocks traded on stock exchanges in Australia and New Zealand (LOK & KAFEV, 2006), among others. In general, these results indicate both integration between markets and also price discovery is predominantly performed in the local (stock) market.

For the Brazilian market, Kawamoto and Kawamoto (2008) analyzed the price of 32 pairs of stocks and ADRs between 1999 and 2006, where a long-term relationship (cointegration) was found in just 15 pairs. Sakamoto (2011) and Camargos et al. (2003) also examined this subject and concluded the existence of arbitrage opportunities between markets. The first author evaluated eight pairs of stocks from 2005 to October 2010, whereas the others considered 35 companies between February 1999 and December 2000.

In this context, the aim of this work is to analyze the process of price discovery of shares of Brazilian companies with cross-listing traded on the BM&FBOVESPA and NYSE. In this sense, we seek to evaluate which markets have the greatest influence on the pricing of those stocks, using tests of cointegration and causality-in-mean and causality-in-variance between the prices of stock-ADR pairs. In addition to reassessing the issue with a broader sample, in relation to the works already done for the Brazilian market, we propose the insertion of a supplementary method for causality-in-variance. To achieve the goal mentioned above, this paper is divided into three parts (as well as this introduction). First, we present the methods used to achieve those goals. Secondly, the results are then analyzed and finally, final considerations are made.

## 2. Methodology

Sample

The series of 22 companies that currently have ADRs on the NYSE and stocks traded on BM&FBOVESPA are objects of study in this work. These were selected from the observation of the existence of operations in 2013[1]. Each company has a series of stocks prices and ADR prices - except for Vale and Petrobrás, which have two stocks and two ADRs. Thus, there were a total of 48 series of daily closing prices in U.S. dollars, which were adjusted for the proceeds received[2]. For adjustments, the calendar of the home market was adjusted to the New York market. On the days when there was no trading on one market, but there was trading in other markets, prices were interpolated. In Table 1, we list the companies, the period of analysis and the data number, n, considered in this study.

Table 1. Companies, assets and characteristics of the samples considered in the study.

| Company | Stock | ADR | Period of analysis | *n* |
|---|---|---|---|---|
| Ambev | AMBV4 | ABV | June/97 to June/13 | 4,198 |
| Bradesco | BBDC4 | BBD | November/01 to June/13 | 3,033 |
| Braskem | BRKM5 | BAK | January/99 to June/13 | 3,715 |
| BRF AS | BRFS3 | BRFS | April/06 to June/13 | 1,865 |
| Cemig | CMIG4 | CIG | September/97 to June/13 | 4,085 |
| Copel | CPLE6 | ELP | August/97 to June/13 | 4,110 |
| CPFL Energia | CPFE3 | CPL | October/04 to June/13 | 2,264 |
| Eletrobrás | ELET3 | EBR | November/08 to June/13 | 1,210 |
| Embraer | EMBR3 | ERJ | June/06 to June/13 | 1,828 |
| Fibria | FIBR3 | FBR | August/09 to June/13 | 1,002 |
| Gafisa | GFSA3 | GFA | March/07 to June/13 | 1,627 |
| Gerdau | GGBR4 | GGB | March/99 to June/13 | 3,689 |
| Gol | GOLL4 | GOL | June/04 to June/13 | 2,332 |
| Itaú-Unibanco | ITUB4 | ITUB | February/02 to June/13 | 2,935 |
| Oi | OIBR4 | OIBR | November/01 to June/13 | 2,990 |
| Pão de Açúcar | PCAR4 | CBD | June/97 to June/13 | 4,151 |
| Petrobrás ON | PETR3 | PBR | October/01 to June/13 | 3,037 |
| Petrobrás PN | PETR4 | PBR.A | August/00 to June/13 | 3,330 |
| Sabesp | SBSP3 | SBS | May/02 to June/13 | 2,878 |
| CSN | CSNA3 | SID | November/97 to June/13 | 4,017 |
| Telefônica | VIVT4 | VIV | November/98 to June/13 | 3,776 |
| Tim | TIMP3 | TSU | November/98 to June/13 | 3,777 |
| Vale ON | VALE3 | VALE | April/02 to June/13 | 2,899 |
| Vale PN | VALE5 | VALE.P | June/00 to June/13 | 3,365 |

Source: research results.

[1] Data were collected from Economatica software.

[2] The prices of shares traded on the BM&FBOVESPA in Real (R$) have been converted into U.S. dollars (US$) at the exchange rate of the day, as announced by the Central Bank of Brazil.

**Methods**

In order to investigate the cointegration among the 24 stock-ADR pairs, the Augmented Dickey-Fuller (ADF) (DICKEY & FULLER, 1981) and Phillips and Perron (PP) (1988) Unit Root tests are initially performed. Assuming that the series are integrated, the next step consists of cointegration testing, using the methods proposed by Engle and Granger (1987) and Johansen (1988). In addition, this study also analyzes the impact of ADRs on the volatility of stocks prices in the domestic market. To achieve this goal, we used the test of causality between price volatility, estimated by a GARCH model (1, 1), using the procedure developed by Cheung and Ng (1996). Below, we present the description of the econometric tools used in this work.

2.2.1. Unit Root Test

The verification of the stationarity of series is initially made by the Augmented Dickey-Fuller Unit Root Test (DICKEY & FULLER, 1981). The ADF test checks whether or not the series have a single unitary root considering models in which the variables are generated by an autoregressive process of p order. The inclusion in the model of the lagged difference in prices, Pt, preserves the condition of white noise error $\varepsilon_t$. The performance of the test consists of estimating three equations:

$$\Delta P_t = \alpha + \beta t + \gamma P_{t-1} + \sum_{i=1}^{p-1} \delta_i \Delta P_{t-i} + \varepsilon_t, \quad (1)$$

$$\Delta P_t = \alpha + \gamma P_{t-1} + \sum_{i=1}^{p-1} \delta_i \Delta P_{t-i} + \varepsilon_t, \quad (2)$$

$$\Delta P_t = \gamma P_{t-1} + \sum_{i=1}^{p-1} \delta_i \Delta P_{t-i} + \varepsilon_t. \quad (3)$$

The difference between the three regression equations is based primarily on the presence of the $\alpha$ constant term and the $\beta$ linear trend. For all three cases, the null hypothesis H0: $\gamma = 0$ indicates the existence of a root unit; if the null hypothesis is rejected, the price series are stationary. The equations are estimated by Ordinary Least Squares (OLS) and the values of the estimated parameters are compared with the critical values of Dickey and Fuller (1981) and MacKinnon (1991). The determination of the number of p lags will be based on the significance of the parameter associated with the greatest lag and the Schwarz Information Criterion (BIC). If the presence of autocorrelation in the residuals is found, lags of the dependent variable should be included in the model (ENDERS, 2004).

To confirm the results obtained by the test mentioned above, the Phillips-Perron procedure is also employed. In contrast to the ADF test, the Phillips-Perron procedure does not assume that $\varepsilon_t$ is a white noise, and it is a consistent test even if there are lagged dependent variables and a serial correlation in the errors (PHILLIPS & PERRON 1988). Thus, it is unnecessary to specify an autoregressive model of order p to correct the correlation of errors. The test equations are similar to the Dickey-Fuller ones, estimating the equations (1) to (3) without the augmented term $\sum_{i=1}^{p-1} \delta_i \Delta P_{t-i}$ and changing the ratio of the $\gamma$ coefficient so that the serial correlation does not affect the asymptotic distribution of the statistic of the test (KAWAMOTO & KAWAMOTO, 2009). In this work, the number of lags included in the model will be determined by the Newey-West criterion.

***2.3. Cointegration***

Assuming that the price series are integrated with order 1, I(1), the next step will evaluate whether the price of the shares and ADRs of a company, traded respectively, on the BM&FBOVESPA and NYSE have a relationship of long-term equilibrium, i.e., if they are cointegrated. For this purpose, the Engle and Granger (1987) and Johansen (1988) procedures will be used.

Consider the variables $P_{s,t}^{BOV}$ and $P_{s,t}^{ADR}$ the logarithms of stock and ADR prices traded on the BM&FBOVESPA and NYSE, respectively, in which s = 1, 2, …, 24 indicate the stock-ADR pairs. According to Engle and Granger (1987), mentioned by Enders (2004), two variables arranged in a vector $X_{s,t} = (P_{s,t}^{BOV}, P_{s,t}^{NY})$T are cointegrated of order (d, b), $X_{s,t} \sim CI(d,b)$, when two conditions are satisfied: i) variables have the same order of integration – I(d), ii) the Yst series formed by the linear combination of variables $a_1 P_{s,t}^{BOV}$ and $a_2 P_{s,t}^{NY}$, $Y_{s,t} = a_1 P_{s,t}^{BOV} + a_2 P_{s,t}^{NY} = a^T X_{s,t}$, $a = (a_1, a_2)^T$, has a lower integration order than that in the original variables – $a^T X_{s,t} \sim I(d-b)$, with b > 0 and a ≠ 0 as the cointegrating vector. Thus, for variables integrated of order 1, d = 1, it follows that (d – b) = 0.

The Engle and Granger test consists of estimating equation (4) by OLS and checking if the estimated residuals are stationary using the ADF procedure.

$$P_{s,t}^{BOV} = \alpha_0 + \alpha_1 P_{s,t}^{NY} + \varepsilon_{s,t}. \tag{4}$$

The unit root test on the estimated residuals, $\varepsilon_{s,t}$, is the estimation of the following equation:

$$\Delta\hat{\varepsilon}_{s,t} = \rho\hat{\varepsilon}_{s,t-1} + \textstyle\sum_{i=1}^{p-1} \theta_i \Delta\hat{\varepsilon}_{s,t-i} + \upsilon_{s,t}. \tag{5}$$

The null hypothesis, $H_0: \rho = 0$, implies that the residuals have a unit root, so that the variables do not cointegrate. As the residuals are estimated, Enders (2004) recommends using, for the cointegrated residual test, the tabulated values proposed by Engle and Granger (1987) and MacKinnon (1991).

Another cointegration test used in this study is the Johansen (1988) procedure. In this case the focus is multivariate, so it is therefore not necessary to determine which variable was previously endogenous or exogenous in the model. The Johansen procedure verifies the presence of a cointegration vector, such that the ratio $P_{s,t}^{BOV} - P_{s,t}^{NY}$ is integrated of order zero. For this purpose, a vector autoregressive model (VAR) is used, which is represented by:

$$X_{s,t} = \alpha_0 + A_1 X_{s,t-1} + A_2 X_{s,t-2} + \cdots + A_k X_{s,t-k} + \varepsilon_{s,t}, \tag{6}$$

in which Xs,t represents the 2-by-1 vector consisting of the logarithms of the prices $P_{s,t}^{BOV}$ and $P_{s,t}^{NY}$ of the s-th stock-ADR pair, and the integrated variables are of the same order, with k lags; Ai is a 2-by-2 matrix of order parameters; $\varepsilon_{s,t}$ denotes the erratic term, with $\varepsilon_{s,t}$ ~ i.i.d.(0,Ω). In this work, to determine the number of lags in the VAR, we will employ the Akaike information criterion (AIC) and the Final Prediction Error (FPE) metrics.

According to Enders (2004), by the Granger Representation Theorem, equation (6) can be expressed through a vector error correction (VEC), when $X_{s,t} \sim CI(d,b)$, obtaining:

$$\Delta X_{s,t} = \Pi X_{s,t-1} + \textstyle\sum_{i=1}^{k-1} \Pi_i X_{s,t-i} + \varepsilon_{s,t}, \tag{7}$$

such that $\Pi = -\left(I - \sum_{i=1}^{k} A_i\right)$, where I is the identity matrix, and

$$\Pi_i = -\textstyle\sum_{j=i+1}^{k} A_j.$$

The $\Pi$ matrix, which in the case of this study is of order 2-by-2, may be represented by the product of two matrices, α and β, of size 2-by-r, where r is the number of long-term ratios and 2 the number of parameters to be adjusted, that is:

$$\Pi = \alpha\beta^T. \tag{8}$$

The α matrix is formed by adjustment coefficients, which express the mean variable adjustments for imbalances in the short-term, and the $\beta$ matrix has the cointegration parameters. The $\beta^T X_{s,t-1}$ expression represents the error correction term.

The model is estimated by maximum likelihood, with assumptions based on normality and no autocorrelation of the random term, i.e., $\varepsilon t \sim N(0, \Omega)$ and $E\{\varepsilon_t, \varepsilon_q\} = 0$ for $t \neq q$. Thus, it has been noted if these conditions are obeyed[3].

The rank of the $\Pi$ matrix, *r*, is equal to the number of characteristic roots of $\Pi$,

[3] For the case of normality, the Jarque-Bera test will be performed. Regarding the autocorrelation, the autocorrelation functions will be checked.

different to zero, which denotes the number of cointegrating vectors. If $r$ is zero, the matrix is zero and equation (7) is a VAR in the first difference - in this case, there is no relationship between the price variables because there is no stationary linear combination between the variables of $Xs,t$. If $r$ is equal to the number of variables in the model ($r = 2$ ), $\Pi$ has full rank and the variables of $Xs,t$ are stationary, then cointegration analysis is not necessary. Finally, if $1 < r < K$, being K the number of variables in the model, there are $r$ vectors of cointegration, with r independent of linear relationships between the variables of $Xs,t$.

Thus, the verification of the number of cointegration vectors occurs by analyzing the significance of the estimated characteristic roots of the $\Pi$matrix, being that performed by two statistics: i) trace statistics, $\lambda_{tr}$; ii) maximum eigenvalue statistic, $\lambda_{max}$ (ENDERS, 2004).

The trace test takes as null hypothesis the existence of, at most, $r^*$ cointegration vectors against the alternative hypothesis of $r > r^*$. The test statistic is given by:

$$\lambda_{tr}(r) = -T \sum_{i=r+1}^{K} \ln(1 - \lambda_i), \tag{9}$$

where $\lambda \in [0,1]$ are the eigenvalues of the $\Pi$ matrix, $T$ is the number of observations, and $K$ is the number of variables employed, which in this work is equal to 2.

The second test to check the rank of the $\Pi$ matrix is the maximum eigenvalue test, which tests the null hypothesis of cointegration vectors $r^*$; the alternative hypothesis is that there are $r^* + 1$ vectors. The statistic of the maximum eigenvalue test is given by:

$$\lambda_{max}(r, r+1) = -T \ln(1 - \lambda_i). \tag{10}$$

The critical values of the trace and maximum eigenvalue statistics were tabulated by Johansen and Juselius (1990). According to Enders (2004), the statistics given by equations (9) and (10) may be conflicting. In this case, it is appropriate to use the maximum eigenvalue test, since this has a more rigorously alternative hypothesis.

Another decision to be made concerns the possible inclusion of deterministic terms inside and/or outside the cointegration vector. Harris (1995) discusses this decision from a model of a simplified error correction written under the following form:

$$\Delta X_{s,t} = \alpha\left[\beta^T X_{s,t-1} + \mu_1 + \delta_1 t\right] + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{s,t-i} + \mu_2 + \delta_2 t + \varepsilon_t. \tag{11}$$

From equation (11), five other models can be obtained, each being more suitable to the particular characteristics of the data.

Model 1: in the absence of deterministic components in the series, the most appropriate model should have a more restricted specification ($\delta_1=\delta_2=\mu_1=\mu_2$);

Model 2: if the series does not exhibit linear trends in the level, in the case that their first difference has zero mean, then the model with intercept is the most appropriate only in the event of cointegration ($\delta_1=\delta_2=\mu_1=0$);

Model 3: if the series exhibit linear trends in the level, a model that allows the presence of the constant inside and outside the cointegration vector must be specified ($\delta 1 = \delta 2 = 0$);

Model 4: to capture an exogenous growth trend (not quadratic) unknown by the model, the constraint being imposed allows the inclusion of stationary trend only in the cointegration vector ($\delta 2 = 0$);

Model 5: to capture the effects of quadratic trends at long-term and linear at short-term, a model should be used in which the $\delta 2$ parameter is unrestricted.

Harris (1995) suggests that the selection of the most appropriate model is performed by visual inspection of the series in order to determine which particular case fits best.

By selecting the appropriate model, we can analyze the adjustment coefficients, αBOV and αNY, that multiply the error correction term to evaluate the hypothesis of price adjustment, even with the presence of short-term imbalances. If $P_{s,t-1}^{BOV} > P_{s,t-1}^{NY}$, the equity of prices at t stems from the decline of $P_{s,t}^{BOV}$ and the increase of $P_{s,t}^{NY}$ , which implies in negative αBOV and positive αNY (NUE & SABHERWAL, 2003). The prices may still display the same tendency of motion (having adjustment coefficients with the same signals) but with different intensities in order to achieve price equilibrium.

2.4. Causality-in-mean and variance tests

In order to complement the previous analysis, causality-in-mean and variance tests among stock-ADR pairs will be conducted. These tests require the equations of the mean for the $\Delta P_{s,t}^{BOV}$ and $\Delta P_{s,t}^{ADR}$ series to be represented by:

$$\Delta P_{s,t}^{BOV} = \mu_{s,t}^{BOV} + \sqrt{h_{s,t}^{BOV}}\,\varepsilon_{s,t}, \tag{12}$$

$$\Delta P_{s,t}^{ADR} = \mu_{s,t}^{ADR} + \sqrt{h_{s,t}^{ADR}}\,\xi_{s,t}, \tag{13}$$

where εs,t and ξs,t are both white noise processes with zero mean and constant variance. The mean and the conditional variance are given by equations (14) and (15) representing specifications of time-series models including autoregressive–moving-average models (ARMA) for the mean and GARCH (1,1) models for variance.

$$\mu_{s,t}^{Z} = \sum_{i=0}^{\infty} \phi_{s,i}^{Z} Y_{s,t-i}, \tag{14}$$

$$h_{s,t}^{Z} = \alpha_{s,0}^{Z} + \alpha_{s,1}^{Z}\left(Y_{s,t-1} - \mu_{s,t-1}^{Z}\right)^2 + \beta_s^Z h_{s,t-1}^{Z}, \tag{15}$$

in which Z = {BOV, NY}, s is the stock-ADR pair, $\phi_{s,i}^{Z}$ is the parameter vector, $Y_{s,t} = \{\Delta P_{s,t}^{BOV}, \Delta P_{s,t}^{NY}\}$, $\alpha_{s,0}^{Z} > 0, \alpha_{s,1}^{Z} > 0$ and $\beta_s^Z > 0$. The $\alpha_{s1}^{Z}$ parameter measures the extent to which a shock of the return affects the volatility in t + 1, and the $(\alpha_{s,1}^{Z} + \beta_s^Z)$ sum shows the persistence measure of the volatility, i.e., the rate that reflects how the impact of a shock in the return today spreads over time on the volatility of future returns.

The Cheung and Ng (1996) method is based on the analysis of the cross-correlation function (CCF) of the squared standardized residuals. After estimating GARCH models, the next step of the causality test is to obtain the series of squared standardized residuals of stock-ADR pairs, respectively, from the conditional variance:

$$u_{s,t} = \frac{\left(\Delta P_{s,t}^{BOV} - \mu_{s,t}^{BOV}\right)^2}{h_{s,t}^{BOV}}, \tag{16}$$

$$v_{s,t} = \frac{\left(\Delta P_{s,t}^{NY} - \mu_{s,t}^{NY}\right)^2}{h_{s,t}^{NY}}, \tag{17}$$

where $u_{s,t}$ and $v_{s,t}$ are the standardized residuals. The cross-correlation of the series of squared standardized residuals, $r_{u_s v_s}(k)$, is represented by the following function:

$$r_{u_s v_s}(k) = \frac{c_{u_s v_s}(k)}{\sqrt{c_{u_s}(0)\,c_{v_s}(0)}}, \tag{18}$$

where $c_{u_s v_s}(k)$, $c_{u_s}(0)$, $c_{v_s}(0)$, are the auto-covariance (lag 0) and variances (lags k) of $\mu$, and ν, for the s asset-ADR pair.

After that, causality-in-variance and mean tests can be performed. First, the CCF is used to test the null hypothesis of non-causality in variance against the alternative hypothesis of causality at k lag, calculating the test statistic given by:

$$CCF_{uv} = \sqrt{T} r_{u_s v_s}(k) \tag{19}$$

Likewise, the CCF is used to test the null hypothesis of non-causality in the mean against the alternative hypothesis of causality at k lag. In this case, standardized residuals are taken into account instead of squared standardized residuals. In both tests, the statistical significance of the CCF should be assessed in order to detect causal relationships and to identify the direction of causality. For the causality test at k lag, $CCF_{uv}$ is compared with a standard normal distribution.

## 3. Analysis of results

The first step in this study consists of the execution of unit root tests using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) methods to assess the stationarity of the series. As typically observed in series of this nature, the results indicated the presence of a unit root in the 24 pairs of stock prices and ADRs of companies with cross listing on the BM&FBVESPA and the NYSE (Annex 1).

After checking for the presence of unit root, we conducted the Engle and Granger and Johansen cointegration tests. Regarding this first procedure, according to Table 2, 16 of the 24 stock-ADR pairs are cointegrated.

Regarding the Johansen test, it is worth noting that, prior to performing the procedure, we evaluated the appropriate number of lags in the VAR model using the values indicated by the Final Prediction Error (FPE) and by the Akaike Information Criterion (AIC). These indicate, in general, a high number of lags in the model (up to seven), with concordance among the adopted criteria. Furthermore we analyzed (based on visual inspection of the series graphs) which model should be used to apply the Johansen method, deciding whether or not to include deterministic terms inside and/or outside the cointegration vector. In general, the models used were 3, 4 and 5, given the presence, in the series, of linear (captured by the first two models) and quadratic (considered by the latter) trends - Table 3.

Maximum eigenvalue and trace tests were conducted to assess the number of cointegration vectors. The results showed the existence of 21 stock-ADR pairs, with long-term relation[4]. Only the assets of Gerdau, Oi and CSN were not cointegrated, and the first two companies were consistent with the Engle and Granger tests. Thus, the hypothesis of arbitrage opportunities between the markets of NYSE and BM&FBOVESPA was rejected.

It should be noted that these results contrasted with those obtained by Kawamoto and Kawamoto (2009), who found that only 15 of the 32 analyzed pairs were cointegrated. This may be due to a greater integration of the Brazilian and U.S. markets in recent years, as well as differences in the samples, since the authors worked over a fixed period for all companies between February 1999 and June 2006. Moreover, the obtained findings were in accordance with the results obtained by a series of recent international studies on the subject - Qadan and Yagil (2012), Kehrle and Peter (2013), Ansotegui et al. (2013) and Furstenberg and Tabora (2004).

Table 2. Results of cointegration tests using the Engle and Granger procedure.

| Companies | CRADF | | Companies | CRADF | |
|---|---|---|---|---|---|
| Ambev | -5.0559 | * | Gol | -6.4789 | * |
| Bradesco | -2.4241 | | Itaú-Unibanco | -2.8725 | |
| Braskem | -11.8076 | * | Oi | -2.1846 | |
| BRF AS | -5.9376 | * | Pão de Açúcar | -2.9878 | |
| Cemig | -3.3243 | *** | Petrobrás ON | -2.4248 | |

[4] This fact does not restrict the possibility of deviations around the equilibrium in the short-term. The ADR is expected to respond to the traded prices in the domestic market and to be adjusted to the imbalances, and this hypothesis is verified by the estimation of the error correction model.

| | | | | | |
|---|---|---|---|---|---|
| Copel | -3.8073 | ** | Petrobrás PN | -2.6376 | |
| CPFL Energia | -4.7054 | * | Sabesp | -3.5586 | ** |
| Eletrobrás | -5.2444 | * | CSN | -3.1518 | *** |
| Embraer | -5.0446 | * | Telefônica | -5.2934 | * |
| Fibria | -5.6521 | * | Tim | -3.4396 | ** |
| Gafisa | -4.8324 | * | Vale ON | -4.3299 | * |
| Gerdau | -2.7553 | | Vale PN | -3.2310 | |

*Significant at 1% ; **Significant at 5%; ***Significant at 10%.

Source: research results.

Table 3. Results of cointegration tests for the Johansen procedure.

| Asset | *r* | Trace statistics | | Maximum statistic | eigenvalue | Model |
|---|---|---|---|---|---|---|
| Ambev | 0 | 26.8370 | ** | 14.1874 | | 4 |
| | 1 | 12.6496 | ** | 1.2650 | ** | |
| Bradesco | 0 | 32.0136 | * | 29.4686 | * | 4 |
| | 1 | 2.5450 | | 2.5450 | | |
| Braskem | 0 | 96.0269 | * | 85.7309 | * | 4 |
| | 1 | 10.2960 | | 10.2960 | | |
| BRF | 0 | 26.1832 | ** | 19.0258 | ** | 4 |
| | 1 | 7.1574 | | 7.1574 | | |
| Cemig | 0 | 30.0550 | ** | 21.1012 | ** | 4 |
| | 1 | 8.9538 | | 8.9538 | | |
| Copel | 0 | 28.0019 | | 20.4884 | | 5 |
| | 1 | 7.5135 | | 7.5135 | | |
| CPFL Energia | 0 | 16.6953 | ** | 10.3470 | | 3 |
| | 1 | 6.3470 | ** | 6.3470 | ** | |
| Eletrobrás | 0 | 29.9990 | * | 29.6315 | * | 5 |
| | 1 | 0.3675 | | 0.3675 | | |
| Embraer | 0 | 23.0423 | ** | 16.3301 | ** | 2 |
| | 1 | 6.7122 | | 6.7122 | | |
| Fibria | 0 | 44.7318 | * | 41.3588 | * | 4 |
| | 1 | 3.3730 | | 3.3730 | | |
| Gafisa | 0 | 25.4332 | ** | 23.9672 | ** | 2 |
| | 1 | 1.4660 | | 1.4660 | | |
| Gerdau | 0 | 10.3847 | | 7.8297 | | 4 |
| | 1 | 2.5550 | | 2.5550 | | |
| Gol | 0 | 29.3618 | * | 18.6583 | ** | 4 |
| | 1 | 10.7035 | *** | 10.7035 | *** | |
| Itaú-Unibanco | 0 | 28.9931 | ** | 26.5337 | * | 4 |
| | 1 | 2.4594 | | 2.4594 | | |
| Oi | 0 | 10.8487 | | 9.4238 | | |
| | 1 | 1.4249 | | 1.4249 | | |
| Pão de Açúcar | 0 | 25.8721 | ** | 23.5614 | ** | 4 |
| | 1 | 1.2518 | | 7.3156 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Petrobrás ON | 0 | 21.8636 | ** | 19.3964 | ** | 5 |
| | 1 | 2.4672 | | 2.4672 | | |
| Petrobrás PN | 0 | 16.6641 | *** | 16.4754 | *** | 5 |
| | 1 | 0.1888 | | 0.1888 | | |
| Sabesp | 0 | 29.9096 | ** | 26.3389 | * | 4 |
| | 1 | 3.5707 | | 3.5707 | | |
| CSN | 0 | 6.6095 | | 6.5307 | | 5 |
| | 1 | 0.0788 | | 0.0788 | | |
| Telefônica | 0 | 53.2874 | * | 43.9624 | * | 5 |
| | 1 | 9.3250 | * | 9.3250 | * | |
| Tim | 0 | 17.9082 | | 14.1286 | *** | 2 |
| | 1 | 3.7796 | | 3.7796 | | |
| Vale ON | 0 | 19.9112 | * | 12.3690 | *** | 3 |
| | 1 | 7.5422 | * | 3.8415 | * | |
| Vale PN | 0 | 19.4265 | ** | 15.4139 | ** | 3 |
| | 1 | 4.0126 | ** | 4.0126 | ** | |

*Significant at 1; ** Significant at 5%; *** Significant at 10%. Source: research results.

Therefore, the vector error correction (VEC) models were estimated for 22 stock-ADR pairs that indicated cointegration in at least one of the methods used[5]. Subsequently we calculated the adjustment coefficients of short-term, α. The results for these estimates can be seen in Table 4.

Table 4. Results of the VEC parameters.

| Asset | $\alpha^{BOV}$ | | $\alpha^{NY}$ | |
|---|---|---|---|---|
| Ambev | 0.028000 | | 0.067811 | * |
| Bradesco | 0.068850 | | 0.174183 | * |
| Braskem | 0.004201 | | 0.175893 | * |
| BRF | -0.131441 | | 0.070219 | |
| Cemig | 0.000002 | | 0.006168 | * |
| Copel | -0.059428 | * | 0.003318 | |
| CPFL Energia | -0.105043 | ** | -0.089225 | ** |
| Eletrobrás | -0.157879 | *** | 0.051677 | |
| Embraer | 0.090537 | * | 0.119659 | * |
| Fibria | -0.505508 | * | -0.322219 | * |
| Gafisa | -0.411140 | * | -0.308709 | * |
| Gol | 0.140132 | * | 0.176175 | * |
| Itaú-Unibanco | 0.156522 | * | 0.281465 | * |
| Pão de Açúcar | 0.047361 | ** | 0.098418 | * |
| Petrobrás ON | 0.028608 | | 0.066543 | * |
| Petrobrás PN | 0.017128 | | 0.116972 | *** |
| Sabesp | 0.164496 | * | 0.244771 | * |
| CSN | -0.002082 | | 0.001425 | |

[5] It is worth noting that normality and autocorrelation tests were performed in the residuals estimated by the Error Correction Model. Using the LM autocorrelation test, we observed no serial autocorrelation problem. Through the Jarque-Bera normality test, the hypothesis of normality was rejected. In an attempt to address this problem, we tried to model supposed outliers in series by introducing a dummy variable of intervention to the subprime crisis period (between September 2008 and April 2009).

| | | | | |
|---|---|---|---|---|
| Telefônica | 0.010372 | | 0.064699 | * |
| Tim | -0.005939 | *** | 0.005272 | ** |
| Vale ON | 0.009752 | | 0.061541 | |
| Vale PN | 0.006800 | | 0.024988 | ** |

*Significant at 1; ** Significant at 5%; *** Significant at 10%.

Source: research results.

We noted that, from the 22 pairs, nine of them had statistically significant coefficients. Analyzing only these nine cases, one observed that five of them (Sabesp, Pão de Açúcar, Gol, Embraer and Itaú-Unibanco) had pricing in the U.S. market, as $\alpha NY > \alpha BOV$. For these five companies, the adjustment coefficients showed positive signs, indicating that the quotations showed a similar trend of movement, but with different intensities. In these cases, by analyzing the negotiations between January 2011 and mid-2013, we can see that there is a similar or higher liquidity of ADRs in relation to shares, except in the cases of Pão de Açúcar and Embraer (however, the ADR of the latter company has significant liquidity).

In the other four cases (CPFL Energia, Fibria, Gafisa and Tim), the national stock exchange had a greater influence on price discovery, i.e., $\alpha NY < \alpha BOV$. With the exception of the Tim asset, where the signs of the coefficients are opposite, indicating the occurrence of adjustment in opposite directions, for the other three assets the signs of the coefficients are the same (negative), suggesting that stock prices fall more than the ADR prices. Still, for these assets, with the exception of Fibria (which had similar liquidity between ADR and stock), there has been a greater amount of trading on the BM&FBOVESPA between January 2011 and June 2013.

The causality-in-mean and variance tests proposed by Cheung and Ng (1996) were performed in sequence. When considering that in the positive lags (negative) the direction of causality is from the stock to the ADR (from the ADR to the stock), there is, in general, bi-causality on the mean (Table 5) and on the variance (Table 6). Considering the stock-ADR pairs with pricing in the U.S. market, i.e., Sabesp, Pão de Açúcar, Gol, Embraer and Itaú-Unibanco, the causality test for the mean indicated, in all cases, the relationship "stock causes ADR" for all lags evaluated. Thus, the causality from ADR to stock is checked for the highest values of k. In terms of causality-in-variance, we found bi-causality for all stock-ADR pairs. On the other hand, for assets with pricing in the domestic market (CPFL Energia, Fibria, Gafisa and Tim), it is possible to perceive a causal relationship in the mean of the stock for the ADR only for smaller values of k. However, it is possible to perceive that the volatility shocks are similar in both markets, and there is no univocal response of variability from the domestic market to the U.S. market, or vice versa.

Table 5. Results of the causality-in-mean tests for stocks-ADR pairs listed on the BM&FBOVESPA and NYSE.

| Company | Lags | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 |
| Ambev | 52.10* | 1.23 | -2.64 | -0.39 | -0.13 | 0.27 | -1.05 | 0.73 | -0.74 | 1.82** | -2.46** | -2.10 | -0.40 | 0.70 | -1.32*** | -2.61* | 0.50 |
| Bradesco | 47.13* | 7.03* | -2.37* | -2.35* | -0.11 | -0.07 | -4.18* | -2.51* | 0.07 | -1.30*** | -0.38 | -0.35*** | -1.56*** | -1.40*** | -3.06* | -2.21** | -0.56 |
| Braskem | 47.45* | 4.85* | -0.99 | 1.79** | -1.08 | 0.94 | -2.14** | 1.24 | 1.63*** | 5.08* | 2.43* | 1.70** | -1.93** | 1.31*** | -0.82 | 0.65 | 1.55*** |
| BRF SA | 35.32* | 5.33* | -2.48* | -0.10 | -2.23** | -1.29*** | -0.01 | -3.39* | -0.43 | 1.98** | -0.11 | 0.48 | -1.48*** | -2.47* | -1.60*** | -0.37 | -0.88 |
| Cemig | 51.34* | 1.85** | -2.59* | -2.11** | -0.35 | 0.65 | -1.27 | -2.72* | 0.42 | 9.09* | -3.15* | -4.32* | 1.13 | 0.32 | -1.13 | -2.41* | -1.56*** |
| Copel | 52.34* | 10.65 | -0.41 | -0.35 | -0.78 | -1.69** | -4.58* | -0.55 | 1.13 | 6.54* | -0.16 | 0.21 | -2.94* | -2.14** | -1.58*** | 0.37 | 0.71 |
| CPFL | 39.43* | 4.23* | -2.50* | -2.69* | -0.83 | -0.48 | -2.28** | -0.39 | -0.66 | 2.14** | -0.87 | -1.82** | -0.45 | 0.25 | -3.90* | -0.64 | 0.27 |
| Eletrobrás | 28.49* | 1.66** | 0.04 | 0.16 | -1.81** | -0.17 | -0.76 | 1.74** | 0.83 | 1.94** | 0.55 | -0.28 | -1.23 | 0.27 | 0.01 | 0.08 | 2.26** |
| Embraer | 35.74* | 2.19** | 0.21 | -1.28 | 0.79 | -1.74** | -1.39*** | -0.11 | 1.41*** | 5.28* | -0.47 | -0.80 | 0.89 | 0.51 | -1.92** | -1.51*** | 1.65** |
| Fibria | 28.47* | 1.41*** | 0.87 | -2.09** | -0.02 | -1.81** | -0.31 | -0.07 | 0.68 | 0.33 | -0.26 | -1.65*** | 0.13 | -1.49*** | -1.23 | 1.06 | -0.08 |
| Gafisa | 36.86* | 2.65* | -1.65*** | -0.52 | 0.83 | 0.66 | -0.76 | -1.23 | 1.27 | 2.37* | -1.08 | -0.02 | -0.45 | 0.60 | -1.05 | -0.23 | 1.53*** |
| Gerdau | 48.50* | 4.18* | -2.70* | -1.17 | -0.57 | -0.42 | -0.37 | -0.48 | 1.54*** | 3.19* | 0.85 | -0.45 | -1.83** | -0.30 | -0.49 | 0.26 | 0.82 |
| Gol | 42.55* | -0.88 | 1.24 | 1.61*** | -2.45* | 1.68** | -1.87** | 1.38* | 0.98 | 3.65* | 0.12 | 0.09 | -1.06 | 0.54 | 0.06 | 0.01 | 0.74 |
| Itaú | 47.68* | 7.44* | -1.39*** | -2.66* | -0.41 | -1.30*** | -4.99* | -2.71* | -1.60*** | 0.74 | -0.27 | -0.37 | -1.75** | -2.08** | -3.78* | -2.24** | -2.02** |
| Oi | 46.71* | 2.57* | -1.21 | 0.05 | -2.66* | -0.14 | -1.26* | -2.03** | 1.07 | 1.53*** | -0.71 | -1.45*** | -0.98 | -1.73** | -0.96 | -0.14 | 0.99 |
| P. Açúcar | 51.79* | 9.84* | -1.29*** | 0.39 | -0.05 | -1.14 | -3.44*** | -0.58 | 0.89 | 2.29** | 0.90 | -0.01 | -1.71** | 0.54 | -2.59* | 0.48 | 0.08 |
| Petrobras | 47.51* | 6.16* | 0.00 | -0.97 | 1.18 | 0.05 | -1.36*** | -0.40 | -2.81* | -1.02 | -1.14 | 0.39 | -1.46*** | -0.20 | -0.39 | -1.04 | -1.97** |
| Petrobras | -1.55*** | -1.58*** | -2.20** | -2.32** | -2.78* | -3.49* | -4.38* | -4.16* | -4.46* | -1.93** | -1.30*** | -1.90** | -2.05** | -1.57*** | -0.81 | -0.73 | -0.59 |
| Sabesp | 45.02* | 6.17* | -3.33* | -2.60* | 2.25** | -1.12 | -1.56*** | -2.15** | 0.22 | 1.47*** | -1.88** | 0.00 | 0.57 | -0.23 | -1.26 | -2.09** | 0.44 |
| CSN | 50.91* | 9.68* | -1.26 | 0.37 | 0.02 | -1.15 | -3.43* | -0.65 | 0.79 | 2.26** | 0.87 | 0.06 | -1.67** | 0.57 | -2.63* | 0.40 | 0.03 |
| Telefônica | 45.13* | 8.06* | -1.28 | 0.42 | -0.53 | -3.84* | -1.34*** | 1.37*** | -0.67 | 3.18* | 0.08 | 1.30*** | -2.79* | -2.56* | -1.59*** | 0.99 | 0.70 |
| Tim | 58.46* | 1.90** | -0.30 | -2.63* | -0.97* | -1.15 | -2.33* | -0.62 | -0.18 | 2.79* | -0.46 | 0.00 | -0.87 | -1.20 | -2.66* | -0.27 | -0.14 |
| Vale ON | 46.19* | 6.79* | -5.30* | -1.56*** | -0.21 | -0.20 | 0.13 | -1.25 | -0.35 | -0.96 | -2.96* | -0.87 | -0.83 | 0.12 | -0.19 | -1.77** | -0.12 |
| Vale PN | 47.58* | 6.30* | -5.60* | -2.26** | -0.21 | 0.30 | -0.30 | -1.79** | -0.31 | 0.89 | -3.87* | -1.40*** | -0.72 | 0.43 | -0.62 | -2.22** | 0.37 |

*Significant at 1; ** Significant at 5%; *** Significant at 10%. Source: research results.

Table 6. Results of the causality-in-variance tests for stocks-ADR pairs listed on the BM&FBOVESPA and NYSE.

| Company | Lags | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 |
| Ambev | 49.44* | 10.04* | 14.34* | 9.40* | 16.85* | 15.90* | 7.93* | 16.39* | 5.59* | 10.98* | 15.08* | 11.74* | 14.09* | 15.58* | 8.84* | 15.08* | 5.80* |
| Bradesco | 46.27* | 7.64* | 14.30* | 7.64* | 11.54* | 15.70* | 9.62* | 20.90* | 5.64* | 11.28* | 21.10* | 10.46* | 9.58* | 13.94* | 13.33* | 18.89* | 6.93* |
| Braskem | 47.44* | 6.20* | 11.02* | 5.09* | 9.91* | 7.96* | 8.86* | 10.92* | 5.66* | 8.02* | 12.83* | 9.96* | 5.44* | 7.01* | 8.92* | 8.35* | 5.18* |
| BRF SA | 34.96* | 5.08* | 10.27* | 8.06* | 12.66* | 10.36* | 8.30* | 16.13* | 3.08* | 10.78* | 9.61* | 8.30* | 6.38* | 11.53* | 8.92* | 15.85* | 4.40* |
| Cemig | 48.75* | 10.80* | 14.87* | 11.58* | 13.87* | 15.35* | 8.69* | 14.87* | 5.69* | 9.87* | 14.13* | 9.24* | 16.62* | 15.67* | 7.79* | 16.13* | 5.48* |
| Copel | 47.50* | 15.75* | 12.57* | 11.89* | 8.71* | 10.84* | 19.61* | 11.05* | 5.78* | 12.28* | 13.05* | 13.34* | 12.36* | 12.74* | 19.08* | 11.28* | 6.76* |
| CPFL | 37.99* | 9.24* | 10.11* | 7.77* | 6.77* | 11.02* | 12.75* | 22.06* | 4.61* | 8.48* | 11.35* | 18.35* | 6.81* | 13.55* | 13.01* | 11.73* | 6.43* |
| Eletrobrás | 8.51* | 2.33* | 1.88** | 1.93** | 3.26** | 0.85* | 1.88 | 2.00** | 6.43** | 2.06* | 0.37** | 1.56 | 3.46*** | 5.66* | 10.94* | 3.80* | 6.09* |
| Embraer | 33.26* | 10.73* | 10.32* | 11.41* | 9.62* | 10.83* | 8.67* | 8.98* | 4.50* | 7.79* | 11.87* | 5.14* | 7.03* | 11.53* | 5.99* | 12.25* | 6.51* |
| Fibria | 26.84* | 2.56* | 5.73* | 3.49* | 1.37*** | 3.00* | 1.30*** | 2.32** | 3.51* | 2.84* | 6.42 | 3.56* | 2.41* | 2.56* | 3.22* | 1.27 | 2.82* |
| Gafisa | 35.68* | 9.17* | 16.09* | 8.32* | 11.30* | 15.39* | 8.41* | 16.00* | 7.52* | 10.13* | 14.21* | 9.69* | 7.93* | 13.66* | 10.74* | 16.37* | 6.82* |
| Gerdau | 40.33* | 6.57* | 15.66* | 7.98* | 12.55* | 16.40* | 9.82* | 12.97* | 9.09* | 10.79* | 15.53* | 12.29* | 11.99* | 14.99* | 15.90* | 11.04* | 6.25* |
| Gol | 40.84* | 14.26* | 7.10* | 9.53* | 11.09* | 9.24* | 11.25* | 10.77* | 8.96* | 9.19* | 5.22* | 4.38* | 18.96* | 7.01* | 7.53* | 7.58* | 11.47* |
| Itaú | 46.02* | 9.16* | 14.73* | 11.16* | 11.48* | 15.96* | 13.34* | 22.43* | 7.50* | 10.52* | 23.29* | 11.31* | 9.17* | 16.13* | 14.50* | 16.49* | 8.75* |
| Oi | 44.53* | 4.94* | 8.69* | 6.36* | 12.12* | 5.63* | 6.93* | 8.80* | 6.26* | 5.57* | 6.14* | 5.31* | 17.47* | 7.78* | 4.24* | 12.40* | 8.92* |
| P. Açúcar | 47.15* | 18.58* | 13.83* | 15.62* | 12.07* | 9.74* | 17.09* | 8.45* | 3.01* | 14.10* | 11.14* | 14.55* | 9.46* | 10.26* | 20.01* | 11.01* | 3.66* |
| Petrobras | 43.64* | 10.65* | 20.66* | 13.17* | 15.04* | 15.01* | 14.93* | 17.87* | 10.35* | 12.94* | 21.86* | 15.98* | 10.79* | 18.70* | 15.23* | 17.04* | 11.66* |
| Petrobras | 23.39* | 31.30* | 29.07* | 31.73* | 30.04* | 29.02* | 29.69* | 28.71* | 30.25* | 24.92* | 22.75* | 23.23* | 24.34* | 22.89* | 22.40* | 20.93* | 22.23* |
| Sabesp | 42.93* | 10.55* | 13.89* | 10.46* | 14.11* | 16.47* | 11.75* | 12.47* | 8.94* | 13.77* | 14.53* | 9.95* | 9.09* | 16.11* | 17.55* | 8.93* | 10.84* |
| CSN | 46.36* | 18.23* | 13.54* | 15.32* | 11.80* | 9.52* | 16.76* | 8.24* | 2.89* | 13.82* | 10.89* | 14.26* | 9.23* | 10.03* | 19.64* | 10.77* | 3.53* |
| Telefônica | 42.30* | 8.53* | 8.45* | 10.17* | 8.66* | 4.75* | 4.27* | 6.77* | 3.54* | 17.31* | 13.35* | 9.53* | 8.18* | 7.30* | 6.48* | 7.55* | 5.52* |
| Tim | 32.00* | 3.27* | 4.26* | 1.42*** | 3.74* | 2.43* | 2.64* | 3.89* | 2.37* | 3.02* | 4.53* | 1.14 | 4.00* | 2.80* | 1.95** | 3.99* | 1.69** |
| Vale ON | 45.77* | 6.95* | 22.34* | 10.36* | 11.93* | 15.08* | 12.43* | 14.99* | 6.48* | 9.06* | 17.02* | 10.94* | 7.54* | 18.04* | 11.91* | 18.81* | 5.48* |
| Vale PN | 43.26* | 6.64* | 20.24* | 9.85* | 12.14* | 15.91* | 11.39* | 16.57* | 5.84* | 8.79* | 17.73* | 10.98* | 8.15* | 18.11* | 10.86* | 17.41* | 5.96* |

*Significant at 1; ** Significant at 5%; *** Significant at 10%. Source: research results.

## 4. Conclusion

This study analyzed the price discovery of 22 cross-listed Brazilian companies, simultaneously traded on the BM&FBOVESPA and NYSE. We used cointegration and causality-in-mean and causality-in-variance tests in stock-ADR pair prices to determine the market that has the greatest influence on the pricing of these bonds. The contribution of this paper to this includes the analysis of a larger sample of Brazilian companies, as well as the joint combination of, in the context of the analysis, cointegration and causality-in-mean and causality-in-variance tests.

The results indicate the existence of a cointegration in most analyzed stock-ADR pairs, indicating rejection of the hypothesis of arbitrage possibilities between the BM&FBOVESPA and NYSE. According to the estimates of the error correction models, from the 22 stock-ADR pairs evaluated, nine of them had significant short-term coefficients. From this set, the assets of the companies Sabesp, Pão de Açúcar, Gol, Embraer and Itaú-Unibanco have price formation in the international market, while, in the other four cases (CPFL Energia, Fibria, Gafisa and Tim), the domestic market had greater influence on price discovery. Finally, the causality-in-mean and causality-in-variance tests revealed, in general, a relation of bi-causality among the stock-ADR pairs. Future works shall include the evaluation of such relations with intraday data.

## 5. References

ANSOTEGUI, C.; BASSIOUNY, A.; TOOMA, E. An investigation of intraday price discovery in cross-listed emerging market equities. Investment Analysts Journal, n. 77, p. 55-67, 2013.

CAMARGOS, M. A.; BARBOSA, F. V.; GOMES, G. D. Integração de mercados e arbitragem com títulos transfronteiriços: ADRs – American Depositary Receipts. Caderno de Pesquisas em Administração, v. 10, n. 2, p. 51-67, 2003.

CHEN, K. C.; LI, G.; WU, L. Price discovery for segmented US-Listed Chinese stocks: Location or Market Quality? Journal of Business Finance & Accounting, v. 37, n. 1-2, p. 242-269, 2010.

CHEUNG, Y. W.; NG, L. K. A causality in variance test and its application to financial market prices. Journal of Econometrics, v. 72, p. 33-48, 1996.

DICKEY, D. A.; FULLER, W. A. Likelihood ratio statistics for autoregressive time series with a unit root. Econometric, v. 49, n. 4, p. 1057-1073, 1981.

ENDERS, W. Applied econometric time series. 2º ed. John Wiley & Sons, 2004.

ENGLE, R. F.; GRANGER, C. W. J. Cointegration and error correction: representation, estimation, and testing. Econometrica, v. 55, n. 2, 251-276, 1987.

EUN, C. S.; SABHERWAL, S. Cross-border listings and price Discovery: evidence from US-listed Canadian stocks. The Journal of Finance, v. 58, n. 2, 549-576, 2003.

FURSTENBERG, G. M. V.; TABORA, C. B. Bolsa or NYSE: price discovery for Mexican shares. Journal of International Financial Markets, Institutions and Money, v. 14, n. 4, p. 295-311, 2004.

GARBADE, K. D.; SILBER, W. L. Dominant and satellite markets: a study of dually-traded securities. The Review of Economics and Statistics, v. 61, n. 3, p. 455-460, 1979.

GRAMMIG, J.; MELVIN, M.; SCHLAG, C. Internationally cross-listed stock prices during overlapping trading hours: price discovery and exchange rate effects. Journal of Empirical Finance, v. 12, n. 1, p. 139-164, 2005.

HARRIS, R. Using cointegration analysis in econometric modeling. Prentice Hall. 1995

IYEKI, M. H. ADR volume lifts market. NYSE, fev., 2013. Disponível em: < http://exchanges.nyx.com/marc-iyeki/adr-volume-lifts-market>. Acesso em 19 jul. 2013.

JOHANSEN, S. Statistical analysis of cointegrating vectors. Journal of Economic Dynamics and Control, v. 12, p. 1551-1580, 1988.

JOHANSEN, S.; JUSELIUS, K. Maximum likelihood estimation and inference on cointegration – with applications to the demand for money. Oxford Bulletin of Economics and Statistics, v. 52, n. 2, 169-210, 1990.

KAWAMOTO, C. A.; KAWAMOTO, C. T. Cointegração e Descoberta de Preços de ADR Brasileiros. Revista de Administração Contemporânea, v. 13, n. 2, p. 272-290, 2009.

KEHRLE, K.; PETER, F. J. Who moves first? An intensity-based measure for information flows across stock exchanges. Journal of Banking & Finance, v. 37, n. 5, p.

1629-1642, 2013.

KORCZAK, P.; PHYLAKTIS, K. Related securities and price discovery: evidence from NYSE-listed Non-U.S. stocks. Journal of Empirical Finance, v. 17, n. 4, p. 566-584, 2010.

LOK, E.; KALEV, P. S. The intraday price behavior of Australian and New Zealand cross-listed stocks. International Review of Financial Analysis, v. 15, n. 4-5, p. 377-397, 2006.

MACKINNON, J. Critical values for cointegration tests. In: ENGLE, R. F.; GRANGER, C. W. J. (eds). Long-run economic relationships: readings in cointegration, Oxford University Press: Oxford, 1991.

PASCUAL, R.; PASCUAL-FUSTER, B.; CLIMENT, F. Cross-listing, price discovery and the informativeness of the trading process. Journal of Financial Markets, v. 9, n. 2, p. 144-161, 2006.

PHILLIPS, P; PERRON, P. Testing for unit root in time series regression. Biometrica, v. 75, p. 335-346, 1988.

PROCIANOY, J. L.; KWITKO, L. C. Ações de empresas brasileiras e suas ADRs: uma nota sobre datas ex-dividend. Revista Brasileira de Economia, v. 61, n. 1, p. 111-124, 2007.

QADAN, M.; YAGIL, J. Main or satellite? Testing causality-in-mean and variance for dually listed stocks. International Journal of Finance and Economics, v. 17, p. 279–289, 2012.

SAKAMOTO, F. A. A diferença de preços entre ADRs e ações de empresas brasileiras como oportunidade de arbitragem. Finanças Aplicadas, v. 1, p. 1-14, 2011.

SU, Q.; CHONG, T. T-L. Determining the contributions to price discovery for Chinese cross-listed stocks. Pacific-Basin Finance Journal, v. 15, n. 2, p. 140-153, 2007.

WAN, J-Y.; KAO, C-W. Price discovery in Taiwan's foreign exchange market. Journal of International Financial Markets, Institutions and Money, v. 19, n. 1, p. 77-93, 2009.

WANG, S. S.; RUI, O. M.; FIRTH, M. Return and volatility behavior of dually-traded stocks: the case of Hong Kong, Journal of International Money and Finance, v. 21, n. 2, p. 265-293, 2002.

Annex 1. Results of unit root tests.

| Asset | | | ADF | | | | | | PP | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Model with intercept and slope | | Model with intercept | | Model without intercept and slope | | Model with intercept and slope | | Model with intercept | | Model without intercept and slope | |
| **Company** | **Type** | **Code** | **Coef.** | **P-value** | **Coef.** | **P-value** | **Coef.** | **P-value** | **Coef.** | **P-value** | **Coef.** | **P-value** | **Coef.** | **P-value** |
| Ambev | Stock | AMBV4 | -3.2305 | 0.0786 | -0.0883 | 0.9489 | 1.5470 | 0.9705 | -2.9933 | 0.1341 | -0.0471 | 0.9531 | 1.7382 | 0.9806 |
| | ADR | ABV | -3.2097 | 0.0826 | -0.1879 | 0.9376 | 1.5061 | 0.9679 | -0.0643 | 0.9514 | -3.0418 | 0.1209 | 1.7549 | 0.9813 |
| Bradesco | Stock | BBDC4 | -1.3084 | 0.8855 | -1.3107 | 0.6267 | 0.5198 | 0.8280 | -1.0155 | 0.9403 | -1.2961 | 0.6336 | 0.6898 | 0.8645 |
| | ADR | BBD | -1.2472 | 0.8997 | -1.2946 | 0.6343 | 0.4741 | 0.8173 | -1.0142 | 0.9405 | -1.2674 | 0.6468 | 0.6086 | 0.8478 |
| Braskem | Stock | BRKM5 | -2.2265 | 0.4741 | -2.3221 | 0.1650 | -0.1064 | 0.6470 | -2.2631 | 0.4536 | -2.3718 | 0.1499 | -0.1142 | 0.6444 |
| | ADR | BAK | -2.2786 | 0.1791 | -2.1326 | 0.5268 | 0.2617 | 0.7620 | -2.1992 | 0.4894 | -2.2933 | 0.1742 | 0.2170 | 0.7493 |
| BRF SA | Stock | BRFS3 | -2.7800 | 0.2049 | -1.5318 | 0.5174 | 0.8252 | 0.8895 | -2.6162 | 0.2730 | -1.4185 | 0.5746 | 0.9969 | 0.9163 |
| | ADR | BRFS | -3.0363 | 0.1225 | -1.6339 | 0.4649 | 0.7041 | 0.8673 | -2.6791 | 0.2455 | -1.4165 | 0.5756 | 1.0008 | 0.9169 |
| Cemig | Stock | CMIG4 | -2.8830 | 0.1681 | -0.7577 | 0.8301 | -0.0709 | 0.6591 | -2.6355 | 0.2643 | -0.6021 | 0.8678 | 0.1285 | 0.7231 |
| | ADR | CIG | -3.0917 | 0.1083 | -0.9365 | 0.7771 | -0.1533 | 0.6308 | -2.9996 | 0.1324 | -0.8376 | 0.8078 | -0.0661 | 0.6608 |
| Copel | Stock | CPLE6 | -2.7566 | 0.2138 | -1.4840 | 0.5419 | -0.4888 | 0.5045 | -2.6740 | 0.2475 | -1.3663 | 0.6003 | -0.4554 | 0.5181 |
| | ADR | ELP | -2.7025 | 0.2355 | -1.5024 | 0.5325 | -0.5429 | 0.4820 | -2.6806 | 0.2447 | -1.4753 | 0.5463 | -0.5334 | 0.4860 |
| CPFL Energia | Stock | CPFE3 | -0.9230 | 0.9517 | 0.7505 | 0.9932 | -0.8512 | 0.3472 | -1.1727 | 0.9145 | 0.7635 | 0.9934 | -0.7254 | 0.4024 |
| | ADR | CPL | -1.2853 | 0.8908 | 0.5902 | 0.9895 | -0.7016 | 0.4130 | -1.1925 | 0.9107 | 0.7317 | 0.9928 | -0.7104 | 0.4091 |
| Eletrobras | Stock | ELET3 | -0.9230 | 0.9517 | 0.7505 | 0.9932 | -0.8512 | 0.3472 | -1.1727 | 0.9145 | 0.7635 | 0.9934 | -0.7254 | 0.4024 |
| | ADR | EBR | -1.2853 | 0.8908 | 0.5902 | 0.9895 | -0.7016 | 0.4130 | -1.1925 | 0.9107 | 0.7317 | 0.9928 | -0.7104 | 0.4091 |
| Embraer | Stock | EMBR3 | -1.6334 | 0.7796 | -1.6980 | 0.4322 | -0.0793 | 0.6562 | -1.6476 | 0.7737 | -1.7125 | 0.4248 | -0.0767 | 0.6571 |
| | ADR | ERJ | -1.5862 | 0.7984 | -1.6546 | 0.4543 | 0.0703 | 0.7051 | -1.6277 | 0.7820 | -1.6953 | 0.4335 | 0.0648 | 0.7033 |
| Fibria | Stock | FIBR3 | -1.7465 | 0.7298 | -1.3211 | 0.6216 | -0.4435 | 0.5226 | -1.7562 | 0.7253 | -1.3130 | 0.6254 | -1.3130 | 0.6254 |
| | ADR | FBR | -1.7704 | 0.7186 | -1.3266 | 0.6189 | -0.4801 | 0.5078 | -1.7574 | 0.7247 | -1.3035 | 0.6298 | -0.4845 | 0.5060 |
| Gafisa | Stock | GFSA3 | -2.0045 | 0.5979 | -0.8322 | 0.8092 | -1.1022 | 0.2457 | -1.9031 | 0.6524 | -0.7362 | 0.8356 | -1.1105 | 0.2427 |
| | ADR | GFA | -1.8674 | 0.6709 | -0.6917 | 0.8468 | -1.0725 | 0.2568 | -1.9139 | 0.6467 | -0.7322 | 0.8366 | -1.0678 | 0.2586 |
| Gerdau | Stock | GGBR4 | -1.1362 | 0.9214 | -2.0522 | 0.2646 | -0.5300 | 0.4874 | -0.9724 | 0.9460 | -2.0678 | 0.2580 | -0.4912 | 0.5035 |
| | ADR | GGB | -0.9322 | 0.9509 | -2.1456 | 0.2268 | -0.5542 | 0.4773 | -0.9852 | 0.9444 | -2.1304 | 0.2327 | -0.5531 | 0.4778 |
| Gol | Stock | GOLL4 | -2.2552 | 0.4580 | -1.2416 | 0.6584 | -0.8241 | 0.3590 | -2.1976 | 0.4901 | -1.1722 | 0.6885 | -0.7947 | 0.3719 |
| | ADR | GOL | -1.7910 | 0.7091 | -0.5186 | 0.8852 | -0.7395 | 0.3963 | -1.7787 | 0.7150 | -0.5057 | 0.8877 | -0.7399 | 0.3961 |
| ItauUnibanco | Stock | ITUB4 | -1.4663 | 0.8409 | -1.4405 | 0.5637 | 0.3847 | 0.7950 | -1.0174 | 0.9400 | -1.4105 | 0.5787 | 0.6131 | 0.8488 |
| | ADR | ITUB | -1.3143 | 0.8841 | -1.4533 | 0.5573 | 0.4056 | 0.8004 | -1.0478 | 0.9357 | -1.4211 | 0.5734 | 0.5459 | 0.8340 |
| Oi | Stock | OIBR4 | -1.3290 | 0.8803 | -1.6164 | 0.4740 | -0.7868 | 0.3755 | -1.0718 | 0.9320 | -1.4909 | 0.5384 | -0.7365 | 0.3976 |
| | ADR | OIBR | -1.2921 | 0.8894 | -1.6242 | 0.4700 | -0.8118 | 0.3645 | -1.0079 | 0.9413 | -1.4772 | 0.5453 | -0.7647 | 0.3852 |
| P.Acucar-Cbd | Stock | PCAR4 | -3.0124 | 0.1288 | -1.2398 | 0.6593 | 0.4952 | 0.8223 | -2.8940 | 0.1645 | -1.1621 | 0.6929 | 0.5556 | 0.8362 |
| | ADR | CBD | -3.0775 | 0.1118 | -1.2022 | 0.6758 | 0.5121 | 0.8263 | -2.9852 | 0.1364 | -1.1316 | 0.7054 | 0.5783 | 0.8412 |
| Petrobras | Stock | PETR4 | -0.7504 | 0.9684 | -1.6509 | 0.4563 | 0.1477 | 0.7289 | -0.5565 | 0.9809 | -1.5944 | 0.4853 | 0.2110 | 0.7475 |
| | ADR | PBR.A | -0.5472 | 0.9814 | -1.5785 | 0.4935 | 0.3466 | 0.7851 | -0.5225 | 0.9826 | -1.5315 | 0.5176 | 0.3361 | 0.7823 |
| Petrobras | Stock | PETR3 | -0.4905 | 0.9840 | -1.2495 | 0.6549 | 0.0202 | 0.6892 | -0.4227 | 0.9868 | -1.2321 | 0.6627 | 0.0400 | 0.6955 |
| | ADR | PBR.A | -0.3659 | 0.9887 | -1.2386 | 0.6598 | 0.1423 | 0.7272 | -0.3511 | 0.9892 | -1.2339 | 0.6619 | 0.1419 | 0.7271 |
| Sabesp | Stock | SBSP3 | -2.3474 | 0.4075 | -0.9863 | 0.7602 | 0.5850 | 0.8427 | -2.2652 | 0.4530 | -0.9541 | 0.7712 | 0.6609 | 0.8587 |
| | ADR | SBS | -2.1996 | 0.4891 | -0.9663 | 0.767 | 0.6965 | 0.8659 | -2.3089 | 0.4284 | -0.9507 | 0.7723 | 0.6687 | 0.8603 |
| Sid Nacional | Stock | CSNA3 | -0.1406 | 0.9942 | -1.2660 | 0.6475 | -0.8952 | 0.3285 | -0.0789 | 0.9952 | -1.2461 | 0.6565 | -0.8739 | 0.3376 |
| | ADR | SID | -0.3629 | 0.9888 | -1.0327 | 0.7436 | -0.6369 | 0.4416 | -0.4755 | 0.9847 | -1.0487 | 0.7377 | -0.6640 | 0.4297 |
| Telef Brasil | Stock | VIVT4 | -3.204 | 0.0837 | -0.6808 | 0.8496 | 0.4746 | 0.8174 | -3.1764 | 0.0893 | -0.6516 | 0.8566 | 0.5029 | 0.8241 |
| | ADR | VIV | -3.2784 | 0.0700 | -0.9721 | 0.7651 | 0.2775 | 0.7664 | -3.2071 | 0.0831 | -0.9084 | 0.7862 | 0.3184 | 0.7776 |
| Tim Part S/A | Stock | TIMP3 | -2.4784 | 0.3390 | -1.9881 | 0.2923 | -0.9175 | 0.3191 | -2.2520 | 0.4598 | -1.9000 | 0.3326 | -0.7338 | 0.3989 |
| | ADR | TSU | -2.2758 | 0.4466 | -1.9451 | 0.3117 | 0.1013 | 0.7147 | -2.2214 | 0.4769 | -1.9007 | 0.3323 | 0.1347 | 0.725 |
| Vale | Stock | VALE3 | -0.6205 | 0.9774 | -1.9306 | 0.3183 | 0.5795 | 0.8415 | -0.5339 | 0.982 | -1.9767 | 0.2974 | 0.6226 | 0.8508 |
| | ADR | VALE | -0.5119 | 0.9831 | -1.9102 | 0.3278 | 0.5802 | 0.8416 | -0.4793 | 0.9845 | -1.9229 | 0.3219 | 0.5871 | 0.8432 |
| Vale | Stock | VALE5 | -0.5246 | 0.9825 | -1.3148 | 0.6249 | 0.6031 | 0.8466 | -0.4323 | 0.9864 | -1.3173 | 0.6237 | 0.6461 | 0.8557 |
| | ADR | VALEP | -0.6153 | 0.9777 | -1.2064 | 0.674 | 0.5387 | 0.8324 | -0.5256 | 0.9824 | -1.1914 | 0.6804 | 0.5896 | 0.8437 |

Source: research results.