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Price Discovery in U.S. and Foreign Commodity Futures Markets: The Brazilian Soybean Example

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Practitioner's Abstract

Trader direct access to the order matching systems on United States and foreign commodity futures markets reduces or eliminates the cost of changing trading venues. The Dodd-Frank Act recognizes that price discovery could now more readily shift to foreign futures markets if futures market regulations in the United States were more stringent than those for foreign futures markets. Price discovery is the incorporation of market fundamentals into price. It is done by traders that make trades based on informed judgments about market fundamentals The Act does not provide guidance on how to measure price discovery. We examine the use of the Gonzalo-Granger Decomposition to measure the relative soybean price discovery contribution of the Chicago Mercantile Exchange and the Brazilian Mercantile and Futures Exchange. Daily opening and closing soybeans prices from the two exchanges are used in the examination. We provide evidence that there is exchange of soybean price fundamentals between the two exchanges after the beginning of direct trader access between the two exchanges. Simultaneous soybean transaction prices are required for making reliable estimates of the relative contribution of each futures exchange to soybean price discovery.

Keywords: price discovery, market fundamentals, direct trader access, Dodd-Frank Act, Gonzalo-Granger Decomposition

Introduction

This paper examines the price discovery linkage between U.S. and Brazilian soybean futures prices on the Chicago Mercantile Exchange (CME) and on the Brazilian Mercantile and Futures (BM&F) Exchange.[1] Price discovery is the attempt to determine equilibrium prices by incorporating market fundamentals into price. Market fundamentals can be discovered in one market and passed to another market trading the same asset.

The United States and Brazil had 44 and 32 percent of the global soybean export market in the 2009/2010 marketing year, respectively.[2] The large U.S. and Brazilian export shares suggests that events in Brazil have large effects on U.S. soybean futures prices. However, perceived changes in market fundamentals based on events in Brazil or elsewhere may largely be incorporated in the U.S. futures price and then passed to the Brazilian futures price**.** The larger volume on the CME may contain more trading based on market fundamentals from events in Brazil than does the volume on the BM&F.

[1] The Brazilian Mercantile and Futures (BM&F) Exchange and the Sao Paulo Stock Exchange (Bovespa) merged in 2008 to form the BM&FBovespa, a combined futures and stock exchange. The futures side of the exchange is referred to as the BM&F.

[2] Source http://www.fas.usda.gov/psdonline

The introduction of direct trading access between the CME and the BM&F futures markets suggests that price changes in one of them will be more quickly transmitted to the other. Direct access enables qualified traders to enter orders directly into the order matching system of an exchange. Direct access to the BM&F futures market began in September 2008 for qualified traders on the CME futures market. Direct access to the CME futures market began in February 2009 for qualified traders on the BM&F futures market. (BM&FBovespa, December 2008 and February 2009)

Direct access between the CME and BM&F futures markets aids buyers seeking to buy soybeans at the lowest price after accounting for transportation costs and exchange rates. Buying in the lowest priced market raises the price relative to the other market. Buyer use of the new trading capability likely links the two prices more closely, by reducing the size and duration of unwarranted futures price differences. As emphasized by Working (1953) futures contracts are often purchased by commodity buyers as a temporary substitute for the actual commodity.

Direct access also makes it easier for speculators to move trades from the CME to the BM&F. Speculators aid in discovering market fundamentals by providing liquidity via bid and ask prices and via holding longer term speculative positions. Hedgers tend to move to the most liquid market. Gray (1961) showed that hedgers tended to use the Chicago wheat futures market over the Kansas City and Minneapolis wheat futures markets when there was an excess of short hedging over long hedging. The larger amount of speculative trading on the Chicago market could absorb the excess of short hedging. Although Gray did not examine price discovery among the three futures markets most of the market fundamentals may have been incorporated into the Chicago price and then passed to the Kansas City and Minneapolis prices because of the larger amount of speculation on the Chicago market.

The Dodd-Frank Wall Street Reform and Consumer Protection Act raises the concern that speculative position limits on a U.S. futures market would cause price discovery to shift to foreign futures markets trading the same commodity, if similar position limits are not imposed on those foreign futures markets (Public Law No. 111-203, Sec. 737). The Act authorizes the Commodity Futures Trading Commission to make direct access to a Foreign Board of Trade from the U.S. conditional on its cooperation regarding speculative position limits. Cooperation by a Foreign Board of Trade requires direct access from the U.S. being more important than not agreeing with the U.S. on speculative limits. Movement of price discovery to a foreign futures market would occur if the speculative trading that is based on buying and selling futures contracts due to perceived changes in market fundamentals shifts to foreign futures markets trading the same commodity. This is the type of speculative trading that attempts to discover the equilibrium or fundamental price. The Dodd-Frank Act does not provide guidance on choosing procedures for measuring price discovery.

Two prices are cointegrated if they are driven by or incorporate the same new fundamental information. In the cointegration framework the new information is represented by a common stochastic trend that is also called the fundamental or equilibrium price. We use a procedure provided by Gonzalo and Granger (1995) to estimate the fundamental price using observed prices. We use it to estimate the portion of the fundamental price discovered in each market.

Data

Daily opening and closing soybean futures prices for CME May contracts and BM&F April contracts maturing in 2007 through 2010 are used in our price discovery examination.[3] BM&F soybean futures contracts are priced and traded in U.S. dollars.

Opening prices and also closing prices on the CME occur later than the corresponding prices on the BM&F because of time zone differences. The observance of daylight savings time in the U.S. and Brazil affects the time zone differences. There is a four hour time difference between Chicago and Sao Paulo in the northern hemisphere winter and a two hour difference in the northern hemisphere summer.

We use a procedure used by Kadapakkam *et al*. (2003) to account for the later occurring CME closing price on price discovery. In addition to using closing prices on both exchanges to examine price discovery we also use opening prices on the CME and closing prices on the BM&F. BM&F closing price occurs after the CME opening price giving it a price discovery advantage.

Our examination using the daily closing price on each exchange provides a price discovery advantage to each price. Since the BM&F trading opens before CME trading, the BM&F closing price should include market fundamentals discovered between BM&F opening and the CME opening. Since the CME closes later than the BM&F, the CME closing price should include market fundamentals discovered between BM&F closing and CME closing. We do not know which price discovery advantage is largest. Both prices may include market fundamentals discovered between CME opening and BM&F closing. There is trading on both markets between CME opening and BM&F closing.

Our examination using the daily CME opening price and BM&F daily closing price gives the BM&F closing price a price discovery advantage since it occcrs after the CME opening price. The CME is trading between its opening and the BM&F closing. Therefore, the BM&F closing price may reflect market fundamentals discovered on the CME. Consequently, the use of the CME opening price and the BM&F closing price may greatly over estimate the contribution of the BM&F to discovering price.[4]

Following Darrat and Zhong (2002) we used one daily observation per week. We chose Wednesday opening and closing prices. Use of one day each week allows us to use prices when individual trading days on the BM&F had extremely low or zero volume.

Use of one day's prices each week does not reduce the price discovery advantage from nonsynchronous prices as claimed by Darrat and Zhong. For example, the BM&F closing price

[3] Soybean price and volume data were obtained from the Commodity Research Bureau. http://www.crbtrader.com/datacenter.asp

[4] Simultaneous CME and BM&F transaction prices provide each price with identical time periods between price changes to incorporate market fundamentals. Examining them with the Gonzalo-Granger Decomposition would improve on our price discovery estimates.

change over a week accumulates its discovered daily market fundamentals. Similarly, the CME closing price change over a week accumulates its daily market fundamentals. The price discovery advantage from nonsynchronous prices would be reduced if the exchanges were open continuously from Wednesday to Wednesday.

Table 1 list the soybean contracts traded on the CME and on the BM&F. Four CME and BM&F contracts expire during the same months. CME and BM&F contracts expiring during the same month offers foreign buyers the opportunity to buy soybeans at the same future time with either contract. Buyers choosing between contracts expiring in the same month based on cheapest to deliver prices may incorporate the same market fundamentals in each price.

However, we chose to examine prices for the CME May contract and the BM&F April contract. The April contract has the largest volume of the BM&F contracts. It expires at the end of harvest period. The larger volume for this contract may be reflecting producer hedging need and buyer need to purchase the available soybeans.

Procedure and Findings

Table 2 summarizes the price data used in the analysis. Corresponding trading volume is also summarized.

CME opening and closing prices were slightly higher than the corresponding BM&F prices in 2007, 2009, and 2010. In these years the CME price was 2 to 12 cents per bushel higher than the BM&F price. The slightly higher average CME prices most likely reflects slightly lower per bushel costs of delivering soybeans from the U.S. to foreign designations. In 2008, the average CME opening price and closing prices were 81and 80 cents more than the corresponding BM&F prices. Price levels were considerably higher in both markets in 2008.

Prices in 2008 were also different from the other three years in that the May CME and the April BM&F contracts had much higher price standard deviations. However, the differences in price standard deviations between the CME and BM&F each year including 2008 were small. The CME price standard deviation is 4 to 8 cents per bushel more than the BM&F in 2007 and 2008 and 6 cents per bushel less in 2009. They are almost the same in 2010. The similar price standard deviations suggest that the CME and BM&F soybean markets are reflecting the same underlying volatility.

Interestingly, average and standard deviations of trading volume on both exchanges in 2008 were highest when the price levels and the price standard deviations were also highest. The differences in daily trading volumes are huge. CME average daily trading volumes ranged from 53 to 163 times the trading volume on the BMF. However, the trading volumes on the BMF are not insignificant. Average daily BMF trading volumes ranged from 205 to 772 contracts. Contrary to our expectations, soybean trading volume on the BMF April contract did not increase in 2009 and 2010 after the beginning of direct access trading between the two exchanges. This finding may be due to the decrease in price level and the price standard deviation from 2008 to 2010. Trading volume is often less when prices are less volatile.[5] CME

[5] We do not attempt to find a causal relationship between trading volume and volatility.

trading volume also decreased from 2008 to 2010 reflecting lower prices and the decreased volatility. However, CME trading volume increased from 2009 to 2010 despite the reduction in price volatility between these years.

We calculated correlations between daily CME and BM&F price changes and between Wednesday to Wednesday CME and BM&F price changes. The correlations were calculated using CME close prices and BM&F close prices and using CME open and BM&F close prices. Table 3 shows the correlations. CME close to BM&F close correlations were much higher than CME open to BMF close.[6] There is a longer time period each trading day between the CME open to the BMF close correlations. Consequently, the BM&F close price represents more additional information and more unanticipated change reducing the correlation.[7] As an experiment we calculated the correlation between CME opening and CME closing daily price changes. We found essentially zero correlations due to the large amount of new unanticipated information arriving between CME opening and CME closing.

The Wednesday CME close to Wednesday BM&F close correlations were about the same as for the daily CME close to BM&F close correlations. These results suggest the Wednesday only price data may preserve any cointegration relationships while offering the potential to use price data with low daily trading volumes.

The Gonzalo-Granger Decomposition requires a unit root in price levels but not in price changes. It also requires that the prices on the two futures exchanges be cointegrated. [8]

The augmented Dickey-Fuller test was used to examine prices for unit roots. It did not reject a unit root in price levels. It did reject a unit root in the daily price changes. The test results indicate that the prices examined incorporated market fundamentals.

We then use the Johansen trace test to judge if prices on the CME and BM&F are cointegrated. That is, to judge if they share market fundamentals. Table 4 contains the test results. They provide support for the notion that direct access between the CME and BM&F has resulted in their soybean prices being driven by and sharing the same market fundamentals.

The cointegration test results for 2010 stand out from the other years. The daily CME close and BM&F close had a significant trace test at the 5 per level as did the daily CME open and BM&F close. In addition, the trace test for the Wednesday CME close and Wednesday BM&F close was significant at the 1 per level as was the Wednesday CME open and Wednesday BM&F close The cointegration test results are consistent with the notion that direct trading between the two exchanges has contributed to the exchange of market fundamentals.

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[6] We suspect that the correlation between the two closing prices would be higher if they were observed at the same time.

[7] As discussed later, an additional factor may contribute to lower correlations for the CME open to BM&F close prices. The CME is trading when the BM&F closes. Consequently, the BM&F close is likely picking up information incorporated in the CME price and thus lower the correlation between CME open and BM&F close.

[8] Figurerola-Ferrtti and Gonzalo (2010) used the Gonzalo-Granger Decomposition to estimate the relative price discovery contributions of forward and spot metals markets.

Cointegration was also detected for 2008. Cointegration for daily CME open and BM&F close prices for 2008 was detected at the 10 percent significance level. Cointegration for Wednesday CME open and BM&F close for 2008 was detected at the 5 percent significance level.

Based on the cointegration test results we chose to estimate the relative CME and BM&F contributions to price discovery using the 2010 price data.

Equations 1 and 2 are the vector error correction (VEC) model used in the price discovery examination.

(1) $\Delta P_{cme,t} = \alpha_{cme}(\beta_{bmf} P_{bmf,t-1} - \beta_{cme} P_{cme,t-1} + C)$

$$+\left(\sum_{i=1}^{k} \delta_{cme,i}\, \Delta P_{cme,t-i}\right) + \left(\sum_{i=1}^{k} \gamma_{cme,i}\, \Delta P_{bmf,t-i}\right) + \epsilon_{cme,t}$$

(2) $\Delta P_{bmf,t} = \alpha_{bmf}(\beta_{bmf} P_{bmf,t-1} - \beta_{cme} P_{cme,t-1} + C)$

$$+\left(\sum_{i=1}^{k} \delta_{bmf,i}\, \Delta P_{cme,t-i}\right) + \left(\sum_{i=1}^{k} \gamma_{bmf,i}\, \Delta P_{bmf,t-i}\right) + \epsilon_{bmf,t}$$

where:

$\Delta P_{cme,t}$ and $\Delta P_{bmf,t}$ are price changes from day t-1 to day t

$\Delta P_{cme,t-i}$and $\Delta P_{bmf,t-i}$ are price changes t-i-1 to day t-i

$P_{bmf,t-1}$ and $P_{cme,t-1}$ are price levels for day t-1

The VEC model requires the two prices to be cointegraed.

The first term on the right hand side in each equation contains the cointegration vector $\beta_{bmf} P_{bmf,t-1} - \beta_{cme} P_{cme,t-1} + C$ that measures deviations in price levels from arbitrage equilibrium for day t-1. The cointegration vector contains a constant term allowing for average price level difference between the CME and BM&F.

Equation 3 is the equilibrium relationship between the two prices due to buyer arbitrage.

(3) $1 P_{bmf,t-1} - 1\, P_{cme,t-1} + C = 0$

For this equilibrium relationship to hold in the cointegration vector, β_{bmf} must equal 1 and β_{cme} must equal -1. The constant C in equation 3 equals the average difference per bushel in delivery costs to foreign markets. We compare our estimated cointegration vectors to the arbitrage equilibrium relationship.

The first terms in equations 1 and 2 also contain adjustment coefficients, α_{cme} and α_{bmf}. The products of the adjustment coefficients and cointegeration vector, is the reduction in deviation

from long run equilibrium from day t-1 to t. The reduction in deviation from arbitrage equilibrium on current price, day t, is made through the product's impact on, $\Delta P_{cme,t}$ and $\Delta P_{bmf,t}$, in equations 1 and 2. Given the coefficient signs on the prices in the cointegrating vector we expect one of the following outcomes for the estimated adjustment coefficients.

- $0 < \alpha_{cme} < 1$ and $-1 < \alpha_{bmf} < 0$ both prices adjust; price is discovered in both markets
- $0 < \alpha_{cme} < 1$ and $\alpha_{bmf} = 0$ only the CME price adjusts; price discovered in BM&F
- $\alpha_{cme} = 0$ and $-1 < \alpha_{bmf} < 0$ only the BM&F price adjusts; price discovered in CME

The second and third terms in each equation contain price changes due to price changes in previous days, t-i. The fourth term in each equation is an error term.

The parameters in equations 1 and 2 were estimated using Johansen's reduced rank regression in the SAS VARMAX procedure and the 2010 prices from the CME May contract and the BM&F April contract. The parameter estimates for the cointegrating vector and adjustment coefficients are shown in table 5. Columns 1 and 2 show the estimates using daily prices and columns 3 and 4 show the estimates using Wednesday prices. The estimates in columns 1 and 3 use CME closing prices and BM&F closing prices. The estimates in columns 2 and 4 use CME opening prices and BM&F closing prices.

Each of the cointegrating vectors was normalized by setting the estimated BM&F cointegrating coefficients (the β_{bmf}'s) equal to 1. The CME estimated coefficients (the β_{cme}'s) are essentially equal to minus 1. We conclude that the cointegration coefficients reflect the arbitrage relationship in equation 3. A negative (positive) constant in a cointegrating vector estimates that the CME price is larger (smaller) than the BM&F price. Column 1 shows that in arbitrage equilibrium the CME price is about 7 cents per bushel smaller than the BM&F price. Column 2 shows that the CME price is about 1.4 cents per bushel larger than the BM&F price. Table 2 shows that the average daily CME closing price was 2 cents larger than the average daily BM&F closing price for 2010. Table 2 also shows that the average daily CME opening price was 4 cents larger than the average daily BM&F closing price for 2010.

The adjustment coefficients in columns 1 and 2 have the correct signs for price adjustments to departures from arbitrage equilibrium. They imply that negative departures from long run equilibrium decrease the CME price and increase the BM&F price. Conversely, they imply that positive departures from arbitrage equilibrium increase the CME price and decrease the BM&F price. Both positive and negative departures from long run equilibrium are reduced by the two price adjustments.

The absolute value of the adjustment coefficient in column 1 for the BM&F is 5.6 times larger than the adjustment coefficient for the CME. Column 1 estimates are based on CME and BM&F closing prices. This result suggests that most of the price is discovered by the CME and passed

to the BM&F via the large adjustment coefficient. Most of the price adjustment to arbitrage equilibrium occurs in the BM&F price.

The absolute of the adjustment coefficient in column 2 for the CME is 3.3 times larger than the absolute value of adjustment coefficient for the BM&F. Column 2 estimates are based on CME opening price and BM&F closing price. This result implies that price is largely discovered in the BM&F market and that the CME makes the largest adjustment to equilibrium. Although the results in columns 1 and 2 concerning price discovery are inconsistent they do indicate that both markets contribute to discovering price.

The estimated adjustment coefficients using Wednesday prices have incorrect signs. They are incorrect because they imply incorrect price adjustments to departures from arbitrage equilibrium. The BM&F trading volumes beyond four months to futures contract maturity may be too small for price discovery examination.

Gonzalo and Granger (1995) show how to estimate common stochastic trends based on linear combinations of observed variables using Johansen reduced rank regression. An outline of their procedure is shown in the appendix. The linear combination of CME and BM&F prices that estimates the common stochastic trend is

(4) $\alpha_{\perp,bmf} P_{bmf,t} - \alpha_{\perp,cme} P_{cme,t}$.

The coefficients $\alpha_{\perp,bmf}$ and $\alpha_{\perp,cme}$ are estimated by the Gonzalo and Granger procedure.[9] Harris *et al*. (2002) were the first to recognize that the relative contribution of each market to the common stochastic trend (fundamental price) can be estimated using the weights for the common trend as shown below.

(5) $\alpha_{\perp,cme}/(\alpha_{\perp,cme} + \alpha_{\perp,bmf}) + \alpha_{\perp,bmf}/(\alpha_{\perp,cme} + \alpha_{\perp,bmf}) = 1$

The first term is the estimated relative contribution of the CME and the second term is the estimated relative contribution of the BM&F to discovering the fundamental market price. Table 6 shows estimates of the common trend coefficients used for estimating price discovery contribution. A larger common-trend coefficient, either $\alpha_{\perp,cme}$ or $\alpha_{\perp,bmf}$, implies a larger price discovery contribution. Adjustment coefficients have the opposite effect. A larger adjustment coefficient, either α_{cme} or α_{bmf}, implies a smaller price discovery contribution.[10]

Table 6 also shows estimates of the relative price discovery contributions of the CME and the BM&F. The CME is estimated to provide 85 percent of the price discovery when daily closing CME and BM&F prices are used, but only 23 percent when daily opening CME and daily closing BM&F prices are used. In both examples the last price to be observed had the largest price discovery estimate reflecting the advantage of additional time to incorporate market fundamentals. However, there is another factor giving the closing BM&F price a price discovery

[9] Their procedure was implemented using GAUSS code that we wrote.

[10] Theissen shows that the common factor weights can be calculated from the adjustment coefficients.

advantage relative to the CME opening price. Trading occurs on the CME between its opening price and the BM&F closing price. Therefore, the BM&F closing price is likely reflecting price fundamentals discovered by the CME. As a result BM&F price discovery is likely to be overestimated.

Conclusions and Directions for Further Work

Detecting cointegration at least the 5 percent significance level for each of the four 2010 opening and closing price combinations examined suggests that the introduction of direct access trading between the CME and BM&F contributes to the exchange of market fundamentals. We provide evidence using daily opening and closing prices that both markets contribute to discovering the fundamental market price. However, we did not provide reliable estimates of the relative price discovery contributions of each market due to the use of nonsynchronous prices.

The use of simultaneous (synchronous) CME and BM&F transaction prices instead of opening and closing prices would likely provide reliable estimates of each market's contribution to discovering market fundamentals. Price changes for CME and BM&F simultaneous transaction prices have identical time periods and consequently equal opportunity to incorporate fundamental price information. Price changes for CME and BM&F opening and closing prices do not have identical time periods and consequently do not have equal opportunity to incorporate fundamental price information.

Relative price discovery estimates may be improved by bringing the U.S.—Brazilian exchange rate into the cointegrating relationship (Grammig, *et al*., 2005). This would likely result in one cointegrating vector and two common stochastic trends. One common stochastic trend would be the fundamental soybean price. The other would be the fundamental exchange rate.

The procedures used in this paper could be used to measure the relative price discovery contributions of commodity futures markets and corresponding swap markets. Regulation under Dodd-Frank will likely include monitoring these swap markets. A swap market could have a large price discovery contribution even when its volume is low relative to the corresponding futures market if the swap market trades were based on information first known by swap market participants. For example, a low volume swap market could contain a significant number of large merchant and processor trades that reflect new market fundamentals. In this situation, volume could be a misleading indicator of importance.

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Table 1. Soybean Futures Contracts on the Chicago Mercantile Exchange and the Brazilian Mercantile and Futures Exchange. 1/

Soybean Contracts	Chicago Mercantile Exchange	Brazilian Mercantile & Futures
January	x	
February		x
March	x	x
April		x
May	x	x
June		x
July	x	x
August	x	x
September	x	
October		x
November	x	

1/ Contracts are named by the month in which they expire.

Table 2. Daily averages and standard deviations of opening prices, closing prices, trading volumes, and number of observations for the May contract on the Chicago Mercantile Exchange and the April contract on the Brazilian Mercantile and Futures Exchange. 1/ 2/

Variable	2007		2008		2009		2010	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
CME-opening price	7.33	0.37	13.06	1.10	9.28	0.63	9.85	0.48
CME-closing Price	7.34	0.37	13.07	1.07	9.29	0.63	9.83	0.48
CME-daily volume	33,326	32,696	45,334	33,157	36,277	29,675	41,748	29,550
BM&F-opening price	7.24	0.29	12.25	1.06	9.16	0.69	9.83	0.49
BM&F-closing price	7.24	0.29	12.27	1.02	9.18	0.69	9.81	0.48
BM&F-daily volume	205	231	772	632	684	412	316	212
Number of Observations 3/	78		76		79		79	

1/ Prices are dollars per bushel and volume is number of contracts.
2/ Data for each contract include observations from December 1 through March 31.
3/ A daily observation for an exchange was excluded if trading did not occur on the other exchange.

Table 3. Correlations between soybean price soybean changes for the May contract on the Chicago Mercantile Exchange and for the April contract on the Brazilian Mercantile and Futures Exchange.

CME Price	BM&F Price	Frequency	2007	2008	2009	2010
close	close	daily	0.74	0.84	0.89	0.70
open	close	daily	0.18	0.49	0.12	0.35
close	close	Wednesday (weekly)	0.74	0.81	0.82	0.72
open	close	Wednesday (weekly)	-0.09	0.14	0.37	0.21

Table 4. Johansen Trace test for Cointegration between Soybean prices for the May contract prices on the Chicago Mercantile Exchange and the April contract on the Brazilian Mercantile Futures Exchange.

Year	Trace statistic	
	CME closing price – BM&F closing price	CME opening price – BM&F closing price
	----------Daily prices----------	
2007	8.45	8.82
2008	10.76	13.74*
2009	7.30	5.62
2010	18.41**	17.76**
	----------Wednesday prices----------	
2007	4.19	6.62
2008	6.80	15.61**
2009	7.99	6.58
2010	21.75***	24.65***

*, **, and *** indicate significance at the 0.10, 0.05, and 0.01 levels.

Table 5. Cointegration vectors and adjustment coefficients using May 2010 soybean futures on the Chicago Mercantile Exchange and 2010 April soybean futures on the Brazilian Mercantile Futures.

Estimate	Daily price 1/		Wednesday price 2/	
	CME closing price – BM&F closing price (col. 1)	CME opening price – BM&F closing price (col. 2)	CME closing price – BM&F closing price (col. 3)	CME opening price – BM&F closing price (col. 4)
cointegrating vector				
β_{cme}	-0.988	-0.996	-0.980	-1.009
β_{bmf}	1	1	1	1
constant ($/bu.)	-0.070	0.014	0.109	-0.150
Adjustment coefficients				
α_{cme}	0.00477	0.03209	-0.01603	-0.0289
α_{bmf}	-0.02656	-0. 00959	0.02438	0.04417

1/ There are 79 daily price observations from December 1, 2009 to March 31, 2010.
2/ There are 54 Wednesday price observations from March 18, 2008 to March 31, 2010.

Table 6. Estimated common trend coefficients and relative contribution of the Chicago Mercantile Exchange and the Brazilian Mercantile and Futures to discovering the fundamental soybean price.

Estimate	Daily price	
	CME closing price – BM&F closing price	CME opening price – BM&F closing price
$\alpha_{\perp,cme}$ 1/	5.567	0.299
$\alpha_{\perp,bmf}$ 1/	1	1
$\alpha_{\perp,cme} / (\alpha_{\perp,cme} + \alpha_{\perp,bmf})$ 2/	85%	23%
$\alpha_{\perp,bmf} / (\alpha_{\perp,cme} + \perp,bmf)$ 2/	15%	77%

1/ Common trend coefficients for the CME and BM&F. The common trend coefficient for the BM&F was normalized to equal one.

2/ Relative price discovery contribution of the CME and BM&F.

Appendix

Johansen's procedure estimates cointegrating relationships (vectors) as the eigenvectors associated with the eigenvalues for the following eigenvalue problem.

(a1) $|\lambda S_{11} - S_{10}S_{00}^{-1}S_{01}| = 0$

S_{00} , S_{11}, S_{01}, and S_{10} are the sum of squares and cross products from reduced rank regression.

Equation a1 for two cointegrated prices has one cointegrating relationship or vector. It is the eigenvector corresponding with the largest of the two eigenvalues. Hall (1989) shows how the preceding equation is solved.

Gonzalo and Granger (1995) show that the eigenvectors associated with the following eigenvalue problem can be used to estimate common trends based upon the observed prices.

(a2) $|\lambda S_{00} - S_{01}S_{11}^{-1}S_{10}| = 0$

Equation a2 for two cointegrated prices has one common stochastic trend or fundamental price. It is the eigenvector corresponding with the smallest eigenvalue for the proceeding equation.

The two equations for the same set of cointegrated prices have the same eigenvalues but different eigenvectors. We solved the preceding equation using the explanation provided by Hall.

The eigenvector for the common stochastic trend is $\alpha_{\perp,bmf}P_{bmf,t-1} - \alpha_{\perp,cme}P_{cme,t-1}$

Gonzalo and Granger show that the adjustment coefficients and common trend coefficients are orthogonal complements. The orthogonal complement relationship is shown below.

$(\alpha_{cme})(\alpha_{\perp,cme}) + (\alpha_{bmf})(\alpha_{\perp,bmf}) = 0$