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Live Cattle as a New Frontier in Commodity Markets

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Abstract. The goal of the paper is threefold. First, we present live cattle, an interesting semi-storable commodity which has not often been discussed in the literature. Second, we analyze the spot price trajectories of the US and Brazilian cattle markets over the period 2002-2013, using the first nearby Future as a proxy for the spot price. We find two distinct periods separated by a structural break in October 2007: a first period where Brazilian prices lead US prices, and a second period where both series are cointegrated. Third, in order to globally compare the two Futures markets, we introduce the notion of distance between forward curves and exhibit that not only do spot prices move together in the second period but also that the forward curves show a much higher level of integration, allowing for pair trading strategies.

***Key words*:** live cattle markets, cointegration, forward curves, distance between forward curves, pair trading.

1. Introduction

Cattle raising for meat and leather can be traced back at least 8,500 years to Europe and the Middle East. European settlers introduced cattle in the Americas at the time of Christopher Columbus. Eventually, large ranches developed from Canada to northern Mexico and from Venezuela to Argentina. Today, raising cattle for meat production takes place on a global scale. The world is currently counting approximately 1.3 billion heads of cattle. The biggest producers are the US, with 25 per cent of world production, Brazil with 20 per cent, and China and India, with 12 and 6 per cent respectively. In contrast, Africa as a whole raises only 5 per cent of world live cattle. It has a small domestic market and minimal number of exports. The largest producer in Africa is South Africa with 20 per cent of the continent's production, followed by Egypt with 10 per cent. The world top exporters are Australia and Brazil, with main export markets including the EU-27, Russia, and Chile. Interestingly, despite Australia being one of the main world exporters, it does not have a Futures market for live cattle.

As the populations in countries such as China and Brazil become richer, their appetite for meat and poultry increases. The growing middle classes in emerging countries generally desire a richer diet with higher protein content. According to the Food and Agriculture Organization, the total meat consumption per capita in emerging countries will double by 2050. Meanwhile, dietary preferences are also changing the kind of beef demanded in the US, the country with the highest consumption of beef per capita - approximately 28 kg per year - because of a more health conscious population that requires higher quality products and more information regarding the food production processes. In addition to changing diets, the economic environment affects demand for meat. For example, cheaper cuts of meat are in higher demand during times of recession. Seasons also play a role, as cuts suitable for roasts are more sought after in winter, and ground beef is more desired in warmer months for barbecues.

Cattle markets are an important matter from the perspective of food improvement worldwide. Meat production is on the minds of governments that want to offer better food to their populations. In this paper, we focus on the live cattle markets of US and Brazil, which are the most important cattle markets in the world based on size and volume of exports. An understanding of the relationship between spot and forward prices in these two regions is a worthwhile topic, which has not often been addressed in the academic literature.

The rest of the paper is organized as follows. Section 2 gives an overview of the cattle markets and their main fundamentals. In Section 3, we study the structural breaks in Brazil and US live cattle spot prices. Section 4 analyzes the relationship between Brazil and US spot prices, while in Section 5 we introduce a new approach to study their integration by considering the distance between the forward curves in the two markets, and infer some profitable pair trading strategies across the two markets. Section 6 concludes.

2. Cattle as a semi-storable commodity

The US is the largest producer of beef because of its abundance of feed grains and pasture land for cattle grazing. It is currently a net exporter of beef, although it also imports meat from Canada and Mexico, due to their proximity, and cooked beef products from Argentina and Brazil. US beef is mainly marketed as high quality cuts; grain-fed beef is primarily used for domestic and export use, while imports consist of lower quality grass-fed beef destined for processing. Hence, dietary changes, such as a reduction in the demand of products with ground beef, can result in variations in the import/export ratio. Brazil is the largest exporting country by volume and value, primarily from the sale of lower value cuts. It ranks second to the US in terms of beef production. Like the US, Brazil has a large amount of land suitable for cattle, in addition to abundant supplies of low cost feed, water, and labor.

The usual age for cattle to be categorized as live cattle is above two years, and CME and BM&F Bovespa Live Cattle Future contracts specify that the age of the livestock cannot exceed 42 months, or 3.5 years. Age is an important factor, since the tenderness of the meat decreases as age increases. Ranchers traditionally breed their cattle in summer. Calves are born in the spring following a gestation period of nine months (on average, a calf weighs 70 to 90 pounds at birth). After weaning, calves are sent to graze for up to nine months and, in this manner, gain the required weight of 650 to 850 pounds needed for transfer to the feedlot as "feeder cattle". They typically remain in the feedlot for three to four months until they reach the required weight for slaughter (1,000 to 1,300 lbs) and become live cattle (Ryan, 2012).

Producers adapt herd sizes to the costs and expected prices of beef. Traders and farmers rely on the US Department of Agriculture (USDA) for pricing. For example, at the onset of the 2013 US government shutdown, the Chicago Mercantile Exchange (CME) stated that an extended closure of government services, including public reports published by the USDA containing information on Brazilian markets, could "interrupt or delay settlement prices of live cattle futures and options" (Wall Street Journal, 2013b).

Both weather and corn price - the main feed since it is the most efficient way to fatten feeder cattle - are important price determinants of live cattle. Dry conditions on pastures and harvested forage can greatly affect early stages in the calves' development. For example, major droughts in the Farm Belt region of the US in 2011 and 2012 led to increased slaughter in order to cover costs due to affected pasture land and increased prices of feed grains (Wall Street Journal, 2013a). Reduced time in pasture due to higher feed costs leads to smaller sized cattle entering feedlots and, in turn, smaller sized cattle exiting feedlots. This results in lighter carcasses and lower average "dressed weights", typically the weight of the skeletal and meat parts of the animal. Hence, the relationship between feeder cattle, corn, and live cattle is a fundamental tool for the actors in this market.

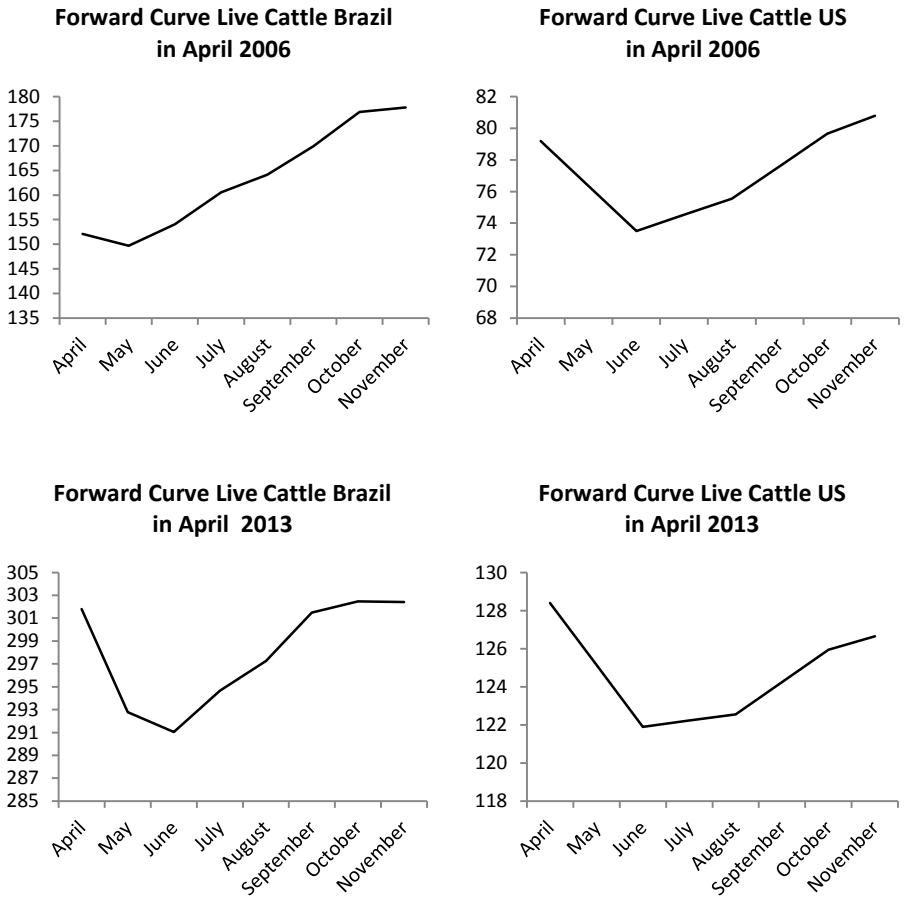


Figure 1. Forward curves from the first to 8th nearby Future contract for Brazil Live Cattle (in Reals per pound) and US Live Cattle (in US cents per pound)

Fama and French (1987) study the convenience yield of several agricultural commodities including cattle and poultry. They use the fundamental relationship between spot and Future prices:

$$F(t,T) = S(t)e^{[r(t)+c(t,T)-y(t,T)](T-t)}$$

where *F(t,T)* is the Futures price, *S(t)* the spot price, *r(t)* the cost of financing and *c(t,T)* and *y(t,T)*, the cost of storage and the convenience yield respectively; the last three terms are expressed as rates (see Geman, 2005). The theory of storage (Kaldor, 1939 and Working, 1949) implies that the difference between the Future and spot prices (they call

the 'basis') should be equal to the cost of carry (cost of financing plus costs of storage) minus the convenience yield. Following Kaldor (1949), Fama and French define the 'adjusted spread' as

$$\frac{F(t,T) - S(t)}{S(t)} = \frac{r(t)(T-t)S(t) + (T-t)c(t,T) - y(t,T)(T-t)}{S(t)}$$

and use it as a proxy for inventory to analyze the relationship between spot volatility and inventory. Geman and Nguyen (2005) validate on a database of world inventories the relationship between this adjusted spread and inventory in the case of soybeans.

Fama and French (1987) also argue that the standard deviation of the adjusted spread tells us if an individual commodity is consistent with the theory of storage, i.e., commodities that present high standard deviations are usually perishable products which are difficult to store and have seasonal variations in the convenience yield, while low standard deviations are present in commodities with no seasonality, such as metals. Analyzing a database ending in 1984, they found from the analysis of the adjusted spread of live cattle that this commodity is not very storable.

Following this approach, and in an ongoing situation of a small number of liquid maturities, we use the 6-month Future to compute the adjusted spread for the period from January 2002 to December 2013. We obtain standard deviations of 5.4 and 6.9 per cent for US and Brazilian live cattle respectively. These results are consistent with the result obtained by Fama and French of 5.6 per cent for US cattle for the period from January 1972 to July 1984. They are also in sharp contrast with commodities such as gold and silver, which present standard deviations of 2 and 1.5 per cent respectively. Hence, for all the above reasons, we can consider cattle as a semi-storable commodity.

There are other factors that affect the long-term cyclical increases and decreases in cattle numbers. This period of expansion and decline is usually referred to as the "cattle cycle", which averages 8 to 12 years and is the longest among all meat animals. In the last decade, outbreaks of Bovine Spongiform Encephalopathy (BSE), more commonly

known as Mad Cow disease, and foot-and-mouth disease (FMD) resulted in severe reductions of herd sizes. Disease is one of the biggest impediments to beef trade and can result in prolonged trade bans and restrictions. The US has suffered several outbreaks of BSE. In Brazil, the occasional presence of FMD and lower sanitary conditions in slaughter houses eventually prevent exports of fresh, chilled, and frozen beef to the US, Canada, Mexico, Japan, South Korea, and Taiwan. Increasing herd size is a slow process due to biological constraints: the time required for breeding, birth, weaning, grazing, and feedlots is relatively inelastic. For example, the retention of female animals for breeding will result in reduced beef production in the short-term. Therefore, beef production is also directly related to the slaughter mix - the number of steers (castrated bulls), heifers (non-child bearing cows), and cows from feedlots intended for slaughter. Since steers have heavier carcasses than heifers or cows, a higher proportion of steers in the slaughter mix will most likely increase average weights. The same effect of higher average "dressed weights" occurs with dairy cows, since their average weight is higher than that of beef cows. Other factors that influence the cattle cycle include governmental policies associated with food safety, animal health, labeling of cattle and red meat products according to the country of origin, and obligatory reporting of prices.

3. US and Brazil Live Cattle Spot Prices

We now turn our attention to the two largest cattle Futures markets in the world. In order to analyze spot prices of Live Cattle, we use, in a classical manner, the first-nearby Future contracts in the CME and BM&F Bovespa as a proxy (see Fig. 2).

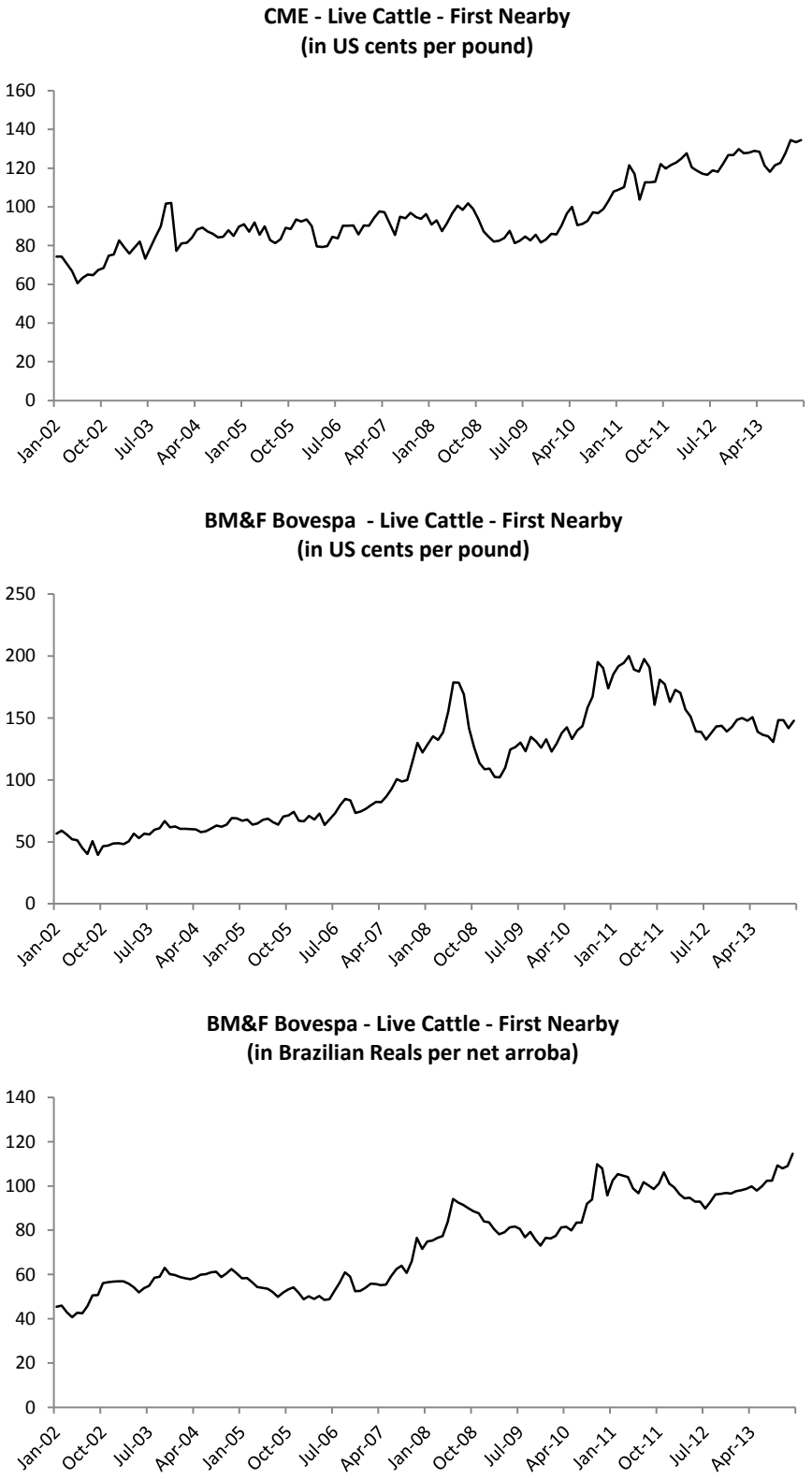


Figure 2. CME Live Cattle prices (in US cents per pound) and BM&F Live Cattle prices (in US cents per pound and Brazilian Reals per net arroba, one net arroba = 15 kg) from January 2002 to December 2013

For the purpose of investigating the existence of breaks in the trajectories, we use the Bai-Perron algorithm (Bai and Perron, 2003) for monthly log prices to identify potential break points in the time series. In other agricultural markets, Geman and Vergel Eleuterio (2013) exhibit synchronous breaks in corn and wheat prices in 2007, and a lagged one in fertilizer markets.

The US Live Cattle Market

The US Live Cattle Future contract specifies physical delivery of 55 per cent 'choice' and 45 per cent 'select' yield grade 3 live steers. Choice and select refer to the degree of 'marbling,' the amount of intramuscular fat of young cattle up to 42 months. Categories from greatest to least amount of marbling for young cattle are prime, choice, select, and standard, and for older cattle include commercial, utility, and cutter. As an estimate of the percentage retail yield, yield grade is based on carcass weight, fat thickness at the 12th rib and rib-eye area, and percentages of kidney, heart and pelvic fat. Yield grade identifies the waste fat and ranges from grade 1, the most desirable, to grade 5 being the least desirable and excessively fat. Grade 3 is the industry average.

In CME Live Cattle, we find a structural break in October 2010 with a confidence interval from September 2010 to December 2010 and a reduction in the BIC from -76.16 to -238.34 (see Fig. 3). This break occurs at a point of major change in the dynamics of the US live cattle industry, when the US changed from being a net importer to a net exporter.

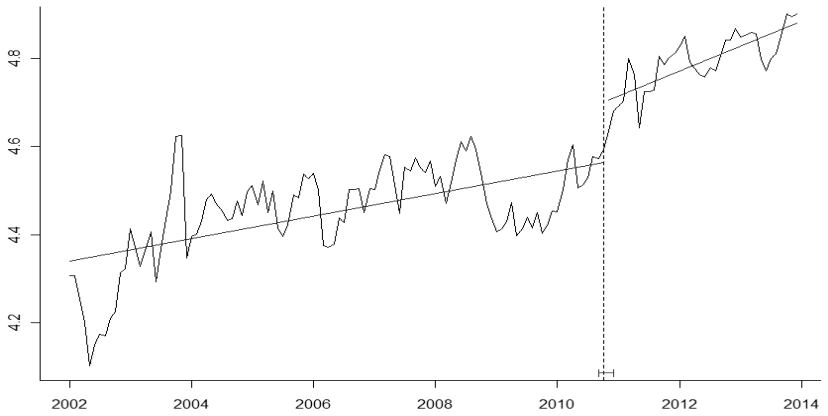


Figure 3. Structural break in CME Live Cattle log prices from January 2002 to December 2013

Upon discovery in December 2003 of the BSE illness, many countries prohibited imports of US beef. Hence, the export trade of the US, and also Canada where the BSE originated, was gravely affected. At the same time, the US beef cycle was at a low point in 2004, resulting in reduced domestic supplies of processed beef and a record high of total imports - 3.6 billion pounds according to the USDA. Herd building began in 2005 but stopped in 2006 due to drought and higher feed prices, which increased the number of cattle slaughtered throughout this period. In 2006, exports were less than half the volume of exports in 2003. It wasn't until 2007 that trade recovered, following a number of events which included the containment of BSE, the growth of global demand for US beef products, a weakening US dollar, and tight supplies in worldwide inventories. All these elements contributed to the US transition from net importer to exporter. In 2011, according to USDA estimates, US beef cattle imports continued trending downwards while exports rose to 2.79 billion pounds - 32 million pounds more than imports - establishing the country as a net exporter (USDA, 2012). With an increase in domestic herd rebuilding since 2011 and a high demand for US beef in Asian countries, the trend of the US as a net exporter is expected to remain strong throughout 2014.

The Brazilian Live Cattle Market

In contrast to the CME Futures contracts which are all physically settled, the Brazilian Futures contract traded on the BM&F Bovespa can either be physically or

financially settled and only specifies carcass weight and maximum age, compared with the CME's specification of yield grade and degree of marbling.

Due to the presence of two different currencies, we conduct the analysis of BM&F Bovespa Futures both in Reals and US dollars. For BM&F Live Cattle (in Brazilian Reals), we find a structural break in October 2007 with a confidence interval from September 2007 to November 2007 and a reduction in the BIC from 49.94 to -199.28. When we look at the BM&F Live Cattle in US cents per pound, we find a structural break in June 2007 with a confidence interval from May 2007 to July 2007 and a reduction in the BIC from 187.93 to -66.57 (see Fig. 4). The structural break in the live cattle prices in Reals can be associated with the replacement of Australia by Brazil in June 2007 as the largest world beef exporter in terms of monetary value.

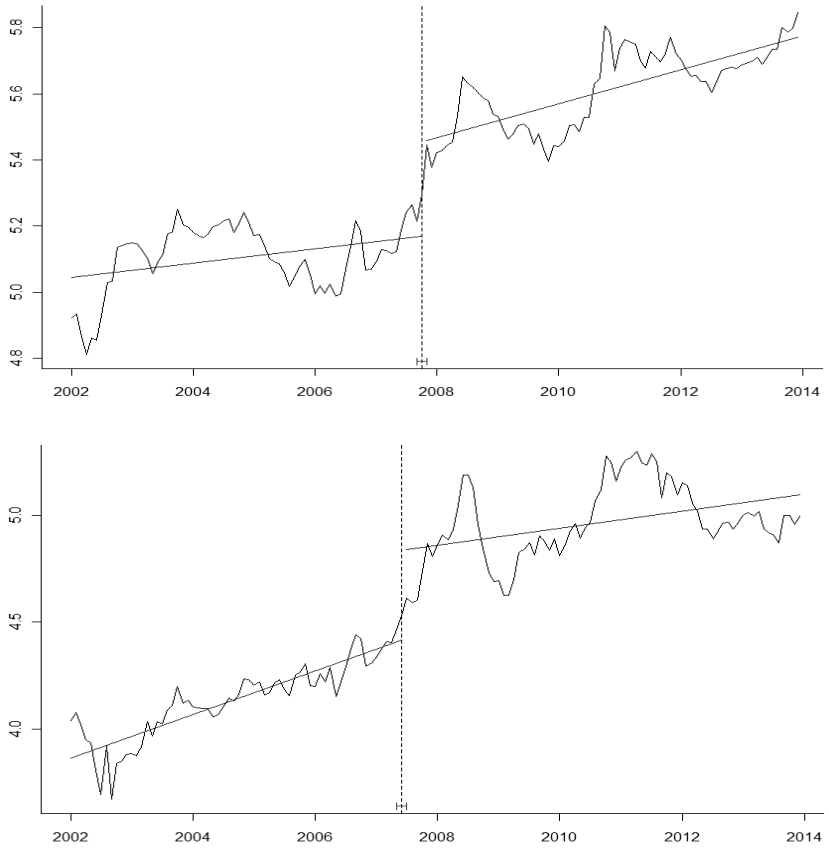


Figure 4. Top: Structural break in BM&F Live Cattle log prices (in Reals cents per pound). Bottom: Structural break in BM&F Live Cattle log prices (in USD cents per pound), from January 2002 to December 2013

It is clear from Fig. 3 and Fig. 4 that the respective structural breaks for US and Brazil live cattle prices represent points in time when prices began to move in a steep uptrend, and when both countries experienced increases in levels of exports.

From 2002 onward, the Brazilian meat industry has experienced rapid development, characterized by the introduction of a traceability system to comply with international requirements, an increase in slaughter rates from 11.6 per cent in 2002 to 24.1 per cent in 2010, and an increase in prices paid by packing plants from 1.12 USD to 3.29 USD per kilogram of beef (ANUALPEC, 2011). A rise in Brazilian exports was one of the main drivers in industry expansion. From 2002 to 2007, exports increased from 13.4 per cent to 28.2 per cent despite a marked decrease in calf production in 2007 caused by the slaughter of a large number of cows due to an FMD outbreak in 2005 (Millen et al., 2011). By 2008, the value of Brazilian exports reached 5 billion USD, twice the value of 2004. Since 2008, exports have decreased and by 2010, exports represented just 19.9 per cent of production, with 35 per cent of this percentage destined for European countries. An increase in exports to Europe was made possible by the certification of Brazilian farms in response to a 2006 ban by Europe of antibiotics in animal production, especially ionophores (growth enhancers), and the prohibition of beta-agonists.

Spot prices spread between US and Brazilian Live Cattle

We also analyze the structural breaks for the spot price spreads expressed both in dollar/cents and different currencies. In our period of study, there are two intervals where exchange rates make the spreads differ more widely, namely 2008-9 and 2012-13 (see Fig. 5).

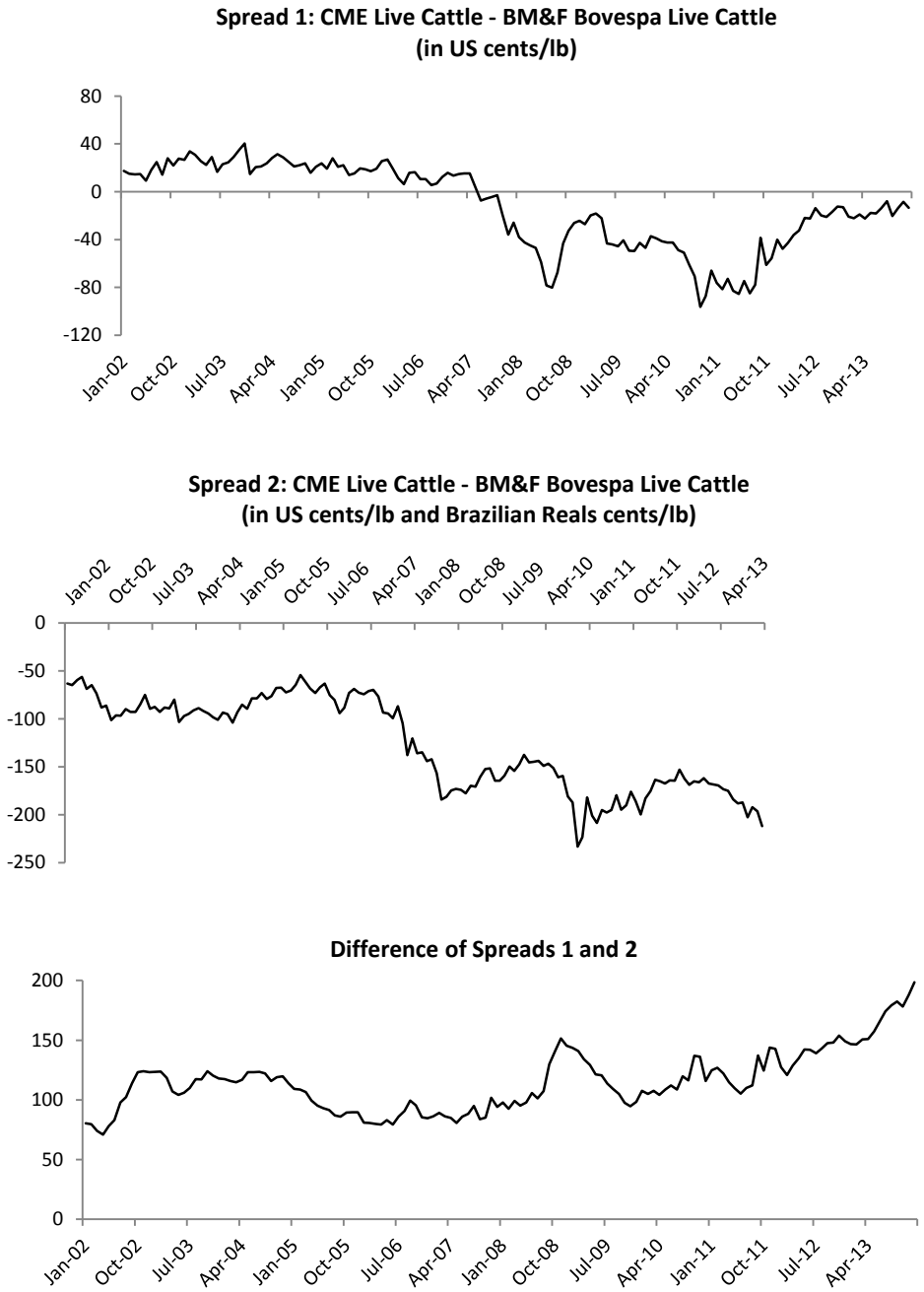


Figure 5. First Nearby spreads between CME and BM&F Live Cattle, and difference between the spreads

In the first spread, where both prices are expressed in US cents per pound, we find a structural break in September 2007 with a confidence interval from July 2007 to October 2007 and a reduction of the BIC from 1441.96 to 1255.89. For the second one, where both prices are expressed in their respective currencies, there is a structural break in October

2007 with a confidence interval from September 2007 to November 2007 and a reduction of the BIC from 1532.22 to 1259.73. Our results show a remarkable synchronicity of breaks in the two spreads, irrespective of the exchange rates. We see that, despite the changes in the value of the Real against the dollar across the period 2002-2013, all of our results so far are essentially the same regardless of the currency we employ to analyse them, exhibiting their commodity-specific nature.

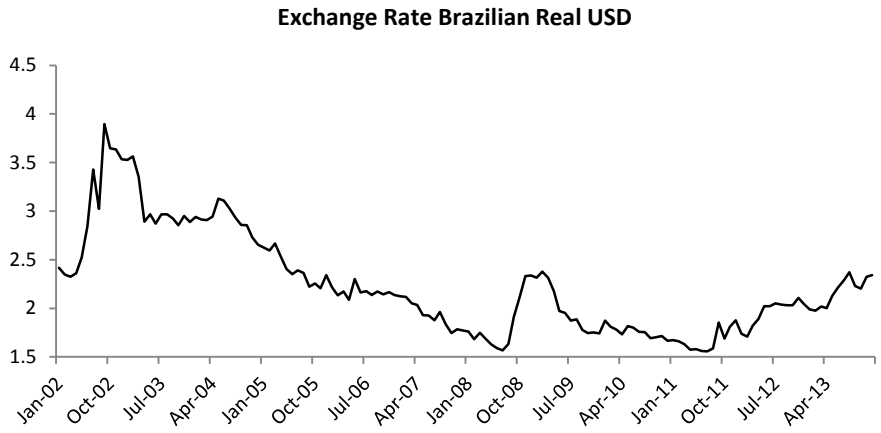


Figure 6. Exchange rate of Brazilian Reals per US Dollar, from Jan 2002 to December 2013

The reduced number of US exports - during most of the past decade the US was not a major international player – as well as the limited relations between the US and Brazil could explain why US dollars are not a significant driver in the comparison of the structural breaks. The USDA has just recently recommended the entry of Brazilian fresh beef products into the US. Therefore, factors other than currency may have a greater impact on prices, such as a restriction on exports due to health concerns. As it is well known, the depreciation of a country's currency typically makes it more competitive in the global market and helps sustain levels of exports to major importers. However, if a country is forbidden to export due to adverse production circumstances, this advantage is obviously lost.

4. Relationship between US and Brazilian Live Cattle Spot Prices

To study the relationship between the US and Brazilian live cattle markets, we perform two kinds of analyses. Firstly, we study the Granger causality on price returns. Secondly, we study the cointegration of log prices, using both the Johansen tests (1991) and the method developed by Engle and Granger (1987).

Granger Causality

Due to the necessary condition of stationarity for the Granger Causality tests (see Granger, 1969), we use price returns. In order to test Granger causality we run the regression:

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \ldots + \alpha_l y_{t-l} + \beta_1 x_{t-1} + \ldots + \beta_l x_{t-l} + \epsilon_t$$

The reported F-statistics are the Wald statistics for the joint hypothesis:

$$\beta_1 = \beta_2 = \ldots = \beta_l = 0$$

As presented in Table 1, we test all possible combinations between BM&F Live Cattle returns in Reals cents/lb, BM&F Live Cattle returns in US cents/lb, and CME Live Cattle returns in US cents/lb. Two criteria are used to select the optimal lag, the Akaike and Bayesian (or Schwartz) Criterion. In all cases, the optimal lag is lag one.

Test:	A	B	C	D
Null Hypothesis:	BM&F Live Cattle (in Reals cents/lb) do not Granger Cause CME Live Cattle	CME Live Cattle do not Granger Cause BM&F Live Cattle (in Reals cents/lb)	BM&F Live Cattle (in US cents/lb) do not Granger Cause CME Live Cattle	CME Live Cattle do not Granger Cause BM&F Live Cattle (in US cents/lb)
Whole Period	8.5022 ***	1.9668	4.8819 **	2.6353
First Period	7.4946 ***	0.8378	3.0625 *	0.82
Second Period	1.7592	1.7259	1.9528	2.0904

Table 1. Granger causality F-test results for several null hypotheses. Note: (***) Denotes significance at 1%, (**) significance at 5%, and (*) significance at 10%

In cases A and C, we reject the null hypothesis for the whole period; this implies that price returns for Brazilian Live Cattle lead the relationship between Brazilian Live Cattle/ US Live Cattle. When causality is tested the other way (cases B and D), we cannot reject the null hypothesis. Hence, there is no causality in the opposite direction, i.e., US Live Cattle returns do not lead Brazilian Live Cattle returns.

When we study causality during the periods before and after the October 2007 structural break, we observe that the causality relationship holds in the first period, i.e., the returns on Brazilian Live Cattle in Brazilian Reals lead those of US Live Cattle/Brazilian Live Cattle. However, for the relationship in US Dollars, we only have results at a ten per cent significance level. Consequently, as in the case of the whole

sample, causality is strongest when each of the variables is expressed in its respective currency.

Cointegration analysis between CME and BM&F Live Cattle Markets

Tests for cointegration are used to identify the existence of a long term relationship between variables or price series. These tests are meant to differentiate between short and long term price variations. If two series are cointegrated, they move together over an extended period of time, with fluctuations occurring over short periods. Goodwin and Schroeder (1991) run cointegration tests for several US cattle markets. They are interested in the degree of cointegration between price series of regional cattle markets and the understanding of the factors driving the relationships in regional fed cattle markets. In our study, we go one step further by analyzing international markets and identifying the factors that explain their changing relationship over time, taking into account the existing structural breaks. In order not to blur the message in this section, we will be using the variables in their own currencies.

As a preliminary step, unit root tests are conducted for each of the time series in log prices and their first differences. If both series of log prices are I(1), i.e., they have unit roots and the first difference - series is stationary, making possible the use of the Engle and Granger methodology. We test all first-nearby Futures time series for stationarity by using two standard unit root tests: the test developed by Phillips and Perron (1988) and the augmented version of the unit root test by Dickey and Fuller (1979). Using both tests, the existence of I(1) processes is confirmed in all cases, so we can proceed to test for cointegration.

Engle and Granger propose a two-step procedure to establish if cointegration exists between two series. In theory, due to the asymptotic properties of the test, the choice of dependent variable affects the regression coefficients but not the distribution of the test statistics. In practice, the procedure is repeated with each of the variables as the

dependent variable, especially for small samples and if the results are close to the critical values. In the first step, a linear regression is estimated:

$$y_t = \alpha + \beta x_t + e_t$$

Estimates from the regression are used to calculate estimated residuals,

$$\hat{e}_t = y_t - \hat{\alpha} - \hat{\beta} x_t$$

where the pair $[-\hat{\alpha}, -\hat{\beta}]$ is known as the cointegrating vector. Once the residuals are obtained, we check for cointegration by testing the residuals for stationarity. The series are cointegrated if the relationship is I(0), i.e., there is no unit root. In this case, since only two variables are involved, we can use the ordinary Dickey Fuller (DF) - we do not need to use additional lags to account for serial correlation in the time series since the DF test uses the optimal lag obtained by BIC/SIC in all cases - and run the following regression:

$$\Delta\hat{e}_t = \alpha + \beta t + \gamma \hat{e}_{t-1} + \varepsilon_t$$

We then use a t–test for γ=0 (see McKinnon, 2010).

Johansen (1991) develops a method that has clear advantages over the Engle and Granger approach. One advantage of the Johansen method is that the results are not dependent on the ordering of the variables. To illustrate Johansen's approach, we extend the standard DF test to *n* variables and write the following:

$$X_t = A_t X_{t-1} + \varepsilon_t$$
$$\Delta X_t = A_t X_{t-1} - X_{t-1} + \varepsilon_t$$
$$\Delta X_t = [A_t - I] X_{t-1} + \varepsilon_t$$
$$\Delta X_t = \pi X_{t-1} + \varepsilon_t$$

where I is the identity matrix, A_t is a matrix nxn and X_t and ε_t are $nx1$ vectors. If π has zero rank, i.e., all its elements are 0, $\Delta X_t = \varepsilon_t$ and, although all the elements are I(1), there are no linear combinations of the variables that are stationary. If π has full rank, we would have *n* linear restrictions. In general, if the rank of π is *r*, we would have *r* cointegrating equations.

Testing the number of characteristic roots that are different from zero is equivalent to testing for the rank of π. Two tests can be used: the trace test, which uses the null

hypothesis of the number of cointegrating equations being less than r against the alternative that $\lambda_{trace} = 0$, i.e., there are no cointegrating equations; and the maximum eigenvalue test, which checks if the number of equations is r versus $r+1$:

$$\lambda_{trace}(r) = -T \sum_{i=1+r}^{n} \log(1 - \hat{\lambda}_i)$$

$$\lambda_{max}(r, r+1) = -T \log(1 - \hat{\lambda}_{r+1})$$

where T is the number of observations and $\hat{\lambda}$ are the estimated values of the characteristic roots from the estimated π.

Whole Sample: from January 2002 to December 2013								
Dependent variable	**Indep. Variable**	**Intercept**	**t-ratio**	**Beta**	**t-ratio**	**R²**	**DF**	**P-value**
US Cattle	Brazil Cattle	1.725***	10.17	0.525***	16.63	0.66	-3.135	0.1
Brazil Cattle	US Cattle	-0.352	-1.02	1.259***	16.63	0.66	-2.907	0.2
First Period: from January 2002 to September 2007								
Dependent variable	**Indep. Variable**	**Intercept**	**t-ratio**	**Beta**	**t-ratio**	**R²**	**DF**	**P-value**
US Cattle	Brazil Cattle	0.794	1.46	0.711***	6.69	0.4	-4.622	<0.01
Brazil Cattle	US Cattle	2.611***	7.01	0.564***	6.69	0.401	-3.022	0.16
Second Period: from October 2007 to December 2013								
Dependent variable	**Indep. Variable**	**Intercept**	**t-ratio**	**Beta**	**t-ratio**	**R²**	**DF**	**P-value**
US Cattle	Brazil Cattle	-1.108***	-2.28	1.026***	11.86	0.66	-4.192	<0.01
Brazil Cattle	US Cattle	2.627***	10.44	0.642***	11.86	0.66	-4.042	<0.01

Table 2. Results of Engle and Granger cointegration tests.

Note: (***) Denotes significance at 1%, (**) significance at 5%, and (*) significance at 10%

	Unrestricted Cointegration Rank Test (Trace)			
Sample	**Eigenvalue**	**Statistic**	**Critical Value**	**P-value**
Whole Sample	0.025	4.824	15.495	0.83
First Period	0.13	14.36	15.495	0.07
Second Period	0.225	19.392	15.495	0.01
	Unrestricted Cointegration Rank Test (Maximum Eigenvalue)			
Sample	**Eigenvalue**	**Statistic**	**Critical Value**	**P-value**
Whole Sample	0.025	3.545	14.265	0.9
First Period	0.13	8.933	14.265	0.29
Second Period	0.225	19.147	14.265	<0.01

Table 3. Results of Johansen cointegration tests.

Note: p-values below 0.05 indicate rejection of the hypothesis of no cointegrating equations (see MacKinnon, Haug, and Michelis, 1999)

In the first period, Brazilian live cattle log prices have a significant explanatory power on US Live Cattle with a p-value of less than 0.01 for the DF test. In the second period, the relationship becomes bidirectional and the variables are cointegrated (see Table 2). These findings are not only supported by the Engle and Granger approach but

also by both types of Johansen tests (see Table 3). In the first period, Brazilian exports had a greater impact on world prices at a time when the US was a net importer. In other words, Brazil had a greater role in the price discovery of the world market, which could explain our results.

As a second step, Engle and Granger propose the estimation of an Error Correction Model. The estimation of this model allows us to establish, using first-differences, the speed of correction in the short-term, θ, while the long-term relationship is taken into account through the inclusion of the estimated residual$\hat{e}_{t-1}$:

$$\Delta y_t = \gamma \Delta x_t + \theta \hat{e}_{t-1} + u_t$$

The existence of cointegration is supported if the parameter θ is negative, which shows the magnitude of the correction in one period - one month in our case.

Below, we present the estimated values of the Error Correction Model for the second period, when the time series are cointegrated. The dependent variable is the first difference of CME Live Cattle log prices, and the two independent variables are the first difference of BM&F Bovespa Live Cattle (in Brazilian Reals per pound) log prices and the lagged estimated residuals from regression (1):

$$\Delta y_t = 0.229\, \Delta x_t - 0.115 \hat{e}_{t-1} + u_t$$

(0.105) (0.051)

The coefficient -0.115 tells us the speed at which the variables return to equilibrium after a short term shock, i.e., the value -0.115 indicates that 11.5% of the deviation of the variables from equilibrium is corrected in each month (the corresponding t-values are presented in parentheses below each estimated coefficient).

All tests agree in their results and indicate that while there is no cointegrating relationship in the whole sample and first period, there exists a cointegrating relationship in the second period. The US and Brazilian cattle markets have been expanding in recent years. In 2011, exports of US beef reached a record 2.8 billion pounds and expansion was reflected in a growing number of export destinations.

Exports to Asia have increased, especially to Japan and a growing market in Hong Kong, Russia (although a ban on US beef was initiated in February 2013), Egypt, Vietnam, and Turkey. This is a substantial development considering that export destinations in 2007 consisted primarily of five countries - Canada, Mexico, Russia, South Korea, and Japan. Furthermore, with tight global supplies and an increasing volume of Australian exports going to China, exports will continue to outpace imports for the foreseeable future and the US will remain competitive with Brazil and other major beef exporting countries. The Brazilian market has also seen great improvements in growth and productivity. Several new markets are now open to Brazil. In addition to main export destinations including Russia, Hong Kong, the EU, and Egypt, beef is now exported from Brazil into Venezuela, Chile, and Iran. Jordan, Turkey, and Congo are also expected to increase beef imports from Brazil and countries including China and Saudi Arabia, which banned imports because of a BSE episode, are expected to resume imports in 2014 (USDA Brazil Annual, 2013).

5. Analysis of the joint dynamics of Live Cattle forward curves

In the last decade, there has been a large increase in the popularity of commodities investing and the addition of commodities to investment portfolios. The classical way to gain exposure to commodities is through the use of Futures contracts (see Erb and Harvey, 2006), and their inclusion in positions held by investors makes the understanding of their dynamics of paramount importance.

Investing in asset pairs

The simplest way to gain exposure to upwards/downwards movements in a commodity spot price is to take a long/short position in a given Future contract. If the margin deposit is made of Treasuries, it gains some accrued interest, which adds to the benefit of the Futures trade.

A second and popular type of strategy is based on commodities' spreads, defined as a price difference between two commodities Futures. Traditionally, Exchanges have provided spreads of closely linked commodities for trading, such as MGEX Wheat (Hard red spring wheat – Minneapolis Exchange) and KC HRW Wheat (Hard red winter wheat – Kansas City) at the CME. As there are many different Future markets around the globe, a commodity trader can either use the spreads on offer in the Exchanges or invest simultaneously in Future contracts of two commodities in order to gain exposure to the spread.

Measures of Distance between Live Cattle forward curves

To analyze the Futures curves of live cattle in the US and Brazilian markets, we use the last trading day of each month from January 2002 until December 2013, with data from Datastream. Real-denominated BM&F live cattle Futures maturities are available every month of the year. The CME only has six maturities for live cattle Futures, with delivery months in February, April, June, August, October, and December. In order to achieve consistent data series for comparison, we interpolate the CME data to create twelve monthly deliveries, respecting the "last trading day" rules. We select only the first eight maturities for our analysis due to the lack of liquidity in the more distant ones (see Fig. 7).

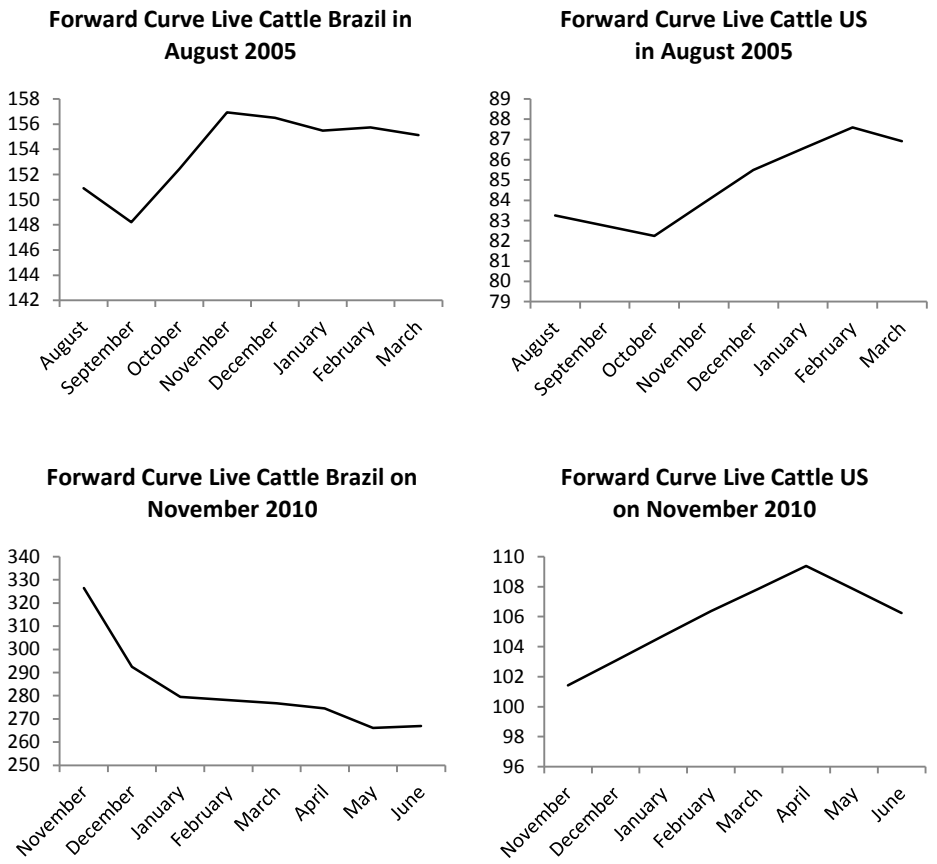


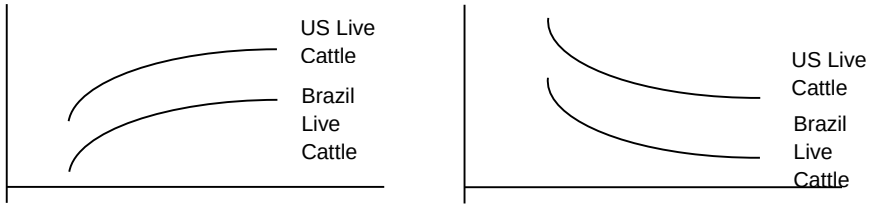
Figure 7. Forward curves from the first to 8th nearby Future contract for Brazil Live Cattle (in Reals per pound) and US Live Cattle (in US cents per pound)

We use two measures of distance that provide distinct information about the relationship between US and Brazilian live cattle Futures markets. A first measure of distance between forward curves is naturally defined as the sum of the differences between forward prices for the same maturity

$$First\ Measure\ of\ Distance = \sum_{j=1}^{8} |F_{CME\ Live\ Cattle}(t,T) - F_{BM\&F\ Live\ Cattle}(t,T)|$$

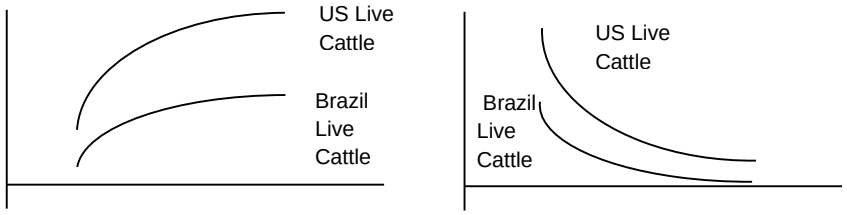
Using the distance between each forward contract has several advantages. It not only uses the first nearby but all price information available in the market. Other information can also be extracted from this measure, as exhibited in Fig. 8.

Parallel US Live Cattle and Brazil Live Cattle curves



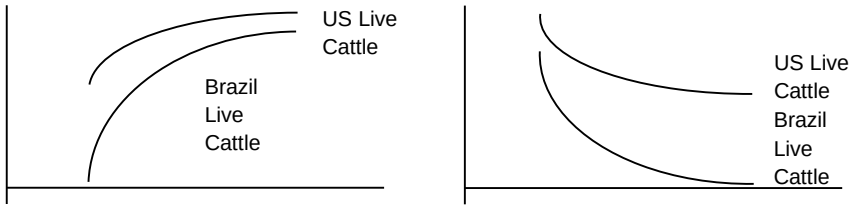
a.1. contango b.1 backwardation

US Live Cattle curve steeper than Brazil Live Cattle's



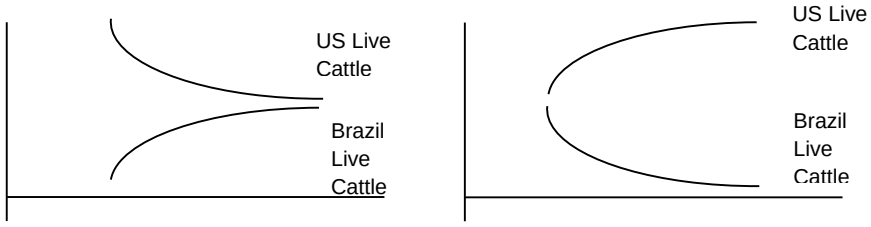
a.2. contango b.2. backwardation

Brazil Live Cattle curve steeper than US Live Cattle's



a.3. contango b.3. backwardation

Mixed shapes



a.4. Brazil contango, US backwardation b.4. Brazil backwardation, US contango

Figure 8. Hypothetical shapes of forward curves with a positive spread for US and Brazil Live Cattle

Additionally, we introduce a second measure to analyze the joint dynamics of the forward curves. This measure consists of the ratio between the normalized first distance to the absolute value of the first nearby spread:

$$Second\ Measure = \frac{1}{N}\frac{\sum_{j=1}^{N}|F_{CME\ Live\ Cattle}(t,T) - F_{BM\&F\ Live\ Cattle}(t,T)|}{|F_{CME\ Live\ Cattle}(t,1) - F_{BM\&F\ Live\ Cattle}(t,1)|}$$

where the number of maturities, N, in each forward curve is eight. If the forward curves move together, the ratio will be very close to one, indicating that the information provided by the whole forward curve is the same as the one provided by the first nearby.

We depict the first and second measure of distances for the whole period in Fig. 9. The first measure exhibits a change in level in 2007-2008, which coincides with our previous analysis of structural breaks. In order to reinforce the message conveyed by the second measure, we compute its standard deviation with a rolling window of 12 months. The standard deviation is much lower as of 2007, indicating that the forward curves in the latter period are moving together.

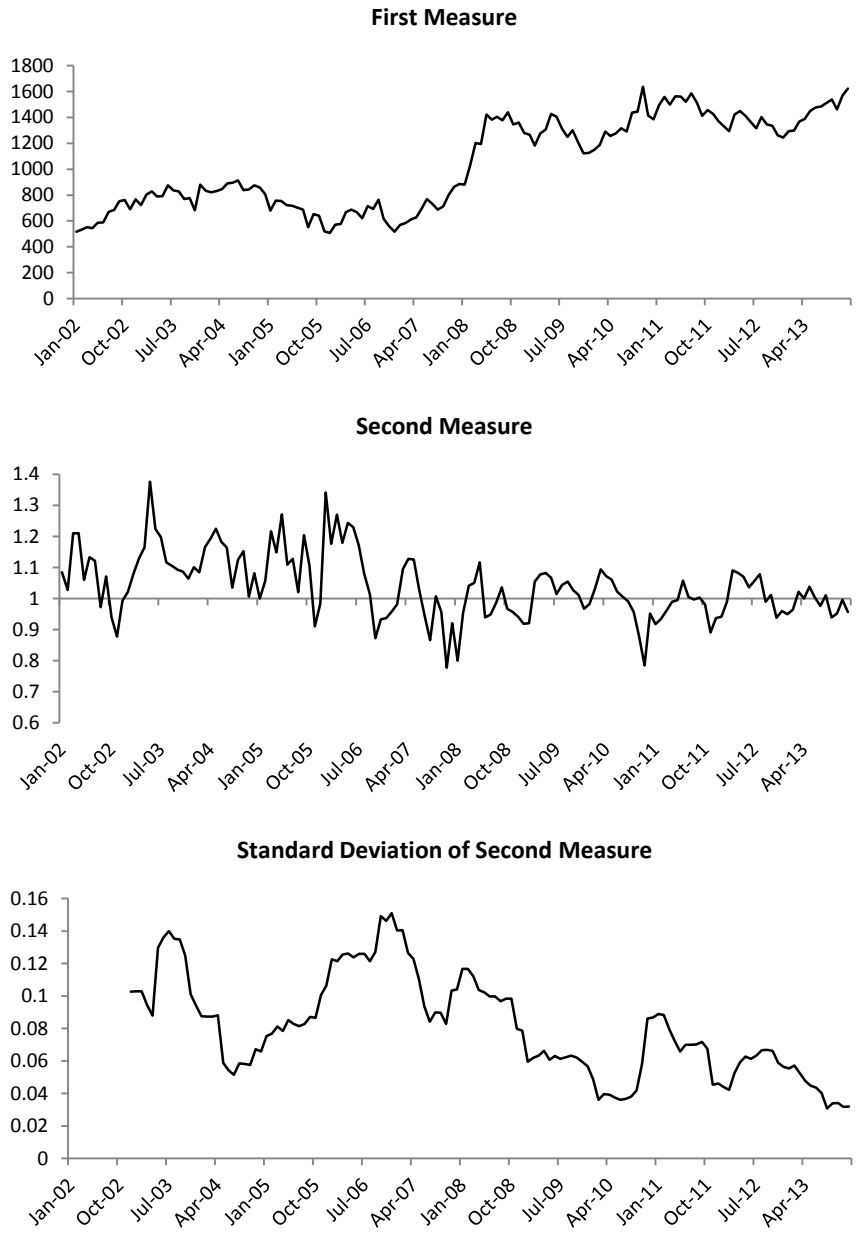


Figure 9. First Measure of Distance, Second Measure and its standard deviation with a rolling window of 12 months, from January 2002 to December 2013

Distance-based strategies

In order to illustrate the use of the first and second measures in trading, we introduce a simple trading strategy for the second period. The strategy is market neutral and consists of using the maxima and minima of the first measure, above and

below the mean respectively, as opening trading signals and the crossing of the mean as the closing trading signal. The trades are executed in the first nearby Futures. Any of the other short maturity Future contracts could also be chosen as alternative contracts, as long as they have identical maturities and exhibit similar volatilities.

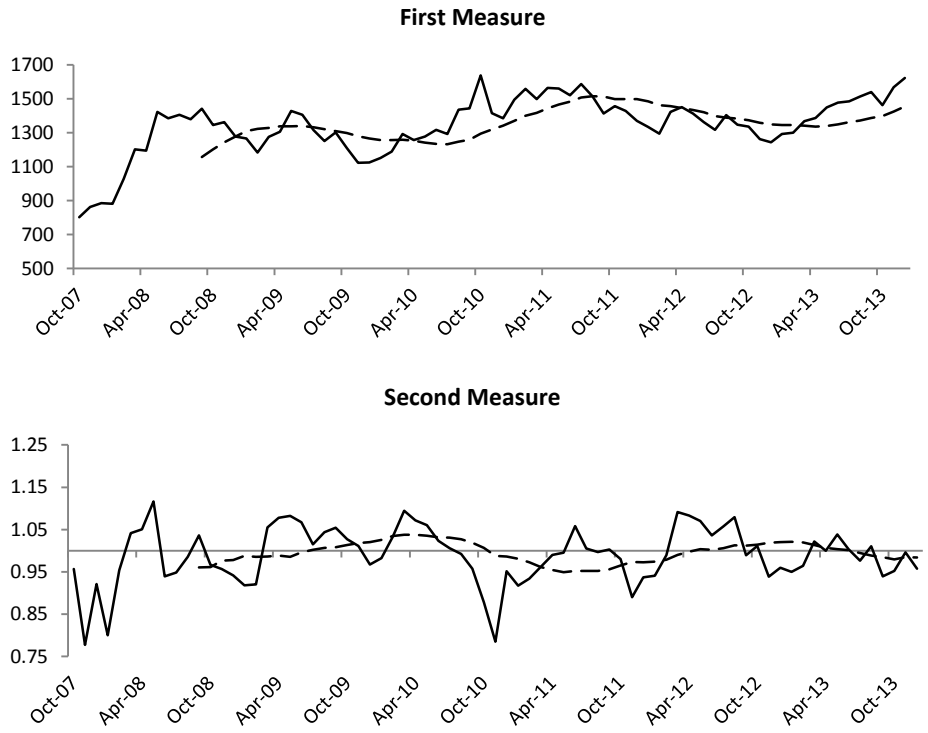


Figure 10. First and second measures of distance with their corresponding means calculated with a 12 month rolling window, from October 2007 to December 2013

We plot both measures of distance and their respective means using a rolling window (see Fig. 10). First, we study the maxima above the mean in the first measure of distance. In a mean-reverting strategy, in agreement with the exhibited integration of the two markets, when we reach a maximum in the first measure, the expectation is that the distance will decrease in subsequent periods. This means taking a long position in the spread, i.e., long CME Live Cattle, short BMY Live Cattle (the spread CME Live Cattle – BMY Live Cattle is negative throughout the period). We have thirteen long trades, ten with positive returns and three with negative returns, with a total return of

105 per cent. Apart from the first two maxima at the beginning of the sample, when prices are still transitioning from the previous state to the new one, i.e., from a higher to a lower standard deviation in the second measure, only one other long trade shows a negative return. The single most profitable trade, with a 34 per cent return, is on the 29th of October 2010, which is also the global maximum. Secondly, we study the minima in the first measure of distance that are located below the mean. When a minimum is reached, the expectation is that the distance will increase in subsequent periods. This signals taking a short position in the spread. There are seven trades, four with positive returns and three with negative returns, making a total return of -11.7 per cent. Overall, the strategy is profitable with a 93 per cent return over 63 months (5.25 years), standard deviation of 11.2, and maximum drawdown of -21 per cent (see Table 4).

Open Trade date	Position Taken	Duration of each trade (in months)	CME Returns	BMY Returns	Spread Return
30 September 2008	Long	4	-0.18	0.07	-0.11
28 November 2008	Long	2	-0.08	0.05	-0.03
27 February 2009	Short	3	0.02	0.01	0.03
29 May 2009	Long	2	0.01	0.01	0.02
31 August 2009	Short	7	-0.19	0.06	-0.13
30 November 2009	Short	4	-0.20	0.11	-0.08
31 March 2010	Long	18	0.24	-0.21	0.03
30 June 2010	Long	15	0.34	-0.18	0.15
29 October 2010	Long	11	0.23	0.10	0.34
28 February 2011	Long	7	0.11	0.06	0.17
29 April 2011	Long	5	0.11	0.03	0.14
29 July 2011	Long	2	0.34	-0.18	0.15
30 September 2011	Short	7	0.03	-0.04	-0.01
29 February 2012	Short	2	0.07	-0.02	0.05
30 April 2012	Long	1	-0.04	0.12	0.09
31 July 2012	Short	1	-0.02	0.03	0.02
31 August 2012	Long	1	0.02	-0.04	-0.01
31 December 2012	Short	3	-0.01	0.02	0.01
30 September 2013	Long	3	0.07	0.05	0.12
		Total Return:	0.87	0.06	0.93

Table 4. Summary of results for trading strategy

In summary, the first measure of distance exhibits a change of level in 2007-2008, which coincides with our previous analysis of structural breaks, while the second measure shows a lower standard deviation in the latter period, supporting the existence of cointegrating spot prices. Furthermore, the first measure gives an indication of the direction of the spread, while the second measure allows us to evaluate the amount of additional information contained in the forward curves versus the first nearby. In this way, it may allow us to identify the points in time where this relationship was broken or changed. One could use this feature of the second measure in the development of new and old trading strategies and add an extra layer of information to the first measure.

6. Conclusion

In this paper we have studied the live cattle markets, a worthwhile subject at a time when a larger number of human beings finally have access to richer diets and meat, in particular in developing countries. Analyzing the price trajectories of the first nearby contracts of the live cattle Futures traded in the US and Brazil, we find two periods, separated by a structural break in October 2007, when the relationship between US and Brazilian cattle markets greatly differs. In the first period, from January 2002 to September 2007, the US was a net importer of meat and Brazilian live cattle prices lead US Live Cattle prices. In the second period, from October 2007 to December 2013, the relationship becomes bidirectional and the variables cointegrated.

We introduce a novel approach to study the joint dynamics of the forward curves. For this purpose, we introduce two measures of distance between forward curves. These measures allow us to take into consideration the information contained in the entirety of the forward curves. Moreover, we show that these measures present different characteristics in each period, supporting our previous structural breaks

analysis and indicating that, in the second period, not only do the spot prices move together but also the whole forward curves.

Lastly, we use the property of integration of the two markets in the period 2007-2013 to devise a profitable strategy related to trading pairs of Futures contracts based on the deviation of the price spread to the mean.

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