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Abstract: The paper describes an attempt to gain insight into the relationship between cash and futures markets for US lean hogs and EU live pigs, and the opportunity of arbitrage hedging. In doing so, the authors use newer methods of threshold cointegration analysis for time series from 1999 until 2008. Besides the existence of a long-run equilibrium, asymmetric price adjustments can be demonstrated. This is especially the case for the EU live pigs, where price variations of the basis are higher and exhibit lower standard deviation. The results also perfectly show that cash prices follow the futures market more than the other way round. Furthermore, a grid search has revealed that the residual-based threshold in either market is near zero and therefore coherent with economic interpretation. Thus, at least theoretically, arbitrageurs in those markets are able to exploit the price differences between the two markets and reap no-risk monetary benefit. Hence, the results are in line with the statement that "speculating the basis" generates a better return.

Key words: futures market, pig market, risk management, threshold cointegration analysis

Producers of agricultural commodities generally are exposed to the price and production risk over time. Due to the immutable fact that price and production volatility increase the variability of revenues, many agricultural producers nowadays conceive risk management as an indispensable tool of their management strategies. One way of alleviating these risks is to engage in the commodity futures exchange markets. Moreover, the use of arbitrage hedging is a considerable tool to reap the benefits of the differences in prices between different markets. Lesser (1993) has already realized the importance of selective hedging by claiming that "selective hedging is a more complex undertaking since it requires ongoing evaluations of when to place or lift a hedge" (Lesser 1993), a task quite heavily eased by the fact that "the rational for the use of selective hedging is that, at least in the short term, the forward rate has been found to be a biased predictor of the future spot rate" (Buckley 2004). This finding leads to the work of Working (1962) and his observation that changes in futures markets somehow reflect or correlate with the changes in spot markets. In other words, future and spot markets are interconnected and the opportunity of arbitrage hedging is prevalent. Errera and Brown (2002) define arbitrage hedging as follows: "Not all changes in basis are random and unpredictable. The tendency of the basis to narrow over time at a fairly predictable rate gives rise for an opportunity for some hedges to profit consistently. *This is called arbitrage hedging.* In a carrying charge market, which is the most common for agricultural and industrial commodities, short hedgers consistently gain as the basis narrows over time and long hedgers consistently lose. The effect is for futures markets to pay all or a part of the storage costs" (Errera and Brown 2002). This quotation is in line with Castelino (2000), who shows that hedging is often a vehicle to speculate and not an instrument to reduce price risks. It is also argued that the commodity futures risk premium is associated with the producer hedging demand and the capital constrained speculation (Acharya et al. 2010).

While the goal of this article is to detect the opportunities of arbitrage hedging for the production of lean hogs in two markets, it is of utmost importance to understand the two classic views on the behaviour of commodity forward and future prices in general. Forward contracting is usually applied for *hedging* a pre-existing risk and for *speculating* on certain price movements. In essence, the *normal backwardation theory* and the *theory of storage* explain the relationship between the spot and the futures prices in commodity markets.

Keynes (1930) developed a theory postulating that speculators, who go long for a commodity future position, insist on obtaining a risk premium for hedging the spot price exposure of producers. Hence, the risk premium rises in line with the demand pressure from hedgers and consequently should be linked to the observed hedger and speculator positions in the commodity forward markets. The essence of this theory is termed *normal backwardation* and has been empirically proven by several academics, e.g. Chang (1985), Bessembinder (1992), de Roon et al. (2000).

The *theory of storage* differs from the one mentioned above in the sense that forward prices are mainly based on the optimal inventory management (e.g. Acharya et al. 2010). Basically, the theory claims that "the return from purchasing the commodity today and selling it for delivery later (the so-called basis) equals the interest forgone by storing the commodity plus the marginal storage cost less the marginal convenience yield from an additional unit of inventory" (Stronzik et al. 2008). Basically, the convenience yield is inversely related to inventories. In other words, the higher the level of stored commodities the lower the value from storing an additional unit.

However, the article at hand tries to determine the opportunity of arbitrage hedging with lean hogs, which are defined as non-storable commodities. In this case, hedging opportunities differ substantially from those for storable commodities. Generally, futures prices of non-storable commodities incorporate only market expectations of the future supply and demand conditions (Emmons and Yeager 2002). In contrast to storable commodities, non-storable commodities are characterized by the immutable fact that the quantity or quality change frequently. Hence, it is argued that future prices are considered to be a perfect forecasting tool for non-storable commodities.

Nevertheless, it must be noted that future prices of these commodities can significantly diverge from spot prices due to the changes in supply or demand. Furthermore, Benth and Meyer-Brandis (2009) have found out that "derivation of forward prices on non-storable-commodities using only information generated by the spot price is fundamentally wrong" (Benth and Meyer-Brandis 2009). In other words, the derivation of forward prices on non-storable-commodities fails to consider the forward-looking information.

While there is an evident lack of economic theory, already claimed from Carter (1999), a lot of research was done to calculate better performing hedge ratios. A very well established approach was conceived by Bond et al. (1987): $\frac{X}{Q} = \frac{Cov(P,F)}{Var(F)}$, where X is the number of contracts, Q the physical quantity, P the spot price, and F the futures price. "The ratio X/Q defines the proportion of commodity stocks that is covered by a short futures contract and is referred to as hedge ratio" (Bond et al 1987). This approach has survived until today, e.g. when Kaur and Rao (2010) determine the coherence between spot- and futures prices for four different commodities with correlation analyses. In their paper, they reveal a substantial potential for arbitrage (Kaur and Rao 2010). For the efficiency of (arbitrage) hedging strategies, a more recent evidence – with respect to decreasing losses or increasing cash flow – can be found in Manfredo and Leuthold (2001) for the Value at Risk (VaR) measure, in Coffey et al. (2000) for grain by-products and different performance measures; for a Bayesian framework that abstains from historical data in Shi and Irwin (2004); and for Soybeans in the South and – again – different performance measures in Sayle et al. (2006). However, as discussed above, Coffey et al. (2002) show that the efficiency of hedging strategies depends on the locality, i.e. the efficiency of a hedging strategy at the CME (Chicago Mercantile Exchange) may vary with the locality of the spot market. Arbitrage hedging, as it appears, promises to amend profit and market risk for commodity producers, however, the concrete performance of hedging depends on space and strategy. Against the background of these results, this paper will investigate the temporal price differences in the US and German pig markets in order to examine the evidence of arbitrage possibilities. Hence the problem statement will be as followed: *Do arbitrage hedging opportunities for non-storable commodities exist?*

US-AMERICAN AND EUROPEAN HOG MARKETS

Considerable differences between those two markets are not only manifested by the market size, but also by the applied method for price determination. The US production of pork (carcass weight equivalent) was at 10.44 million tons in 2009 (USDA 2010). Lawrence (2010) detected for the first quarter in the year 2010 that the proportion of pigs, marketed at the spot market, is not more than 20 000 to 30 000 hogs per day, or 5% to 7% of the whole market volume (17% in 2002). Packer-owned hogs, going to their own plant, represent 26% of hogs marketed, while different forms of marketing contracts accounted for approximately 60% of the market hogs sold. "The largest single market contract category is the 'hog or pork market formula', meaning that the transaction price in the contract is tied to the spot market for hogs or wholesale pork" (Lawrence 2010). This is in conformity with the statements of Chan and Lien (2001), indicating that the futures market is leading the cash market. The importance of the futures market for lean hogs at the CME is also acknowledged by the open interest, which was 97 333 in November 2010 (contract size: 40 000 pounds or approximately 18 tons).

Production of the EU-27 amounted to 22.29 million tons in 2009 (Eurostat 2010). Marketing in the most important production areas is predominantly done at the cash market, whereby the published quotes are ascertained by auction (France)[1], by announcement (Germany)[2], or by negotiation (Spain)[3]. Marketing is done corporatively by producers in Denmark (Danish Crown) and the Netherlands (Vion).

The first German futures contract for live pigs was launched in 1998 at the Warenterminbörse (WTB) Hannover, which later transformed into the Risk Management Exchange (RMX), and still suffers from a very low Open Interest (< 1000).

METHOD

The concept of cointegration has emerged as a powerful technique for analyzing the non-stationary time series and offers a sound methodology for modelling both long run and short run dynamics in a system (Chen et al. 2005). Basically, this method is based on the fact that two (or more) variables can exhibit a linear relationship to one another which is stationary, even though the variables per se are non-stationary. "This definition leads to interesting interpretations as the variables can then be interpreted to have a stable relationship (a long-run equilibrium), can be represented in an vector error-correction model, and share a common stochastic trend" (Stigler 2012).

As illustrated by Stigler (2012), the cointegration concept gained a significant interest with the so-called Granger representation theorem, which states that cointegrated variables have a vector error correction model (VECM) representation that can be seen as a vector autoregressive (VAR) model including a variable representing the deviations from the long-run equilibrium. This VECM representation is particularly interesting as it allows estimating how the variables adjust deviations towards the long-run equilibrium.

To illustrate these ideas, let X_t and Y_t denote two random variables at time t, both of which may be integrated of order one. The cointegrating relationship is defined as

$$X_t = \beta Y_t + ECT_t$$

where β, the cointegration coefficient, is estimated from the data, and ECT_t, the time-varying error correction term, captures the deviation from the equilibrium relationship between the two variables at time t. In order to ensure that the two variables are cointegrated, the distribution of ECT_t must be stationary and can thus be used as a regressor for predicting the future price changes ΔX_{t+1} and ΔY_{t+1}.

Because the impact of the error correction term on future price changes is not necessarily linear, Balke and Fomby (1997) extended the original idea of linear cointegration to the concept of *threshold* cointegration. Here, the impact of ECT_t on future price changes may vary for different values of ECT_t. This approach has received recent attention in agribusiness applications, see e.g. Peri and Baldi (2010) or Ziegelbäck and Kastner (2011).

The following equation displays a threshold vector error correction model (TVECM) with the error correction term split into two regimes (high and low). Both regimes contain distinct constants, regression coefficients and VAR(1) terms.

$$\begin{bmatrix} \Delta X_t \\ \Delta Y_t \end{bmatrix} = \begin{Bmatrix} \begin{bmatrix} c_{1L} \\ c_{2L} \end{bmatrix} + \begin{bmatrix} a_{XL} \\ a_{YL} \end{bmatrix} \\ \begin{bmatrix} c_{1H} \\ c_{2H} \end{bmatrix} \quad \begin{bmatrix} a_{XH} \\ a_{YH} \end{bmatrix} \end{Bmatrix} ECT_{t-1} + \begin{Bmatrix} \begin{bmatrix} b_{11L} & b_{12L} \\ b_{21L} & b_{22L} \end{bmatrix} \\ \begin{bmatrix} b_{11H} & b_{12H} \\ b_{21H} & b_{22H} \end{bmatrix} \end{Bmatrix} \begin{bmatrix} \Delta X_{t-1} \\ \Delta Y_{t-1} \end{bmatrix} + \begin{Bmatrix} \begin{bmatrix} \varepsilon_t^{XL} \\ \varepsilon_t^{YL} \end{bmatrix} \\ \begin{bmatrix} \varepsilon_t^{XH} \\ \varepsilon_t^{YH} \end{bmatrix} \end{Bmatrix} \qquad ECT_{t-1} = (1, -\beta) \begin{bmatrix} X_{t-1} \\ Y_{t-1} \end{bmatrix}$$

[1]Approximately 80 000 hogs are placed at the Marché du pork Breton (Plerin) per week. This represents around 10% of the total French market volume. The average price of this video auction is published (www.marche-pork-breton.com).
[2]25 producer organizations submit their anticipated subjective trading price for the following week. The median is published as a reference price. Vereinigung der Erzeugergemeinschaften für Vieh und Fleisch e. V. available at www.vezg.de.
[3]Representatives of producers and processors agree on an equilibrium price for a week, based on the evident supply and demand numbers. Available at www.mercolleida.com.

The practical importance of cointegration models for the financial time series derives from the fact that while the correlation analysis of *returns* serves as the traditional starting point for the portfolio risk management, cointegration is also based on the *raw price*. "Since high correlation alone is not sufficient to ensure the long-term performance of hedges, there is a need to augment standard-risk modelling methodologies to take account of common long-term trends in prices. This is exactly what cointegration provides. It extends the traditional models to include a preliminary stage in which the multivariate price data are analyzed, and then augments the correlation analysis to include the dynamics and causal flows between returns" (Alexander 1999). Based on the elaboration mentioned above, we will apply the threshold cointegration model to our data in order to detect hedging opportunities within hog markets in Europe and the USA.

EMPIRICAL ANALYSIS

The sample under study consists of data for live pigs contracts at the Risk Management Exchange (RMX) Hannover, and contracts for lean hogs at the Chicago Mercantile Exchange (CME). The data base was arranged according to the one-month (nearest) maturity daily closing prices and it covers the period from January 04, 1999 to December 30, 2008[4]. Prices are given in Euro per 1 kg, respectively in USD per 1 pound and have been converted to natural logarithms for a further exploration. Closing prices of each trading day are combined with the respective spot prices of the German "Vereinigungspreis"[5] (2518 data points) and the CME Lean Hog index[6] (2524 data points).

We start our analysis by conducting a Phillips-Ouliaris test for the two markets, implemented in *R* as po.test in the package tseries by Trapletti and Hornik (2011). Both for the US and the European market, we find highly significant evidence (p-value << 0.01) against the null hypothesis that either time series is not cointegrated. Furthermore, we test the null of linear cointegration against the threshold cointegration, following Hansen and Seo (2002), implemented as the TVECM.HSTest in the package tsDyn by Stigler (2012). Here, we obtain highly significant evidence (bootstrap p-value << 0.01) against the linear cointegration for the US market, and strong evidence against the null for the European market with a p-value of 0.042. These results show that both the US and EU market most likely depict nonlinear cointegration features, causing an asymmetric behaviour.

Estimation of the TVECM coefficients with two regimes is conducted using TVECM() in tsDyn, which yields an estimated cointegration coefficient of β = 0.996 for the US lean hogs and β = 0.993 for the EU live pigs. Thus, the rounded error correction term for both markets simplifies to the difference between the cash and futures price at time t,

$$\mathrm{ECT}_t \approx \mathrm{Cash}_t - \mathrm{Future}_t$$

The estimated TVECMs are presented below, whereas the threshold between high and low regimes is determined by minimizing the sum of squared residuals. The corresponding p-values are given in the parentheses.

US Lean Hogs

Regime 1 (low, $ECT_t < 0.012$, 50% of all cases)

$$\Delta Cash_t = 0.001_{(0.001)} - 0.023_{(<0.001)} ECT_{t-1} + 0.731_{(<0.001)} \Delta Cash_{t-1} + 0.042_{(<0.001)} \Delta Future_{t-1} + \varepsilon_t^{XL}$$

$$\Delta Future_t = 0.001_{(0.151)} + 0.016_{(0.0254)} ECT_{t-1} - 0.018_{(0.737)} \Delta Cash_{t-1} + 0.051_{(0.083)} \Delta Future_{t-1} + \varepsilon_t^{YL}$$

Regime 2 (high, $ECT_t \geq 0.012$, 50% of all cases)

$$\Delta Cash_t = -0.001_{(0.011)} - 0.016_{(<0.001)} ECT_{t-1} + 0.762_{(<0.001)} \Delta Cash_{t-1} + 0.055_{(<0.001)} \Delta Future_{t-1} + \varepsilon_t^{XH}$$

$$\Delta Future_t = -0.002_{(0.144)} + 0.030_{(0.054)} ECT_{t-1} + 0.131_{(0.044)} \Delta Cash_{t-1} + 0.050_{(0.098)} \Delta Future_{t-1} + \varepsilon_t^{YH}$$

EU live pigs

Regime 1 (low, $ECT_t < -0.005$, 40.1% of all cases)

$$\Delta Cash_t = -0.002_{(0.013)} - 0.133_{(<0.001)} ECT_{t-1} + 0.001_{(0.964)} \Delta Cash_{t-1} + 0.167_{(<0.001)} \Delta Future_{t-1} + \varepsilon_t^{XL}$$

$$\Delta Future_t = -0.002_{(0.055)} + 0.037_{(0.100)} ECT_{t-1} + 0.003_{(0.917)} \Delta Cash_{t-1} + 0.145_{(<0.001)} \Delta Future_{t-1} + \varepsilon_t^{YL}$$

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[4]The contract specifications have changed in 2009, therefore the time series were cut at this time point.

[5]The Central-European Lean Hog Index is only available since 2005, therefore, a leading German spot price was chosen.

[6]Lean hog futures contracts are cash-settled to the CME Lean Hog Index, a two-day weighted average of the United States Department of Agriculture (USDA) cash prices for the producer-sold swine or the pork market formula transactions.

Regime 2 (high, $ECT_t \geq -0.005$, 59.9% of all cases)

$$\Delta Cash_t = 0.001_{(0.003)} - 0.130_{(<0.001)} ECT_{t-1} + 0.014_{(0.592)} \Delta Cash_{t-1} + 0.095_{(<0.001)} \Delta Future_{t-1} + \varepsilon_t^{XH}$$

$$\Delta Future_t = 0.001_{(0.232)} + 0.063_{(<0.001)} ECT_{t-1} + 0.049_{(0.111)} \Delta Cash_{t-1} + 0.128_{(<0.001)} \Delta Future_{t-1} + \varepsilon_t^{YH}$$

The threshold for the error correction term in each market lies around zero, which in essence means that the "low" regime (1) roughly corresponds to the periods when the cash price is lower than the futures price. Vice versa, the "high" regime (2) corresponds to the periods when the cash price is higher than the futures price. This threshold divides the US market into two equally sized states, while the EU market is split in the ratio of 4 : 6. Figure 1 shows the price spreads between the cash and futures markets and the distribution of scenarios along the time axis, indicated by solid dots on the bottom of the graph. A "low" dot corresponds to the first regime; a "high" dot corresponds to the second regime. Note that the regimes in the US market tend to be slightly more stable over time than those in the EU market, which switch more frequently. Looking at the vertical axis, it can be recognized that the volatility of deviations between the cash and futures market is larger in the US (sd = 0.069) than in the EU (sd = 0.034).

Investigating the estimated TVECM coefficients for the US market reveals several insights: Firstly, we observe that the cash market is statistically significantly predictable in both regimes. We expect a positive change in the lean hog price when observing a positive change in the futures price the day before, and we also observe a noticeably strong autocorrelation (i.e. the dependence of $\Delta Cash_t$ on ECT_{t-1}). The dependence of $\Delta Cash_t$ on ECT_{t-1} is highly significant in both regimes while being slightly stronger in regime 1. This means that the cash price of the US lean hogs is drawn towards the long run equilibrium in both regimes, however, a somewhat stronger in times of a comparably low cash value. Secondly, while observing a similar tendency for the futures market, we see a strikingly less correlation on the past values. Observing the dependence of $\Delta Future_t$ on ECT_{t-1}, we find positive regression coefficients, indicating again a tendency towards the long run equilibrium. Notice, however, that when the futures price is comparably high (regime 1), this tendency is clearly not significant. Interestingly, an evident asymmetry effect in the terms of dependence on $\Delta Cash_{t-1}$ is present: While there is hardly any effect of the past cash price changes in regime 1, this effect is significantly present in regime 2. Thus, the past changes in cash price seem to affect the futures prices in this market mainly if the cash price is "leading", i.e. high in comparison to the futures price. These results imply that the prices for US spot lean hogs follow the CME futures contract market more than the other way round. A trend towards the long-run equilibrium can clearly be seen in both markets, its strength, however, differs and also exhibits an asymmetry with respect to the two regimes.

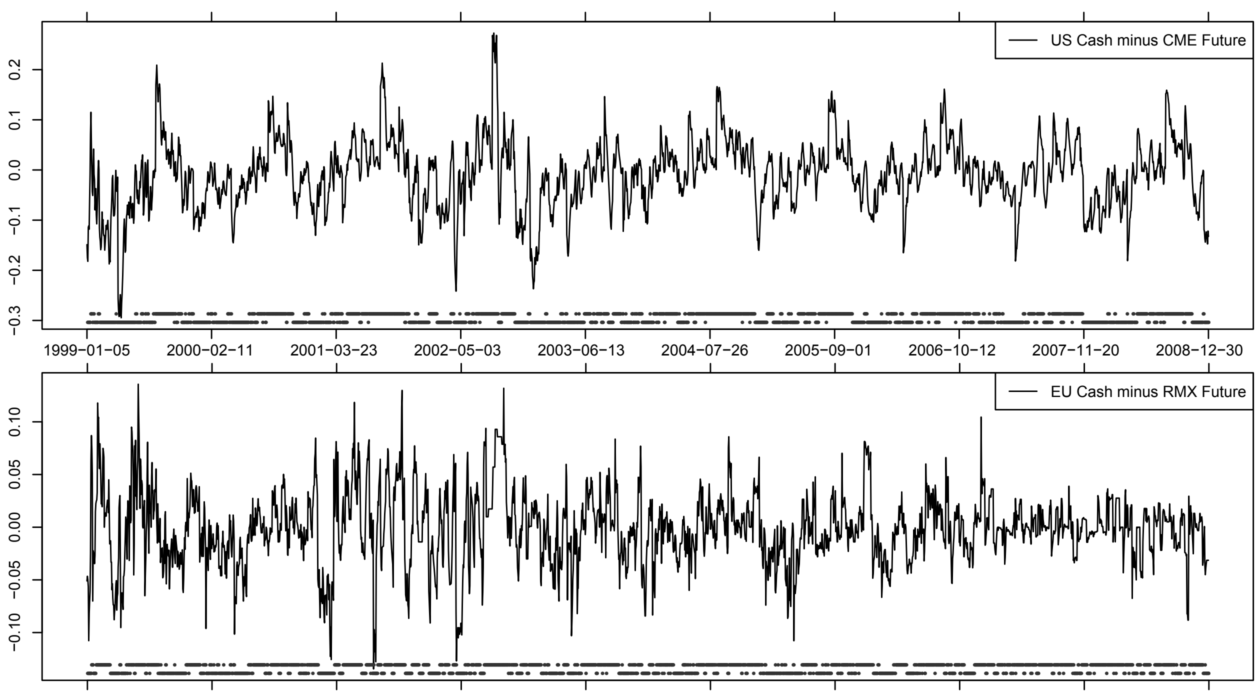

Figure 1. Spread between the cash and futures market

In the European market, a similar overall picture can be observed – note that the signs of all statistically significant coefficients (excluding constants) are the same. As before, we see a tendency towards the long run equilibrium for both series, with an asymmetric behaviour in the futures market. Here, the dependence of $\Delta Future_t$ on ECT_{t-1} in regime 2 amounts to almost twice the value in regime 1. This means that the error correction term is "pulling the futures price back up" more strongly when this price itself is low. Also, we see striking evidence that the futures market leads the cash market in both regimes, with the effect size being more pronounced in regime 1. Nevertheless, some noticeable differences exist: Firstly, neither the cash nor the futures price changes depend significantly on $\Delta Cash_{t-1}$. This is, however, not surprising, since the cash prices for live pigs in the EU are fixed for a whole week and thus obviously do not serve as good predictors. Secondly, $\Delta Future_{t-1}$ serves as a highly significant predictor for all price changes in both regimes, meaning that the EU futures market exhibits a stronger autocorrelation than its US analog.

CONCLUSION

Applying a threshold cointegration model, we have shown that a long-run equilibrium between the cash and futures markets for the US lean hogs market and the EU live pigs markets exists. Furthermore, we have demonstrated that certain asymmetric movements occur between these price-pairs. A tendency of the cash and futures prices to push towards each other at a fairly predictable rate can be observed, which gives rise to an opportunity to hedgers to obtain better results. Grid search has revealed that the residual-based threshold in either market is near zero in both cases and thus coherent with the economic interpretation. These results have been statistically significant. The paper shows that the opportunity of arbitrage hedging is prevalent. Thus, provided that the trading costs are low enough, arbitrageurs are able to exploit the price differences between the two markets and to reap a no-risk monetary benefit. The authors further point out strong indications that the futures market drives the spot market in both the US and the EU with a varying intensity.

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