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Wholesale Beef Futures Contract

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Wholesale Beef Futures Contract

In this research, we develop methods to derive a price series that is theoretically sound for a hypothetical futures contract. We extend a futures valuation model to provide a valuation for a hypothetical futures contract. One such hypothetical contract that has been suggested as a possible solution to recent problems in live cattle futures is the wholesale beef futures contract. We present two different methods for generating the term structure of the hypothetical futures contract. The results show that both methods perform very well. The methods developed here are tested for validity using futures markets for hogs and cattle and are found similar in accuracy to a futures valuation model for existing futures. We also use the derived price series for the hypothetical wholesale beef futures contract to evaluate and compare its effectiveness as a risk management tool to the existing live cattle futures.

Keywords: prices, commodity prices, cattle, futures valuation

Introduction

The Chicago Mercantile Exchange's (CME) Live Cattle (LC) futures contract has been subject to recent criticism over extreme levels of volatility and basis issues (Gee 2016). LC contract issues are occurring at the same time as negotiated live cattle transactions are becoming scarce in the cattle industry. The negotiated live cattle market has been thinning in favor of formula and grid pricing methods (USDA-AMS 2001-2016). Negotiated pricing arrangements use a price that is negotiated between buyer and seller. Formula pricing arrangements use a price that is determined by a function of some reported price such as the nearby live cattle futures price or the boxed beef cutout value. Grid pricing arrangements use a price determined by the quality of the carcass itself through premiums and discounts off some base price. The base price used in grid pricing arrangements can be a negotiated or formula price.

In February of 2016, the CME addressed the concerns over the extreme volatility and attempted to ameliorate some of the volatility of the contract. The CME eliminated almost three hours of trading time in the afternoon when only 13 percent of trades occurred. The CME also acknowledged that volatility is driven at least in part by the lack of negotiated cash transactions which are obstructing the price discovery process (CME Group 2016).

Basis variability in the live cattle futures contract has also been increasing recently. Figure 1 shows the basis of the live cattle futures contract between 2006 and 2016. The figure shows that basis has been especially volatile since 2014, highlighting the issues related to the effectiveness of the live cattle futures contract as a risk management tool.

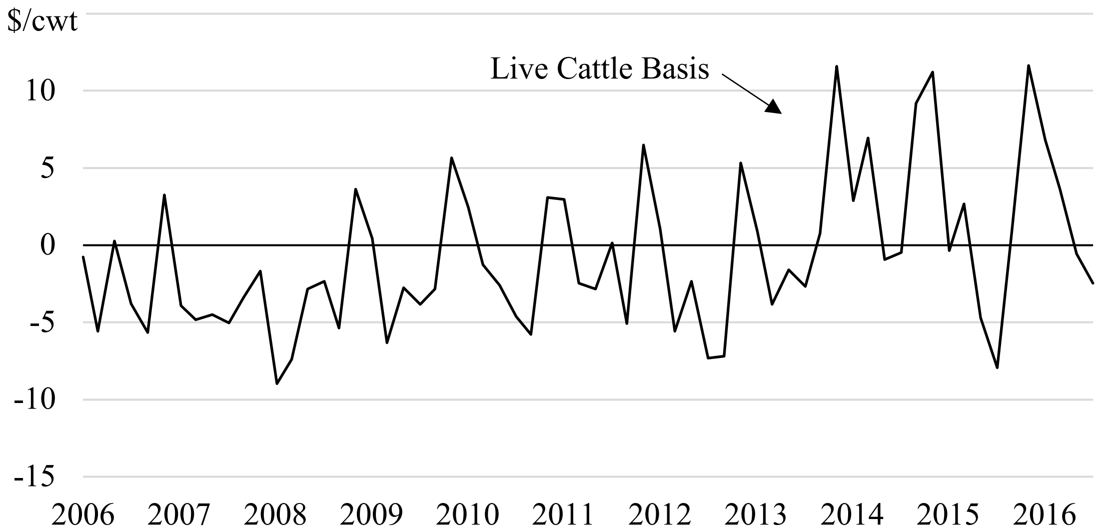

Figure 1. Live cattle basis between 2006 and 2016

Note: The basis shown is the 5 market average spot price for steers minus the live cattle futures contract's price that is 3 weeks from maturity.

Ward et al. (2003, p. 1) estimated that in 1996 "82 percent of fed cattle were marketed on a live or carcass-weight pricing method and 16 percent were sold using grids". By 2016, according to the United States Department of Agriculture (USDA) Agricultural Marketing Service (AMS) Grain Inspection, Packers and Stockyard Administration (GIPSA), 25.46 percent of cattle were marketed on a live or carcass weight method and 62.62 percent of cattle were marketed on a formula or grid (USDA-AMS 2016).

When grid pricing with a downstream market price as a base price the effectiveness of the LC futures contract as a risk management tool is degraded (Harri et al. 2009). Specifically, the ability to manage risk is reduced because downstream market price movements do not follow live cattle futures price movements as closely as live cattle prices do. However, using a downstream market price such as the boxed beef cutout value in live cattle marketing arrangements is recommended by previous research (Harri et al. 2009; Kovanda, Schroeder and Wheeler 2004; Schroeder et al. 1997; Ward et al. 2003; Ward and Butcher 2001; Ward, Schroeder and Feuz 2002). Using a downstream market price is beneficial to producers because of the improvement in signals from wholesale markets and because packers have an economic incentive to keep prices high. However, producers that might be considering the use of grid pricing systems with a downstream market price as a base price face a dilemma. The benefits of using a grid pricing system with a downstream market price as a base price are accompanied by a cost of reduced ability to manage price risk.

One possible solution is to introduce a futures contract based on a downstream market price that aligns with recommended marketing practices. One such price is the boxed beef cutout value (BBCV). The introduction of a futures contract on the BBCV could provide an effective price risk management tool for firms using the boxed beef cutout value as a base price. Schroeder and Yang (2001) and Mattos et al. (2003) considered the possibility of a futures contract based on a downstream market price for price risk management in wholesale beef cuts. To derive a price series for this hypothetical BBCV futures contract both Schroeder and Yang (2001) and Mattos et al. (2003) assumed the futures price was equivalent to the BBCV index, or spot price of the commodity. This restrictive assumption was made because there was no data available for such a hypothetical BBCV futures price series. Under the assumption that the spot price of a commodity follows some process that can be defined, a relationship between the spot price and futures price that depends on the time left to maturity of the futures contract can also be defined. In this case, the complete term structure of futures prices for all maturities can be derived. The assumptions made by Schroeder and Yang (2001) and Mattos et al. (2003) do not allow for this relationship, which limits any interpretations of the price series for the BBCV futures contracts. There have been no other attempts to derive a price series for a futures contract based on the BBCV.

The first objective of this research is to develop methods to derive theoretically based price series for a hypothetical futures contract and test the accuracy of these methods. To test the methods developed, we use futures markets for hogs. The live hog futures contract was replaced by the lean hog futures contract with the release of the February 1997 lean hog futures contract. The change from live to lean hog futures occurred because the most widely used marketing arrangements in 1996 were using carcass weight prices instead of live weight prices. The price of a live hog futures contract was specified in pounds of live hogs and the price of a lean hog futures contract is specified in pounds of lean carcass weight. The live hog futures contract is similar to the live cattle futures contract in that they are both tied to the live weight price of the commodity, and the lean hog futures contract is similar to the hypothetical BBCV futures contract we are proposing in that they are both tied to carcass weight prices. Moreover, the change in futures contract in the hog markets is very similar to the change proposed in the cattle markets. We can use the overlapping observations available in live and lean hog futures markets to test the accuracy of our methods. There is a period between 1995 and 1997 in which both live hog futures and lean hog futures are trading, so using my methods and the observations available from live hog futures prices we can derive a price series for a "hypothetical" lean hog futures. We then compare the derived lean hog futures prices with the lean hog futures prices observed during this period to evaluate the accuracy of my methods.

The second objective is to use the methods developed in objective two derive a theoretically based BBCV futures price series and evaluate its effectiveness as a risk management tool for the beef industry. We use regression methods to determine the effectiveness of BBCV futures as a hedging instrument of various stages of the industry.

Given the recent problems in live cattle futures, a BBCV futures contract has the potential to benefit the buyers and sellers of live cattle and wholesale beef cuts by providing them with a better risk management tool. Therefore, the evaluation of this hypothetical BBCV futures contract has serious implications for the beef industry. This has the potential to benefit the CME as well, as a better product for risk management could result in more trading volume. Also, this is just one application of the methods we develop to derive a hypothetical futures contract. The methods we develop here could be extended to evaluate other proposed futures contracts in other markets.

In this chapter, we have described the recent problems with the live cattle futures and discussed a possible solution, the offering of a BBCV futures contract. In the next chapter, we review the relevant research to the problems in live cattle markets and the methods we develop to derive the hypothetical BBCV futures contract price series. In the third chapter, we discuss the conceptual framework used to derive a hypothetical futures contract. In the fourth chapter, we discuss the empirical methods used to derive the price series of a hypothetical futures. In the fifth chapter, we discuss the data used to complete the objectives of this research. In the sixth chapter, we present the results of this research. Finally, in the seventh chapter, we provide conclusions and implications.

Literature Review

The first section of the literature review discusses the pricing methods used in fed cattle and how those pricing methods have changed recently. The second section addresses the price discovery process and issues with negotiated cash prices. The third section addresses problems in the existing live cattle futures contract and previous research on a proposed boxed beef futures contract. The last section discusses previous research that studies the relationship between cash prices and futures prices.

Pricing Methods

Pricing methods in the cattle industry are complex and there is no standard pricing system that the industry primarily uses as a whole. There are two main categories that these pricing methods fall under, live/dressed weight pricing and formula/grid pricing.

Live/dressed weight pricing is the traditional system of pricing which used to account for the overwhelming number of transactions in the industry (Schroeder et al. 2002; Schroeder et al. 2003). For this reason the Chicago Mercantile Exchange (CME) live cattle futures contract is based on the live cattle price. In live weight and dressed weight pricing the same price is paid per pound for all cattle or all similar cattle at the transaction.

There has been a trend away from live or dressed weight, also known as negotiated, cattle transactions toward grid and formula transactions. Schroeder et al. (2002) conducted surveys in an attempt to show the direction the industry was moving with respect to marketing arrangements and reported that in 1996, 82.3 percent of cattle were marketed on a live or carcass weight price and 15.6 percent were marketed on a grid system. By 2001, 52.5 percent were marketed on a live or carcass weight method and 45.4 percent were on a grid system. The survey also estimated that by the year 2006, the percentages would be 33.1 and 62.1 respectively.

The USDA-Agricultural Marketing Service (AMS) Grain Inspection, Packers and Stockyard Administration (GIPSA) began mandatory price reporting in 2001 where pricing methods reported are either negotiated, negotiated grid, formula, or forward contract. The pricing method data reported by GIPSA are presented in figure 2, where it is shown that the industry has slowly reduced the amount of negotiated pricing methods used from 2001 to 2016. The reduction in negotiated pricing has been replaced by an increase in formula pricing. The actual amount of the industry that has adopted grid pricing is difficult to determine with the available data provided by the GIPSA, because of the categories of pricing methods reported. Negotiated grid pricing methods reported is the only category that is definitely grid pricing. However, many formula prices are also used in grids. Therefore, we can assume that the actual percent of grid pricing used can be found somewhere between the percent of negotiated grid and the percent of negotiated grid plus the percent of formula. In 2016 that was somewhere between 4.36 and 62.62 percent. In 2016 only a minority (25.46 percent) of the domestic cattle industry still used negotiated live or dressed weight pricing methods (USDA-AMS).

Figure 2 shows how the industry has moved away from negotiated live and dressed weight pricing in favor of formula and grid pricing. This has an important implication. The number of negotiated cash transactions has thinned significantly. Therefore, the negotiated cash price may not accurately represent the underlying value of the commodity (Koontz 2016; Schroeder and Mintert 2000). The live cattle futures price is also based on the underlying value of the commodity. This increase in uncertainty about the value of the underlying commodity has contributed to the increases in volatility and basis risk in live cattle futures.

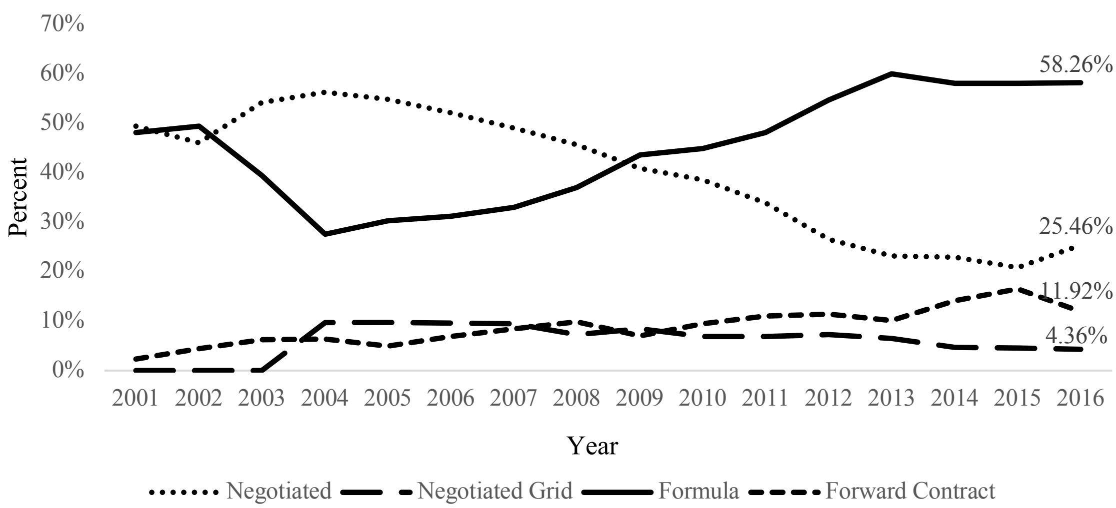

Figure 2. National Slaughter Cattle Domestic Marketing Arrangements

Source: USDA-AMS

Koontz (2016) found that the majority of price discovery information comes from live cattle futures. Koontz (2016) performed a study on the cash fed cattle prices with an objective of answering the question “how thin is too thin” (Koontz 2016, p. 1). Koontz (2016) concluded that reductions in volume of negotiated cash transactions resulted in less price discovery by those cash markets. More concerning are the implications of this as negotiated cash transactions are expected to continue to decline into the future. Results regarding transactions from Koontz (2016, p. 30) shows that even as negotiated cash transactions have become scarce, the number of transactions that happen are still sufficient for accurate pricing. However, they are converging with the number of transactions that need to occur for accurate pricing and if negotiated cash transactions continue to decrease there will be errors larger than 50 cents/cwt in the price.

Live Cattle Futures and Boxed Beef Futures

The previous section has made apparent the issues with the negotiated live cash price. However, producers seeking to market by using different prices, for example the boxed beef cutout value, might be discouraged as there is no futures contract for boxed beef. Therefore, producers face a price risk trade-off in marketing cattle on a grid with a downstream market price as a base price (Harri et al. 2009). To solve this dilemma faced by producers, previous research has investigated the possibility of a boxed beef futures contract. Using the wholesale boxed beef price as a base price has often been advocated in previous research (Harri et al. 2009; Kovanda, Schroeder and Wheeler 2004; Schroeder and Mintert 2000; Schroeder et al. 1997; Ward et al. 2003; Ward and Butcher 2001; Ward, Schroeder and Feuz 2002). A futures contract on boxed beef could allow producers to both avoid negotiated cash pricing issues and effectively mitigate price risk.

Previous research on hedging the price risk in grid pricing systems (Riley 2004; Harri et al. 2009) questioned the efficacy of the live cattle futures contract when using grid pricing, especially when the base price is linked to downstream markets such as the boxed beef cutout value. A solution to this problem could be a futures contract that follows the structure of pricing methods more closely than the existing live cattle futures contract. Many economists have suggested a boxed beef cutout value (BBCV) futures contract as the solution to this problem (Mattos et al. 2003; Schroeder and Yang 2001; Riley 2004; McDonald and Schroeder 2003; Harri et al. 2009).

Harri et al. (2009) investigated price risk management in value based marketing of fed cattle. Harri et al. (2009) concluded that the closer the base price in the grid pricing arrangements are linked to the downstream wholesale markets, the more difficult it is to hedge effectively with the live cattle futures contract. This paper acknowledged that closely linking fed cattle prices with downstream wholesale market prices can improve pricing efficiency in the industry. However, this improvement will be coupled with a trade-off of a diminished ability to manage price risk with the live cattle futures contract. As the industry converts to grid pricing combined with a downstream market price as the base price, it distances itself from the live cattle futures contract specifications and reduces its ability to manage price risk.

Schroeder and Yang (2001) concluded that using the live cattle futures contract to hedge for price risk in wholesale beef cuts is not an effective strategy. This introduces the first known empirical study on the viability of this proposed boxed beef futures contract. However, because no boxed beef futures contract exists, in this paper the choice boxed beef cutout value (BBCV) price series was used as the theoretical nearby BBCV futures price series and the assumption is made that this theoretical contract would follow the choice BBCV price closely.

Mattos et al. (2003) also showed that the live cattle futures contract may not be a sufficient tool to mitigate price risk in the wholesale meat industry and performed an empirical study of how a futures contract based on the BBCV might perform as a risk management tool. Similar to Schroeder and Yang (2001), Mattos et al. (2003) uses the BBCV as the theoretical nearby BBCV futures contract price with the assumption that this contract would follow the BBCV index closely.

Problems with the live cattle contract have left producers concerned as to its effectiveness and research has suggested an alternative BBCV contract. Schroeder and Yang (2001) and Mattos et al. (2003) are the only empirical attempts to study the feasibility of this proposed downstream market price futures contract. There has been no attempt to develop a conceptually valid BBCV futures price series that models a relationship between the BBCV price index and the proposed BBCV futures price series accurately.

Spot Price/Futures Relationship

The theory of storage (Working 1949) explains the relationship between the spot price of a commodity and the futures price. Also, contingent valuation models, like Gibson and Schwartz (1990), can estimate futures price series that are conceptually valid under certain assumptions.

To accurately model a relationship between spot and futures prices we start with the theory of storage. The theory of storage as in Fama and French (1987) models a futures price as a function of the spot price, interest rate, storage costs, and convenience yield. The theory of storage states that the difference in the spot price and futures price is a result of the interest lost from the spot price of the commodity, the convenience yield accrued from holding the commodity, and the cost to store the commodity until delivery. Spot price, interest rate, and storage costs are all straight forward, but a concept like convenience yield is a more abstract concept.

Originally explored by Kaldor (1939), convenience yield is the flow of benefits from holding inventory, because "stocks of all goods possess a yield" (Kaldor 1939, p. 3). A firm that uses a commodity as an input will have a benefit from sufficient levels of inventory to account for increases in the rate of production, and similarly, wholesale firms will benefit from having inventory to account for unexpected shifts in demand. The theory of storage assumes when inventory levels are very high, marginal convenience yield will be very low and when inventory levels are very low marginal convenience yield will be very high (Fama and French 1987). According to Gibson and Schwartz (1990, p. 959) convenience yield "has already proven to drive the relationship between futures and spot prices of many commodities" (Brennan 1986; Fama and French 1987, 1988).

There is a family of futures valuation models that stem from the model derived in Brennan and Schwartz (1985). The model derived in Brennan and Schwartz (1985) allows for stochastic spot price. It is assumed that the interest rate is constant, and that convenience yield is a function of the spot price. This simplifying assumption does not allow futures prices to fluctuate relative to the spot price. This also prevents futures prices moving between contango and normal backwardation.

The two-factor model as in Gibson and Schwartz (1990) and Schwartz (1997) extends the Brennan and Schwartz (1985) model to allow for two stochastic factors, spot price and convenience yield whose random movements are correlated over time. In this model it is assumed that interest rates are constant. According to Gibson and Schwartz (1990, p. 971), when the market price of convenience yield risk was updated to correspond to respective monthly periods “the two-factor model is a quite satisfactory tool” when used to value short term contingent claims of oil like futures contracts.

Another two factor model, called the short-term/long-term model, was derived in Schwartz and Smith (2000) that approaches the problem from an alternative point of view. The two stochastic factors in this model are a long term equilibrium price and short term deviations from that equilibrium price. This model is found to be equivalent to the two factor convenience yield model in that the factors in the short-term/long-term model are a linear combination of the factors in the convenience yield model and vice versa. By estimating the parameters of one of these models, it is easy to calculate the parameter estimates of the other model. The short-term/long-term model is found to be advantageous over the convenience yield model because the concept of convenience yield is debated and it can be difficult to even grasp the concept, whereas it can be much simpler to view prices as having some long term equilibrium price with short term deviations over time.

In summary, previous research has shown that there are problems with the live cattle futures contract. A BBCV futures contract has been suggested as a solution to these problems in previous research but has never been accurately modelled. The futures valuation models discussed above are used to model prices of existing futures contracts. In the next chapter, we discuss how we extend one of these futures valuation models to accurately model prices of a hypothetical futures contract.

Conceptual Framework

In this chapter, we discuss the conceptual framework behind the methods used to derive the term structure[2] for a hypothetical futures contract that is theoretically accurate under reasonable assumptions. To generate this term structure, we first extract the parameters that describe the relationship between spot price and the existing futures using a futures valuation model. Next, we apply that relationship to the new spot price related to the hypothetical futures contract.

In the first section of this chapter, we describe the futures valuation model that is used to derive the relationship between spot and futures prices. The futures valuation model used is the Short Term/Long Term model derived in Schwartz and Smith (2000). In the second section, we extend the model to include a seasonal component. In the third section, we describe the application of that model in generating the hypothetical futures prices.

[2] At any given time the prices of futures contracts for different maturities can differ. This series of different prices is called term structure.

Short-Term/Long-Term Model

Schwartz and Smith (2000) developed a simple model of commodity prices with two stochastic factors, a long term equilibrium price and short term deviations from that price. The short term deviations represent short term supply/demand shocks that increase or decrease the spot price from some long term equilibrium price in the short term, but eventually disappear. When prices are higher than the long term equilibrium level, positive pressure is put on the supply, and negative pressure is put on demand. This drives the prices back down towards the long term equilibrium level. Also, when prices are lower than the long term equilibrium negative pressure is put on supply, and positive pressure is put on demand. This drives prices back up to the long term equilibrium level.

The Short Term/Long Term (ST/LT) model first decomposes the spot price into two factors, a long term equilibrium price level and short term deviations from that equilibrium price, given by:

$$ln\left(S_t\right) = \chi_t + \xi_t \qquad (1)$$

where S_t is the spot price of the commodity, χ_t is the short term deviation of prices, ξ_t is the long term equilibrium price level, and *ln* denotes the natural logarithm. The two factors ξ_t and χ_t, referred to as state variables, are assumed to follow these processes:

$$\begin{aligned} d\chi_t &= -\kappa\chi_t dt + \sigma_\chi dz_\chi && \text{(a)} \\ d\xi_t &= \mu_\xi dt + \sigma_\xi dz_\xi && \text{(b)} \\ dz_\chi dz_\xi &= \rho_{\chi\xi} dt. && \text{(c)} \end{aligned} \qquad (2)$$

The short term deviations of prices $\left(\chi_t\right)$ are mean reverting toward zero through an Ornstein-Uhlenbeck process and the long term equilibrium price level $\left(\xi_t\right)$follows a Brownian motion process with drift μ_ξ. dz_χ and dz_ξ are increments to a Brownian motion process that are correlated with $\rho_{\chi\xi}$. Changes in the long term equilibrium price level $\left(\xi_t\right)$ show fundamental changes in the price level that will hold for the "long term", and changes in the short term deviations of prices $\left(\chi_t\right)$ show deviations that will eventually, in the "short term" go to zero. κ is the rate at which those short term deviations revert back to zero. σ_χ and σ_ξ are the standard deviations of the short term deviations and long term equilibrium level, respectively.

According to the process defined in equations (2a), (2b), and (2c), the two state variables are jointly normally distributed with a mean vector:

$$E\left[\left(\chi_t, \xi_t\right)\right] = \left[e^{-\kappa t}\chi_0,\ \xi_0 + \mu_\xi t\right] \tag{3}$$

and covariance matrix:

$$Cov\left[\left(\chi_t, \xi_t\right)\right] = \begin{bmatrix} \left(1-e^{-2\kappa t}\right)\dfrac{\sigma_\chi^2}{2\kappa} & \left(1-e^{-\kappa t}\right)\dfrac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{\kappa} \\ \left(1-e^{-\kappa t}\right)\dfrac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{\kappa} & \sigma_\xi^2 t \end{bmatrix}. \tag{4}$$

The above model represents the true process that ξ_t and χ_t follow in a world where risk is present. Adjusting the model for a "risk neutral" world allows equating the expected spot price with the futures price. In a risk neutral world, the state variables are assumed to follow the risk-neutral process:

$$\begin{aligned} d\chi_t &= \left(-\kappa\chi_t - \lambda_\chi\right)dt + \sigma_\chi dz_\chi^* && \text{(a)} \\ d\xi_t &= \left(\mu_\xi - \lambda_\xi\right)dt + \sigma_\xi dz_\xi^* && \text{(b)} \\ dz_\chi^* dz_\xi^* &= \rho_{\chi\xi}dt. && \text{(c)} \end{aligned} \tag{5}$$

The new parameters in this model, λ_χ and λ_ξ, are the risk premiums associated with the risk neutral process which represent reductions in the drift of each process. In other words, λ_χ and λ_ξ represent the additional premiums above the risk free return that investors in the real world require as a compensation for taking on the respective risks. In the risk neutral process $\left(\chi_t\right)$ still follows an Ornstein-Uhlenbeck process but now reverts toward $-\dfrac{\lambda_\chi}{\kappa}$ instead of zero. The risk neutral process for $\left(\xi_t\right)$ also still follows a Brownian motion process but has a drift of $\mu_\xi^* = \mu_\xi - \lambda_\xi$ instead of μ_ξ. Again, dz_χ^* and dz_ξ^* are increments to a standard Brownian motion process correlated with $\rho_{\chi\xi}$.

Now, under the risk neutral process defined above, expected spot prices for time *T* are equivalent to futures contract prices which expire at time *T.* This equivalence is used to calculate futures prices from the risk neutral process's expectations and variance of the log of the spot price.

Following the notation in Schwartz and Smith (2000), $F_{T,t}$ is the price of a futures contract at time *t* that matures at time *T* so that:

$$ln\left(F_{T,t}\right) = ln\left(E^{*}\left[S_T\right]\right)$$

$$ln\left(F_{T,t}\right) = E^{*}\left[ln\left(S_T\right) + \frac{1}{2}Var^{*}\left[ln\left(S_T\right)\right]\right]$$

$$ln\left(F_{T,t}\right) = e^{-\kappa T}\chi_t + \xi_t + A\left(T\right)$$

$$A\left(T\right) = \mu_\xi^{*}T - \left(1-e^{-\kappa T}\right)\frac{\lambda_\chi}{\kappa} + \frac{1}{2}\left(\left(1-e^{-2\kappa T}\right)\frac{\sigma_\chi^2}{2\kappa} + \sigma_\xi^2 T + 2\left(1-e^{-\kappa T}\right)\frac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{\kappa}\right). \quad (6)$$

Given values for the parameters and the state variables, a futures contract price can be valued for any given time to maturity *T*.

ST/LT model with Seasonal Component

The ST/LT model does not account for seasonality. The commodities being analyzed, hogs and cattle, have seasonal patterns in prices. A seasonal component can be added to the Schwartz and Smith (2000) model by adding a deterministic term that is dependent on the time of the year to the equation that defines the natural log of the spot price, shown in equation (7). The deterministic term γ_t is defined as

$$ln\left(S_t\right) = \chi_t + \xi_t + \gamma_t \quad (7)$$

$$\gamma_t = \begin{Bmatrix} \beta_t & \text{if month}\left(t\right) = 1,...,11 \\ 0 & \text{if month}\left(t\right) = 12 \end{Bmatrix}. \quad (8)$$

This additional factor in the definition of the natural log of the spot price results in an additional term in the futures valuation function. The futures valuation function with the seasonal component is shown in equation (9), where the superscript *S* is used to denote that the model accounts for seasonality.

$$ln\left(F_{T,t}\right)=e^{-\kappa T}\chi_t+\xi_t+A^S\left(T\right)$$

$$A^S\left(T\right)=\gamma_T+\mu_\xi^*T-\left(1-e^{-\kappa T}\right)\frac{\lambda_\chi}{\kappa}+\frac{1}{2}\left(\left(1-e^{-2\kappa T}\right)\frac{\sigma_\chi^2}{2\kappa}+\sigma_\xi^2T+2\left(1-e^{-\kappa T}\right)\frac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{\kappa}\right). \quad (9)$$

The additional term in the valuation function is the seasonal variable that corresponds with month *T*. It can be noted that this is the same method of adding seasonality to the ST/LT model as in Sørensen (2002). The only difference being Sørensen (2002) used a sinusoidal function instead of monthly constant variables.

Deriving the Term Structure of Hypothetical Futures Prices

In the first two sections of this chapter, we have discussed the ST/LT model. This model derives the term structure of futures prices according to the stochastic processes the two state variables follow. Given the two state variables and the parameters that describe the process that they follow, futures prices with different maturities can be generated using equation (9). In this section, we discuss the use of the ST/LT model to derive the term structure of a hypothetical futures.

First, we establish the notation used in the following. Let S_t^E denote the spot price that corresponds to an existing futures contract, whose price is denoted by $F_{T,t}^E$. The two state variables and seasonal component for S_t^E are given by:

$$ln\left(S_t^E\right)=\chi_t^E+\xi_t^E+\gamma_t^E. \quad (10)$$

The parameters $\left(\kappa^E,\lambda_{\chi^E},\sigma_{\chi^E},\mu_{\xi^E},\lambda_{\xi^E},\sigma_{\xi^E},\rho_{\chi^E\xi^E}\right)$ describe the process the state variables χ_t^E and ξ_t^E follow. The term structure of this existing futures using equation (9) is given by:

$$ln\left(F_{T,t}^E\right)=e^{-\kappa^E T}\chi_t^E+\xi_t^E+A^S\left(T\right)$$

$$A^S\left(T\right)=\gamma_T^E+\mu_{\xi^E}^*T-\left(1-e^{-\kappa^E T}\right)\frac{\lambda_{\chi^E}}{\kappa^E}+\frac{1}{2}\left(\left(1-e^{-2\kappa^E T}\right)\frac{\sigma_{\chi^E}^2}{2\kappa^E}+\sigma_{\xi^E}^2T+2\left(1-e^{-\kappa^E T}\right)\frac{\rho_{\chi^E\xi^E}\sigma_{\chi^E}\sigma_{\xi^E}}{\kappa^E}\right)$$

$$\text{where} \quad \mu_{\xi^E}^*=\mu_{\xi^E}-\lambda_{\xi^E}. \quad (11)$$

Now, let S_t^H denote the spot price that corresponds to a hypothetical futures contract, whose price is denoted by $F_{T,t}^H$. The two state variables and seasonal component for S_t^H are given by:

$$ln\left(S_t^H\right) = \chi_t^H + \xi_t^H + \gamma_t^H. \tag{12}$$

The parameters $\left(\kappa^H, \lambda_{\chi^H}, \sigma_{\chi^H}, \mu_{\xi^H}, \lambda_{\xi^H}, \sigma_{\xi^H}, \rho_{\chi^H\xi^H}\right)$ describe the process the state variables χ_t^H and ξ_t^H follow. The term structure of this hypothetical futures again using (9) is given by:

$$ln\left(F_{T,t}^H\right) = e^{-\kappa^H T}\chi_t^H + \xi_t^H + A^S\left(T\right)$$

$$A^S\left(T\right) = \gamma_T^H + \mu_{\xi^H}^* T - \left(1-e^{-\kappa^H T}\right)\frac{\lambda_{\chi^H}}{\kappa^H} + \frac{1}{2}\left(\left(1-e^{-2\kappa^H T}\right)\frac{\sigma_{\chi^H}^2}{2\kappa^H} + \sigma_{\xi^H}^2 T + 2\left(1-e^{-\kappa^H T}\right)\frac{\rho_{\chi^H\xi^H}\sigma_{\chi^H}\sigma_{\xi^H}}{\kappa^H}\right)$$

where $\mu_{\xi^H}^* = \mu_{\xi^H} - \lambda_{\xi^H}$. (13)

Method for Deriving the Term Structure of Hypothetical Futures Prices

First, we discuss conceptually the steps taken to derive the term structure of the hypothetical futures. Second, we discuss in details using equations these same steps. These steps are displayed in a flow chart in figure 3.

The state variables, seasonal component, and parameters of the ST/LT model can be obtained if observations of futures prices with different time to maturity are available. Spot prices and futures prices with different maturities are available for the existing futures, therefore, we can obtain the state variables, seasonal component, and parameters of the ST/LT model for the existing futures. With this information, we have what is needed to derive the term structure for the existing futures contract using equation (11).

Turning now to the case of the hypothetical futures contract, the only information available for this contract is the spot price. Thus the state variables, seasonal component, and parameters cannot be directly obtained from the ST/LT model. The steps and assumptions we employ are as follows. First, to obtain ξ_t^H, we define ξ_t^H as a function of ξ_t^E . Second, we assume the seasonal components are equivalent for S_t^E and S_t^H. With ξ_t^H and γ_t^H available we can obtain the short term deviation χ_t^H by subtracting ξ_t^H and γ_t^H from $ln\left(S_t^H\right)$ using (12). Third, we assume that the parameters that describe the process of the short term deviations are equivalent, $\kappa^H = \kappa^E$, $\lambda_{\chi^H} = \lambda_{\chi^E}$, $\sigma_{\chi^H} = \sigma_{\chi^E}$, and $\rho_{\chi^H\xi^H} = \rho_{\chi^E\xi^E}$, for S_t^E and S_t^H. Last, using S_t^H and $\left(\kappa^H, \lambda_{\chi^H}, \sigma_{\chi^H}, \rho_{\chi^H\xi^H}\right)$, the parameters that describe the process ξ_t^H follows, $\left(\mu_{\xi^H}, \sigma_{\xi^H}\right)$ can be estimated. λ_{ξ^H} cannot be estimated, so we assume λ_{ξ^H} is equivalent to λ_{ξ^E}. After all the required components are available we can derive the term structure of the hypothetical futures, using equation (13).

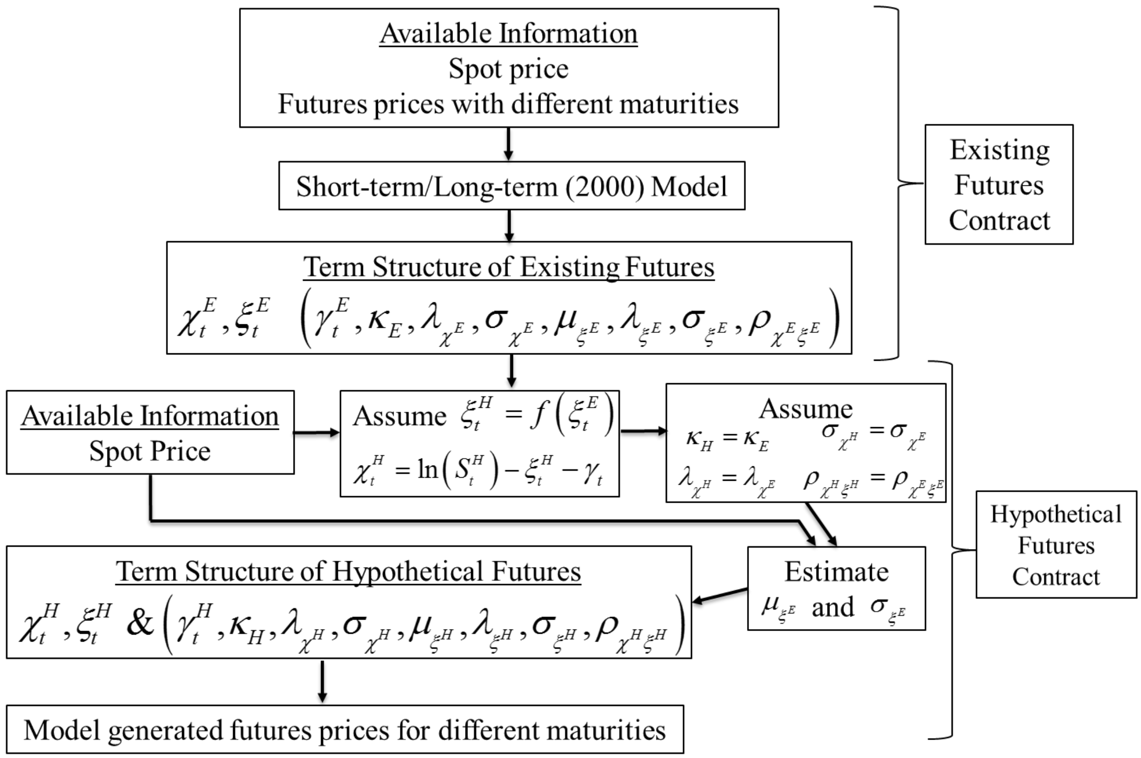

Figure 3. Hypothetical Futures Generation

Empirical Methods

In the first section of this chapter, we discuss the Kalman filter and maximum likelihood estimation used to estimate the ST/LT model (estimation of the term structure of the existing futures). In the second section, we discuss the estimation of the state variables and parameters used to derive the term structure of the hypothetical futures. In the third section, we discuss the two applications of the methods. The first application tests the accuracy of the methods with live hog and lean hog futures. The second application applies the methods to live cattle futures to derive BBCV futures, and then estimates optimal hedge ratios using regression methods.

The Kalman Filter and Maximum Likelihood Estimation

The ST/LT model presents a unique challenge for estimation. The first problem is that the two state variables are unobserved. To estimate these state variables we can use the Kalman filter (Kalman 1960; Hamilton 1994). To compute the Kalman filter, a system of equations must first be cast into state-space representation. To derive the Kalman filter as in Hamilton (1994) we first cast the dynamic system of equations into state space representation and lay out the assumptions required for that system. Equations (14a) and (14b) show our system cast into state space representation.

$$\mathbf{x}_t = \mathbf{c} + \mathbf{G}\mathbf{x}_{t-1} + \boldsymbol{\omega}_t \qquad t = 1,2,3,...,t \quad (a)$$

$$\mathbf{y}_t = \mathbf{d}_t + \mathbf{F}'\mathbf{x}_t + \mathbf{v}_t \qquad t = 1,2,3,...,t_n \quad (b) \tag{14}$$

Equation (14a) is referred to as the state or transition equation. This equation describes the process followed by the two state variables. The transition equation is given by the mean vector and covariance matrix of the state variables defined in the conceptual framework, equations (3) and (4). Equation (14b) is referred to as the observation or measurement equation. This equation describes the process followed by the observed futures prices, which depends on the state variables. The measurement equation is given by the futures valuation model defined in the conceptual framework, equation (9). The Kalman filter is derived here for the ST/LT model with the seasonal component[3]. The state variable vector and parameter matrices are defined as;

$\mathbf{x}_t \equiv [\chi_t, \xi_t]$, a 2x1 vector of state variables where χ_t and ξ_t are as previously defined[4],

$\mathbf{c} \equiv [0, \mu_\xi \Delta t]$, a 2x1 vector,

$\mathbf{G} \equiv \begin{bmatrix} e^{-\kappa\Delta t} & 0 \\ 0 & 1 \end{bmatrix}$, a 2x2 matrix,

$\mathbf{d}_t \equiv [A^S(T_1), ..., A^S(T_n)]$, an nx1 vector,

$\mathbf{F}_t \equiv [e^{-\kappa T_1} \; 1, ..., e^{-\kappa T_n} \; 1]$, an nx2 matrix,

$\boldsymbol{\omega}_\mathbf{t}$, a 2x1 vector of normally distributed error terms with $E[\boldsymbol{\omega}_t] = 0$,

$\Delta t \equiv$ length of discrete time steps,

$t_n \equiv$ number of time periods;

$\mathbf{y}_t \equiv [ln(F_{T1}), ..., ln(F_{Tn})]$, a nx1 vector of n observed futures prices with times to maturity $T_1, ..., T_n$, and the only observed element of this system;

And $\mathbf{v}_\mathbf{t}$, a 2x1 vector of normally distributed error terms with $E[\mathbf{v}_t] = 0$.

The vectors $\boldsymbol{\omega}_t$ and $\mathbf{v}_\mathbf{t}$ are error term vectors that are assumed to not be correlated across time so that:

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[3] The ST/LT model with seasonal component is defined here. A simple restriction of $\gamma_t = 0$ removes the seasonal component and results in the model as in equation (6) with no seasonal component.

[4] To simplify notation, WE have removed the superscripts E or H from the state variables and parameters.

$$E\left(\boldsymbol{\omega}_t \boldsymbol{\omega}_\tau'\right) = \begin{cases} \mathbf{W} & \forall\ t = \tau \\ 0 & \forall\ t \neq \tau \end{cases} \quad (\text{a})$$

$$E\left(\mathbf{v}_t \mathbf{v}_\tau'\right) = \begin{cases} \mathbf{V} & \forall\ t = \tau \\ 0 & \forall\ t \neq \tau \end{cases} \quad (\text{b}) \tag{15}$$

where $\mathbf{W}$ and $\mathbf{V}$ are the covariance matrices of the error term vectors $\boldsymbol{\omega}_t$ and $\mathbf{v}_t$, respectively for some given point in time. $\mathbf{W}$ is given by the equation below,

$$\mathbf{W} = \begin{bmatrix} \left(1-e^{-2\kappa t}\right)\dfrac{\sigma_\chi^2}{2\kappa} & \left(1-e^{-2\kappa t}\right)\dfrac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{\kappa} \\ \left(1-e^{-2\kappa t}\right)\dfrac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{\kappa} & \sigma_\xi^2 t \end{bmatrix}. \tag{16}$$

The covariance matrix $\mathbf{V}$ is assumed for simplicity to be a diagonal matrix with diagonal elements $\left(s_1^2,\ldots,s_n^2\right)$, that is, the covariance of error terms across futures prices with different times to maturity is zero. It is also assumed the error terms $\boldsymbol{\omega}_t$ and $\mathbf{v}_t$ are not correlated across time so that:

$$E\left(\boldsymbol{\omega}_t \mathbf{v}_\tau'\right) = 0 \quad \forall\ t \text{ and } \tau. \tag{17}$$

Given the above state space system and assumptions, the Kalman filter can be used to estimate the state variables if given some observed values $\mathbf{y}_1, \mathbf{y}_2, \mathbf{y}_3, \ldots, \mathbf{y}_n$, and given the matrices of parameters $\mathbf{c}$, $\mathbf{G}$, $\mathbf{d}$, $\mathbf{F}$, $\mathbf{W}$, and $\mathbf{V}$. In our case, the matrices of parameters are unknown, however, the Kalman filter gives the expected value and covariance matrix of the measurements, $\mathbf{y_t}$. $\mathbf{y_t}$ has conditional mean and variance given by:

$$\mathbf{y}_t \left| \boldsymbol{\psi}_{t-1} \sim N\left(\left(\mathbf{d}_t + \mathbf{F}'\hat{\mathbf{x}}_{t|t-1}\right), \left(\mathbf{F}'\mathbf{P}_{t|t-1}\mathbf{F} + \mathbf{V}\right)\right)\right.. \tag{18}$$

With this conditional distribution a likelihood function can be calculated. The likelihood function as given in Hamilton (1994) is as follows:

$$f_{\mathbf{y}_t|\mathbf{x}_t,\boldsymbol{\psi}_{t-1}}\left(\mathbf{y}_t\left|\boldsymbol{\psi}_{t-1}\right.\right)=\sum_{t=1}^{T}(2\pi)^{-\frac{t}{2}}\left|\mathbf{F}'\mathbf{P}_{t|t-1}\mathbf{F}+\mathbf{V}\right|^{-\frac{1}{2}}$$

$$\times\exp\left(-\frac{1}{2}\left(\mathbf{y}_t-\mathbf{d}_t-\mathbf{F}'\hat{\mathbf{x}}_{t|t-1}\right)'\left(\mathbf{F}'\mathbf{P}_{t|t-1}\mathbf{F}+\mathbf{V}\right)^{-1}\left(\mathbf{y}_t-\mathbf{d}_t-\mathbf{F}'\hat{\mathbf{x}}_{t|t-1}\right)\right)$$

$$ln\left(f_{\mathbf{y}_t|\mathbf{x}_t,\boldsymbol{\psi}_{t-1}}\left(\mathbf{y}_t\left|\boldsymbol{\psi}_{t-1}\right.\right)\right)=\sum_{t=1}^{T}\ -\frac{t}{2}ln(2\pi)-\frac{1}{2}ln\left|\mathbf{F}'\mathbf{P}_{t|t-1}\mathbf{F}+\mathbf{V}\right|$$

$$-\frac{1}{2}\left(\mathbf{y}_t-\mathbf{d}_t-\mathbf{F}'\hat{\mathbf{x}}_{t|t-1}\right)'\left(\mathbf{F}'\mathbf{P}_{t|t-1}\mathbf{F}+\mathbf{V}\right)^{-1}\left(\mathbf{y}_t-\mathbf{d}_t-\mathbf{F}'\hat{\mathbf{x}}_{t|t-1}\right)$$

$$\forall\ \ t=1,2,3,...,T$$

defining $\mathbf{Z}=\mathbf{y}_t-\mathbf{d}_t-\mathbf{F}'\hat{\mathbf{x}}_{t|t-1}$ and $\mathbf{B}=\mathbf{F}'\mathbf{P}_{t|t-1}\mathbf{F}+\mathbf{V}$;

$$ln\left(f_{\mathbf{y}_t|\mathbf{x}_t,\boldsymbol{\psi}_{t-1}}\left(\mathbf{y}_t\left|\boldsymbol{\psi}_{t-1}\right.\right)\right)=\sum_{t=1}^{T}\ -\frac{n}{2}ln(2\pi)-\frac{1}{2}ln|\mathbf{B}|-\frac{1}{2}\mathbf{Z}'\mathbf{B}^{-1}\mathbf{Z} \qquad (19)$$

$$\forall\ \ t=1,2,3,...,T\ .$$

The log-likelihood function presented in equation (19) can be numerically evaluated with different parameter values, computing the Kalman filter for each different set of parameters. The Kalman filter is ran for a variety of combinations of parameter values. The parameters that maximize the likelihood function are used as parameter estimates for the model. Standard deviations for parameter estimates are found in the diagonal terms of the inverse of the negative hessian matrix of the log likelihood function. This section has shown that given futures prices with different maturities, $\mathbf{y}_1,\mathbf{y}_2,\mathbf{y}_3,...,\mathbf{y}_n$, the term structure of existing futures can be estimated.

Empirical Applications

We have now shown how to estimate the term structure of the hypothetical futures. Using equation (41), hypothetical futures prices for different maturities can be generated. Now we apply our methods in two futures markets. First, we use live and lean hog futures to test the accuracy of our methods. Second, we derive the term structure of a BBCV futures contract and evaluate its effectiveness as a hedging instrument.

Empirical Application to Hog Futures

We use the case of hog futures to test our methods. All hog futures with expiration prior to February 1997 were live hog futures based on the live price of hogs. The live hog futures contract was replaced by the lean hog futures contract, based on a lean weight carcass price, with the release of the lean hog futures contract for expiration in February 1997. The February 1997 lean hog futures contract began trading in November 1995, replacing the February live hog futures contract. From that point, a new lean hog futures contract replaced the existing live hog futures contract as the latter matured. The last live hog futures contract was the live hog futures contract that expired in December 1996.

During the period of time between November 1995 and December 1996 live hog futures contracts and lean hog futures contracts were trading at the same time. We use our methods to generate lean hog futures prices and compare them to the realized lean hog futures prices during this period.

The futures contracts for different maturities traded between October 1995 and December 1996 are displayed in figure 4 where black lines denote live hog futures contracts with different maturities and gray lines denote the new lean hog futures contracts. At any given point in time between December 1984 (where our data begins) and January 1996 there is a deferred live hog futures contract trading that is at least 11 months to maturity. Specifically, as of January 1996 the December 1996 contract is 11 months out to maturity. Note that the December 1996 live hog contract is the last live hog futures contract. After January 1996 there is no deferred live hog futures contract trading that is at least 11 months to maturity. Note that the February 1997 live hog futures contract (the shortest black line in figure 4) is replaced by the new lean hog futures contract. Between January 1996 and March 1996 the number of live hog futures contracts is reduced by one and the maturity of the furthest contract (December 1996) is shortened to only 9 months (March 1996 – December 1996). As this process continues, where new lean hog futures contracts start trading to replace live hog futures contracts as they mature, after October 1996, there is only 1 remaining live hog futures contract (the December 1996 contract) with only 1 month to maturity. After November 1996 no more live hog futures contracts exist.

We estimate the model through November 1996, using all available prices of live hog futures[5]. This allows me to estimate the model for the entire overlapping period so that we can extend the comparison of the generated lean hog futures prices to observed lean hog futures contracts over the overlapping period.

[5] The dimensions of the measurement equation matrix, equation (14b), are reduced to fit the available vector of futures prices at any given period.

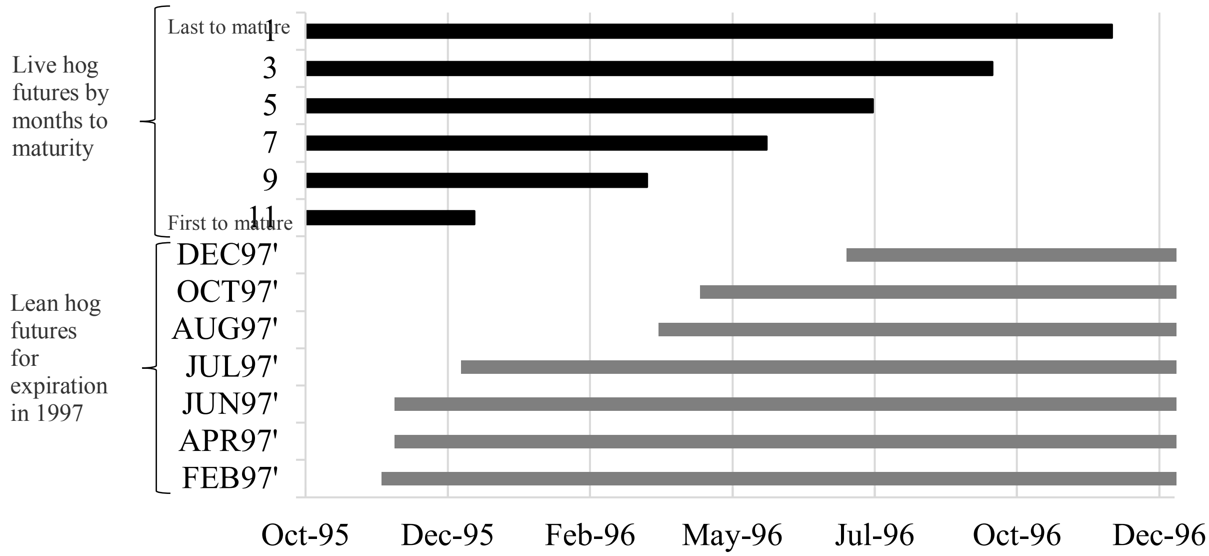

Figure 4. Overlap in Live Hog Futures Contracts and Lean Hog Futures Contracts

To test the accuracy of the model we calculate root mean square errors (RMSE) of the generated futures prices from the observed futures prices as done in Schwartz (1997). we generate futures prices, denoted by $F_{T,t}^{G}$, at time t with time to maturity T for each observed futures contract price, denoted by $F_{T,t}^{O}$ at time t with time to maturity T. Then we calculate RMSE as shown in equation (42) to determine the accuracy of the model.

$$\text{RMSE} = \sqrt{\frac{\sum_{t=1}^{N}\left(F_{T,t}^{G} - F_{T,t}^{O}\right)^{2}}{N}}. \tag{20}$$

We calculate four RMSEs. We first calculate the in-sample RMSE for live hog futures between December 1984 and January 1996 to obtain a benchmark RMSE. Second, we calculate an out-of-sample RMSE for live hog futures prices between January 1995 and December 1995. We use a one year out-of-sample period to match the length of overlap period when both live hog and lean hog contracts are trading. This out-of-sample RMSE calculation for the live hog futures matches the RMSE calculation for the lean hog futures. This overlapping period is shown in figure 5, where the black lines represent live hog futures for expiration in 1995 and earlier, and the gray lines represent live hog futures for expiration in 1996. The ST/LT model is estimated with futures for expiration in 1995 and earlier (the black lines). Then live hog futures prices are generated in the overlapping period that correspond with the live hog futures for expiration in 1996. Comparing these generated and observed live hog futures prices, generates RMSEs that are out-of-sample in the exact same manner as the RMSEs for the hypothetical lean hog futures. This allows for a better comparison of the model performance when generating out-of-sample lean hog futures prices.

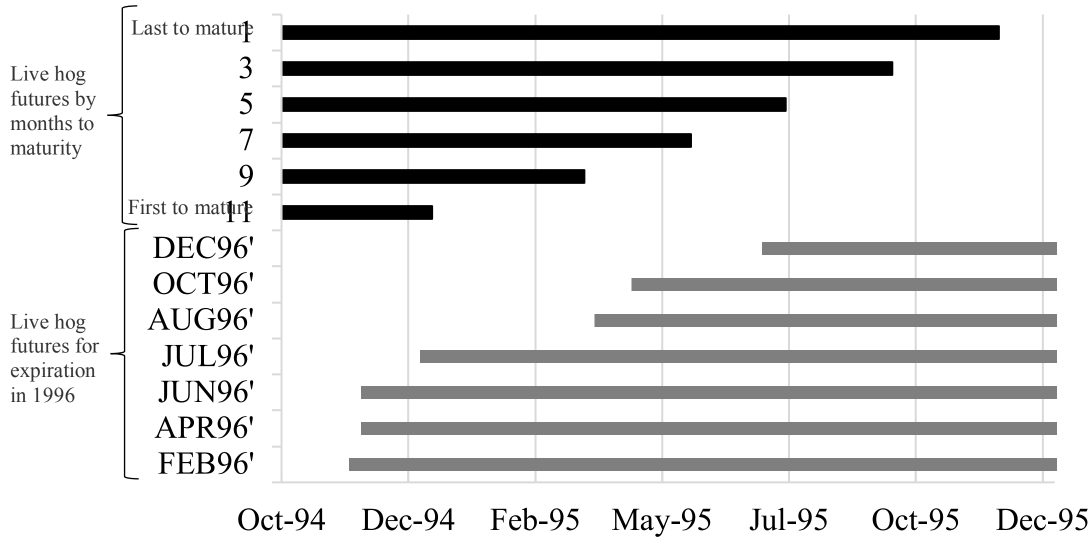

Figure 5. Overlapping period to obtain out-of-sample RMSEs of generated live hog futures

Next we calculate out-of-sample RMSE for lean hog futures prices during the overlapping period as shown in figure 4.

Empirical Application to Live Cattle Futures

This section describes the application of our methods to live cattle futures. Using the existing live cattle futures contract, we derive the term structure for a boxed beef cutout value futures contract and generate futures prices for that hypothetical contract. Next we use regression methods to determine optimal hedge ratios for various hedging scenarios using both the live cattle futures contract and the derived BBCV futures contract as hedging tools.

We employ two regression methods to estimate optimal hedge ratios. In the following notation, $Spot_t$ and $Futures_t$ are the log spot price and the log futures price, respectively. First, we test the data for stationarity. Next, we regress log spot prices on log futures prices using ordinary least squares (OLS) estimation. An augmented Dickey-Fuller test (as shown previously) is used to determine whether the data is stationary.

The regression equation is:

$$\Delta Spot_t = \alpha + \beta \Delta Futures_t + \varepsilon_t \tag{21}$$

where $\Delta Spot_t = Spot_t - Spot_{t-1}$ and $\Delta Futures_t = Futures_t - Futures_{t-1}$. The estimated slope coefficient $\hat{\beta}$ represents the optimal hedge ratio.

If spot and futures prices are cointegrated, the OLS estimates of the optimal hedge ratio can be biased because they do not account for the long term relationship between the prices. We test for cointegration between prices using the Engle and Granger (1987) two step procedure (as shown previously). The error correction model is:

$$\Delta Spot_t = \gamma u_{t-1} + \beta \Delta Futures_t + \sum_{i=1}^{p} \delta_i \Delta Spot_{t-1} + \sum_{j=1}^{q} \phi_j \Delta Futures_{t-1} + \omega_t \qquad (22)$$

where $u_{t-1} = Spot_t - \alpha_0 - \alpha_1 Futures_t$ is the error correction term that captures the long term relationship between spot and futures prices. The estimated $\hat{\beta}$ is the optimal hedge ratio. The number of lagged prices to be included in the ECM will be determined by the Akaike information criterion (Akaike 1973).

Data

The data needed to apply the methods described in the empirical methods chapter consist of futures and spot prices for hogs and cattle. Data for hogs include live hog futures prices, lean hog futures prices, and the Omaha spot price. Data for cattle include live cattle futures, the five market average spot price for steers, and the boxed beef cutout value index. All futures prices used were weekly average observations obtained from Barchart.com (2017). Spot prices were obtained from Barchart.com (2017) and the USDA-AMS (2017)

Hog Prices

Estimating the ST/LT model requires a vector of futures prices that have fixed times to maturity. Live hog futures from December 1984 through November 1996 were organized into six different fixed time to maturity futures prices denoted here as F1, F3, F5, F7, F9, and F11. At any given point in time during this period, there are at least 6 futures contracts trading. The futures contract that was at least 1 month from maturity, but no more than 3 months to maturity was the F1 futures price, the contract that was at least 3 months to maturity but no more than 5 months to maturity was the F3 futures prices, and so on. For example, the price of a February futures contract trading in early January would be the F1 price because it is about a month and a half to maturity.

Futures prices for over 13 months to maturity were not consistently trading over the period of time we used to estimate the model, therefore the furthest fixed time to maturity futures prices we used was for 11 months. The spot price used is the Omaha price for live hogs as reported by Barchart.com (2017). Table 1 shows summary statistics of the live hog spot and futures prices.

Table 1. Summary Statistics of Live Hog Spot Prices and Fixed Time to Maturity Live Hog Futures for the period between 12/07/1984 to 11/29/1996

Price	Mean Price (Standard Deviation)	Mean Months to Maturity (Standard Deviation)	# of weekly observations
Spot	46.97 (6.98)	0 (0)	626
F1	47.57 (5.97)	1.42 (0.496)	626
F3	46.70 (5.10)	3. 51 (0.502)	617
F5	45.97 (4.34)	5.41 (0.495)	608
F7	45.42 (3.81)	7.41 (0.495)	600
F9	44.98 (3.24)	9.42 (0.496)	591
F11	44.74 (3.17)	11.42 (0.496)	582

Note: All prices are weekly average prices in $/cwt.
Source: Barchart.com.

The futures prices that have lower time to maturities had more observations available, because the live futures contract was slowly replaced by the lean hog contract beginning with the release of the February 1997 lean hog contract. During this period in 1996 the longer time to maturity live hog futures contracts were phased out one by one as shown in figure 4.

The lean hog index is the spot price of the lean hog futures contract. The lean hog index was first reported by the Chicago Mercantile Exchange (CME 2017) in November 1995.
The lean hog futures contract began with the release of the February 1997 lean hog futures contract, which began trading in November 1995. All the hog futures contracts set for expiration starting in 1997 were lean hog futures contracts. We use all 7 new lean hog futures contracts with expiration in 1997 that started trading beginning in November 1995 to assess how accurate our generated lean hog futures are. Table 2 contains the summary statistics of the lean hog futures contracts used. Only the overlapping period as described in figure 4 is used, from 11/10/1995 to 11/29/1996. February has the lowest time to maturity and most observations because it was the first contract to begin trading and subsequently the closest lean hog contract to maturity at any given time during 1996.

Table 2. Summary Statistics of Lean Hog Spot and Futures Contracts for the period between 11/10/1995 to 11/29/1996

Lean Hog Futures Contract	Mean Price (Standard Deviation)	Mean Months to Maturity (Standard Deviation)	# of weekly observations
Spot	73.01 (8.63)	0 (0)	56
February 1997	71.27 (5.05)	0.74 (0.314)	56
April 1997	68.91 (4.38)	0.90 (0.308)	55
June 1997	74.07 (3.61)	1.08 (0.308)	55
July 1997	72.90 (2.60)	1.13 (0.280)	50
August 1997	69.56 (1.13)	1.08 (0.197)	35
October 1997	64.83 (1.44)	1.24 (0.180)	32
December 1997	66.14 (2.45)	1.31 (0.119)	21

Note: All prices are weekly average prices in $/cwt.
Source: Barchart.com.

Cattle Prices

The spot cattle price used is the weekly five market average price for live steers as reported by the USDA-AMS (2017).

As with the live hog futures, live cattle futures prices from December 2003 through January 2017 were organized into six different fixed time to maturity futures prices denoted here as F1, F3, F5, F7, F9, and F11. Futures prices for over 13 months to maturity were not consistently trading over the period of time we used to estimate the model, therefore the furthest fixed time to maturity future prices used was for approximately 11.5 months. Table 3 shows summary statistics of the live cattle spot and futures prices. The boxed beef cutout value (BBCV) is the spot price used for the boxed beef cutout value futures contract we derive. The BBCV is a wholesale beef price reported by the USDA (2017). The BBCV takes the prices of the individual beef cuts and constructs a carcass price by weighting each beef cut price by the percentage it makes up of the entire carcass. The weekly five market average price for dressed steers is also used when estimating hedge ratios. The summary statistics of this price are also reported in table 3.

Table 3. Summary Statistics of Live Cattle Spot Prices, Fixed Time to Maturity Live Cattle Futures, and the BBCV index for the period between 12/05/2003 to 1/27/2017

Price	Mean Price (Standard Deviation)	Mean Months to Maturity (Standard Deviation)	# of weekly observations
BBCV	175.77 (35.62)	0 (0)	686
5 Market Average	171.83 (38.91)	-	686
Spot	108.30 (24.45)	0 (0)	686
F1	108.00 (23.37)	1.5 (0.5)	686
F3	108.72 (23.10)	3.5 (0.5)	686
F5	108.84 (23.09)	5.5 (0.5)	686
F7	108.86 (22.85)	7.5 (0.5)	686
F9	108.74 (22.52)	9.5 (0.5)	686
F11	108.52 (22.24)	11.5 (0.5)	686

Note: All prices are weekly average prices in $/cwt.
Source: Barchart.com and USDA-AMS.

Results

In the following sections, we present the results from the objectives stated in the introduction. In the first section of this chapter we discuss the results for objective one, where the methods to generate hypothetical futures are tested for accuracy using the live hog and lean hog futures contracts. In the second section we discuss the results for objective two, where the hypothetical BBCV futures contract is derived and evaluated for its effectiveness as a hedging instrument in comparison to the live cattle futures contract.

Empirical Application to Hog Futures

In this section, we discuss the results from the empirical application to hog futures, where we evaluate the accuracy of the model to generate hypothetical futures prices. To evaluate the accuracy of the model, we calculate RMSEs of the generated prices as discussed in the empirical methods. First, we estimate the state variables and parameters required for generating futures prices for in-sample live hogs, out-of-sample live hogs, and out-of-sample lean hogs. The results of the state variable and parameter estimation, along with stationarity and cointegration testing, can be found in the appendix. Then, we generate futures prices for in-sample live hogs, out-of-sample live hogs, and out-of-sample lean hogs. In the following section, we present the results of the RMSEs of those generated futures prices.

Model Accuracy Evaluation Results

We used the generated futures prices to calculate four RMSEs. First, we calculated RMSEs of the generated in-sample live hog futures prices. This gives a base model error to compare to the other results. Second, we calculated RMSEs of the generated out-of-sample live hog futures prices. Third, we generated out-of-sample hypothetical lean hog futures prices by using a

Kalman Filter model and calculated the RMSEs. Fourth, we generated out-of-sample hypothetical lean hog futures prices using the SUR methods and calculated the RMSEs.

RMSEs of the in-sample live hog futures are displayed in table 4. To allow better comparison of RMSE of live hog futures to RMSE of lean hog futures, RMSE is also shown as a percent of the overall average live hog price during the sample period and organized by contract month.

Table 4. RMSE of generated live hog futures prices

	RMSE	Feb	Apr	Jun	Jul	Aug	Oct	Dec
In-sample	$/cwt	0.88	0.78	1.32	1.01	0.97	0.89	1.06
	%	1.88	1.67	2.80	2.15	2.07	1.90	2.26
Out-of-sample	$/cwt	1.48	2.68	3.58	3.64	4.29	4.89	4.87
	%	3.15	5.70	7.62	7.75	9.13	10.41	10.37

Note: RMSE organized by contract month. % RMSE is the $/cwt RMSE divided by the average live hog price during 1996, 46.97 $/cwt, times 100.

Table 5. RMSE of generated lean hog futures prices

	RMSE	Feb	Apr	Jun	Jul	Aug	Oct	Dec
Out-of-sample	$/cwt	3.24	2.83	4.67	5.94	8.68	8.00	10.28
	%	4.44	3.88	6.40	8.14	11.89	10.96	14.08

Note: RMSE organized by contract month and all contracts were for expiration in 1997. All prices used were on or before 11/29/1996. % RMSE is the $/cwt RMSE divided by the average live hog price during 1996, 73.01 $/cwt, times 100.

This is a more appropriate measure of comparison because live hog prices are much lower, with an average of 46.97 $/cwt, than lean hog prices, with an average of 73.01 $/cwt. The RMSEs of the out-of-sample live hog futures prices are also shown in table 4 organized by contract month. These RMSEs are higher than the RMSEs of the in-sample live hog futures generated. This shows that the model for existing futures will have larger errors when the prices generated are out-of-sample, and motivates the use of these out-of-sample RMSEs in comparison to the RMSEs of the hypothetical lean hog futures prices. It needs to be noted that the generated prices have different out-of-sample lengths. The latest maturity futures prices used in the estimation of the model that generates these out-of-sample prices was for expiration in December of 1995. Therefore, the generated February 1996 futures prices are about 2 months out-of-sample. The generated April 1996 futures prices are about 4 months out-of-sample, and so on. This shows the prices generated for the contracts that mature later in the year have much larger RMSEs because they are further out-of-sample.

The RMSEs of the out-of-sample hypothetical lean hog futures are presented in table 5 organized by contract month. These RMSEs are out-of-sample by the same length as the out-of-sample generated live hog prices with corresponding maturities. This allows for a better comparison of the RMSEs. It needs to be noted though that the out-of-sample live and lean hog futures prices are for two different periods. The out-of-sample lean hog futures prices for all maturities are generated for the period December 1995 - December 1996 while the out-of-sample live hog futures prices are generated for the period December 1994 - December 1995. The out-of-sample RMSE in percentage terms for live hogs shown in table 4 are very similar to the RMSE of the lean hog futures prices shown in table 5. This shows that the methods developed in this research to derive hypothetical futures prices, generate futures prices with an accuracy similar to that for the existing futures.

Empirical Application to Live Cattle Futures

In this section, we report the results the evaluation of the hedging performance of the derived BBCV futures contract in comparison to the live cattle futures contract. First, we estimated all the parameters required to generate BBCV futures prices. The results of the state variable and parameter estimation, along with stationarity and cointegration testing, can be found in the appendix. Then, we generated BBCV futures prices. In the following section, we present the results of the performance evaluation of the BBCV as a hedging instrument.

Hedging Performance of BBCV futures

The results shown here used BBCV futures prices derived using the Kalman Filter model. The hedging performance of the live cattle futures contract and BBCV futures contract was evaluated for three spot prices that may be used to market live cattle, the five market average prices for live and dressed steers, and the BBCV index for choice cattle.

All price series were tested for stationarity, using an augmented Dickey-Fuller test. The results of the augmented Dickey-Fuller tests are shown in table 6. The null hypothesis of a unit root is not rejected for all prices, shown by the rho and tau statistics. All price series are found to be non-stationary so first differences of the prices are taken. The null hypothesis of a unit root is strongly rejected for the first differences of the prices, therefore, all of the following regressions were performed using the first differences of the price series.

The error correction model (ECM) is used if the spot and futures price series are cointegrated. The spot and futures prices are tested for cointegration using the Engle and Granger two step procedure. The results from the cointegration tests are displayed in table 7. All spot and futures price series are found to be cointegrated because null hypothesis of a unit root is strongly rejected for all residuals of the ordinary least squares estimation.

Table 6. Augmented Dickey-Fuller tests of Prices

	Price	Rho	Pr < Rho	Tau	Pr < Tau
ln(Price)	BBCV index	0.069	0.699	0.573	0.839
	5 Market Average Live Steers	0.094	0.704	0.755	0.876
	5 Market Average Dressed Steers	-4.63	0.470	-1.70	0.426
	Live Cattle Futures	-4.574	0.477	-1.754	0.403
	BBCV futures	-6.769	0.289	-1.994	0.289
First Difference of *ln*(Price)	BBCV index	-430.1	<.0001	-17.84	<.0001
	5 Market Average Live Steers	-580.2	<.0001	-22.65	<.0001
	5 Market Average Dressed Steers	-593	<.0001	-23.07	<.0001
	Live Cattle Futures	-584.9	<.0001	-22.71	<.0001
	BBCV index	-516.8	<.0001	-20.54	<.0001

Note: Augmented Dickey-Fuller tests log prices with single mean, and tests first difference of log prices with a zero mean.

Table 7. Cointegration Tests

Spot Price	Futures Price	Rho	Pr < Rho	Tau	Pr < Tau
5 Market Average Live Steers	Live Cattle	-69.136	<.0001	-6.029	<.0001
	BBCV	-162.25	<.0001	-9.597	<.0001
5 Market Average Dressed Steers	Live Cattle	-154.18	<.0001	-9.307	<.0001
	BBCV	-187.34	<.0001	-10.41	<.0001
BBCV index	Live Cattle	-63.840	<.0001	-5.784	<.0001
	BBCV	-63.975	<.0001	-5.785	<.0001

Note: All residuals were tested for single mean.

The ECM as described in the empirical methods was used to estimate optimal hedge ratios in each hedging scenario because all prices are cointegrated. The optimal hedge ratios are presented in table 8. There are six optimal hedge ratios presented in table 8. The hedge ratios are calculated for three different spot prices, 5 market average price for live and dressed steers, and the BBCV index, and two futures prices, live cattle and BBCV futures used to hedge each of the three spot prices. The adjusted r-squares are also reported along with the optimal hedge ratios. The adjusted r-square shows how well the model fits the data, and is commonly thought of as a measure of the effectiveness of the futures hedge. The live cattle futures contract is very effective when hedging the 5 market average price for live and dressed steers, and the BBCV futures contract is very effective when hedging the BBCV index price. The "cross-hedges", hedging the 5 market average price for live steers with the BBCV futures contract and hedging the BBCV index with the live cattle futures contract, are not as effective.

Hedging the BBCV index with the BBCV futures contract is found to be more effective than hedging the 5 market average price for live steers with the live cattle futures contract. This increase in effectiveness must be interpreted carefully, however, because the BBCV futures contract is derived directly from the BBCV index price. When deriving this price, the methods force the futures price to have perfect convergence to the spot price for every futures contract. This allows for the futures prices to be theoretically sound, but does not allow for any market effects that may prevent convergence if the contract was actually trading. The live cattle future contract is exposed to these market effects, which might explain some of the lack of its hedging effectiveness.

Table 8. Optimal Hedge Ratios

Spot Price	Futures Price	Optimal Hedge Ratio β (Adjusted R-squared)
5 Market Average Live Steers	Live Cattle	0.752 (0.622)
	BBCV	0.458 (0.413)
5 Market Average Dressed Steers	Live Cattle	0.677 (0.575)
	BBCV	0.360 (0.378)
BBCV index	Live Cattle	0.382 (0.414)
	BBCV	0.667 (0.667)

Note: ECM was used to estimate all optimal hedge ratios and adjusted r-squares. Number of lagged prices in the ECM were 4 for all 5 market average steer hedges and 5 for both BBCV index hedges.

The cross-hedges are much less effective. The lack of effectiveness when hedging the BBCV index with the live cattle futures contract highlights the problem producer's face in the industry now. When marketing cattle in marketing arrangements that are tied to the BBCV index, the risk management tools available to them are not very effective. These results suggest that if a BBCV futures contract were implemented to replace the live cattle futures contract, the risk management abilities of producers marketing cattle using the BBCV index would increase. However, the risk management abilities of producers marketing cattle in marketing arrangements that are tied to the 5 market average, live and dressed, would decrease.

Finally, we look to the possibility of a BBCV futures contract for hedging price risk of wholesale beef cuts as well. we, as in Mattos et al. (2003) and Yang and Schroeder (2001), estimate optimal hedge ratios for various wholesale beef cuts that make up the composition of the BBCV index itself. These optimal hedge ratios and adjusted r-squares are presented in table 9.

All the optimal hedge ratios were estimated using OLS estimation. The adjusted r-squares are also presented in figure 6, where the gray bars represent the adjusted r-squares when hedging with the BBCV futures and the black bars represent the adjusted r-squares when hedging with the live cattle futures. All the adjusted r-squares when hedging with the BBCV futures contract are higher than the adjusted r-squares when hedging with the live cattle futures contract. This shows that BBCV futures hedge the price risk of wholesale beef cuts much more effectively than live cattle futures.

Table 9. Optimal Hedge Ratios of Wholesale Beef Cuts

Wholesale Beef Cut	Live Cattle HEDGE β	Live Cattle HEDGE Adjusted R-squared	BBCV HEDGE β	BBCV HEDGE Adjusted R-squared
109 E Rib, ribeye, lip-on, bn-in	0.054	0.015	0.231	0.209
112 A Rib, ribeye, bnls, light	0.076	0.028	0.247	0.223
112 A Rib, ribeye, bnls, heavy	0.060	0.017	0.257	0.243
113 C Chuck, semi-bnls, neck/off	0.122	0.054	0.278	0.215
114 Chuck, shoulder clod	0.139	0.063	0.393	0.393
114 A Chuck, shoulder clod, trmd	0.166	0.104	0.352	0.363
115 Chuck, bnls, 2 pc bnls	0.045	0.010	0.151	0.084
116 A Chuck, roll, lxl, neck/off	0.119	0.067	0.279	0.283
116 B Chuck, chuck tender	0.141	0.052	0.391	0.311
120 Brisket, deckle-off, bnls	0.135	0.037	0.363	0.208
120 A Brisket, point/off, bnls	0.023	0.001	0.243	0.112
123 A Short Plate, short rib	0.042	0.012	0.056	0.017
130 Chuck, short rib	0.003	0.000	0.015	0.007
160 Round, bone-in	0.005	0.001	0.023	0.016
161 Round, boneless	0.163	0.053	0.422	0.274
161 Round, bnls, peeled heel-out	0.075	0.015	0.313	0.194
167 A Round, knuckle, peeled	0.170	0.079	0.405	0.343
168 Round, top inside round	0.145	0.085	0.354	0.391
168 Round, top inside round 1	0.164	0.096	0.358	0.354
169 Round, top inside, denuded	0.121	0.044	0.420	0.411
169 A Round, top inside, side off	0.116	0.081	0.220	0.217
170 Round, bottom gooseneck	0.103	0.032	0.327	0.246
171 B Round, outside round	-0.00	0.000	0.006	0.002
171 C Round, eye of round	0.130	0.047	0.357	0.272
174 Loin, short loin, 2X3	0.022	0.002	0.252	0.209
174 Loin, short loin, 0X1	0.060	0.013	0.301	0.268
175 Loin, strip loin, 1X1	0.075	0.030	0.226	0.206
180 Loin, strip loin, bnls, heavy	0.050	0.016	0.196	0.178
180 Loin, strip, bnls, 1X1	0.043	0.008	0.286	0.273
180 Loin, strip, bnls, 0X1	0.074	0.024	0.288	0.284
184 Loin, top butt, bnls, heavy	0.053	0.020	0.178	0.177
184 Loin, top butt, boneless	0.100	0.035	0.305	0.254
185 A Loin, bottom sirloin, flap	0.023	0.002	0.249	0.203
185 B Loin, ball-tip, bnls, heavy	0.061	0.012	0.224	0.128

185 C Loin, sirloin, tri-tip	0.073	0.019	0.182	0.093
185 D Loin, tri-tip, pld	0.038	0.004	0.181	0.086
189 A Loin, tndrloin, trmd, heavy	0.091	0.022	0.341	0.239
191 A Loin, butt tender, trimmed	0.002	0.000	0.013	0.005
193 Flank, flank steak	0.039	0.004	0.212	0.098

All optimal hedge ratios and adjusted r-squares are estimated from OLS estimation.

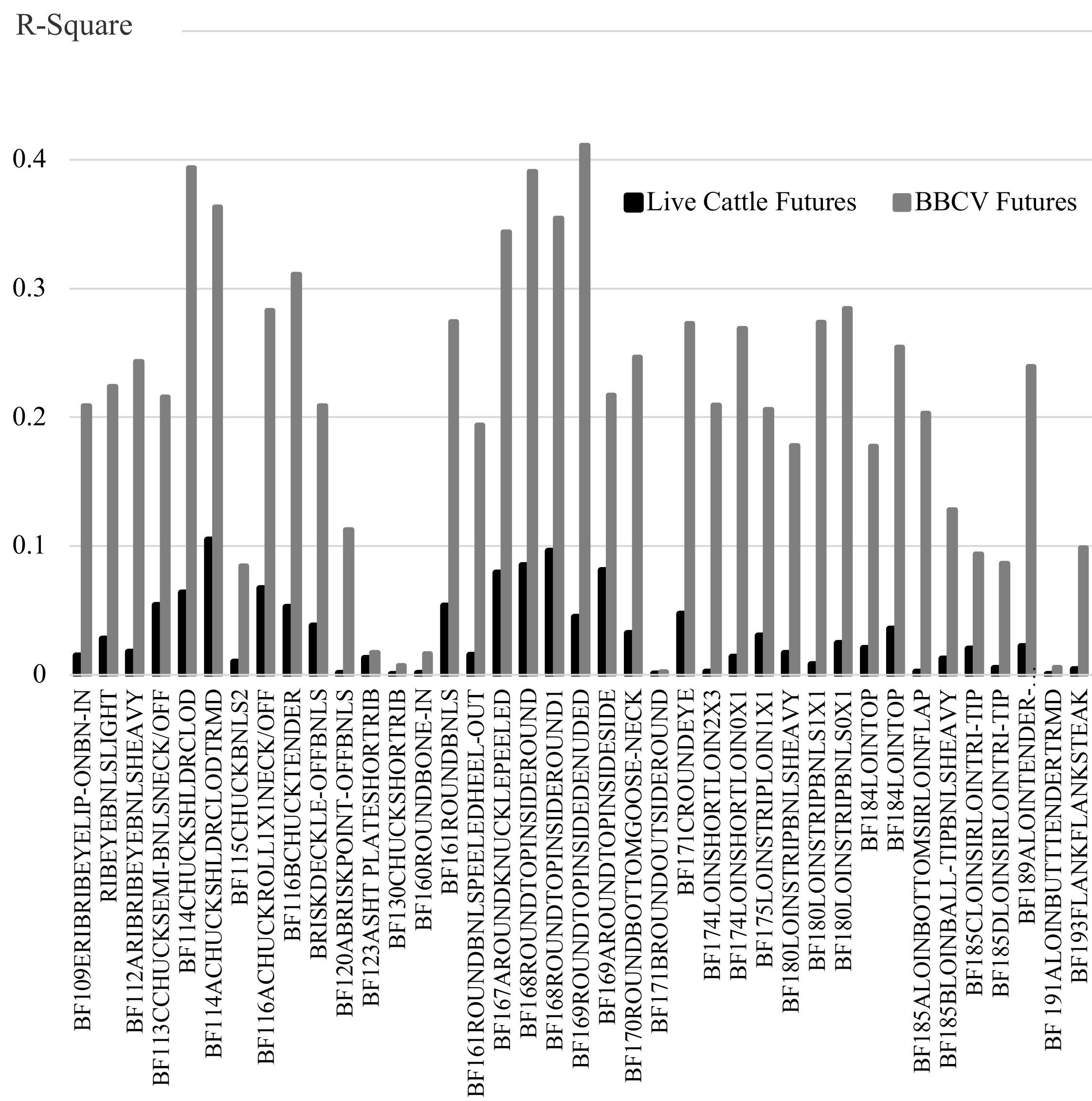

Figure 6. R-Squares of Hedging Wholesale Beef cuts with Live Cattle and BBCV futures

In this chapter, we have presented results from testing the model to derive a hypothetical futures contract for accuracy with futures markets for hogs, deriving a hypothetical BBCV futures contract, and evaluating its effectiveness as a hedging instrument. The results from testing the model for accuracy show that the model we developed to generate hypothetical futures prices has accuracy that is similar to the model for existing futures. The results from evaluating the hypothetical BBCV futures contract as a hedging instrument suggest that if a BBCV futures contract were implemented, it could be more effective at hedging price risk than the live cattle futures contract when using marketing arrangements that were tied to the BBCV. Also, the results show that the live cattle contract is currently ineffective as a hedging instrument for wholesale beef cuts, however, a BBCV futures contract has the potential to be an effective hedging instrument in this market.

Conclusions and Implications

The live cattle futures contract has had issues recently. A BBCV futures contract has been suggested as a possible solution to the problems with the live cattle futures contract. Previous evaluations of the potential of the BBCV futures contract, Yang and Schroeder (2001) and Mattos et al. (2003), were performed under the assumption that a BBCV futures contract's price was equal to the BBCV spot price. This is a restrictive assumption that doesn't allow futures prices to have any term structure across different maturities, which limits any interpretations of the findings in Yang and Schroeder (2001) and Mattos et al. (2003). Until now, no effort has been made to derive a hypothetical futures contract's price series that is conceptually valid under reasonable assumptions.

we extend the ST/LT futures valuation model developed by Schwartz and Smith (2000) to provide a valuation for a hypothetical futures contract. Given an existing futures contract, its spot price, and the spot price that corresponds with the hypothetical futures contract, that hypothetical futures contract can be valued for different maturities.

The methods developed here are tested for validity using futures markets for hogs and cattle. The results presented in show that the methods perform very well, with accuracy similar to that of the ST/LT futures valuation model for existing futures. The methods are applied to live hog and live cattle futures here, however, they are certainly not limited to hog and cattle markets. The methods developed here can easily be extended to other markets to evaluate other proposed futures contracts. Future research could apply these methods to other futures markets to allow the evaluation of other proposed futures contracts.

The live cattle futures contract is not very effective at mitigating price risk when marketing cattle in a marketing arrangement that is tied to the BBCV. The results found suggest that if a BBCV futures contract were implemented, the ability to mitigate price risk when marketing cattle in marketing arrangements that are tied to the BBCV would be improved. On the other hand, the results suggest that if a BBCV contract were implemented to replace the live cattle futures contract, the ability to mitigate price risk when marketing cattle in marketing arrangements that are tied to the 5 market average would be diminished. This is certainly a trade-off, however, agricultural economists have widely recommended using marketing arrangements that are tied to the BBCV in previous research. The live cattle futures contract is currently ineffective at mitigating price risk in wholesale beef markets. The results show that a BBCV futures contract has the potential to be an effective hedging instrument for buyers and sellers of wholesale beef.

A BBCV futures contract could benefit the buyers/sellers of live cattle and wholesale beef, because the BBCV futures contract could improve these two groups ability to manage price risk. Also, a BBCV futures contract could benefit CME Group because a BBCV futures contract has the potential to be a better product than the live cattle futures, which would translate to more trading volume. In addition to this, the BBCV futures has the potential to be used in wholesale beef markets where the live cattle futures is currently ineffective, which would also translate to more trading volume.

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Appendix

In this appendix, we present the results from testing data and estimating all state variables and parameters required to generate futures prices. First, we present the results for live and lean hog futures. Second, we present the results for live cattle and BBCV futures.

Estimation of State Variables and Parameters Used to Generate Live and Lean Hog Futures Prices

In the following section, we discuss the results from estimating the state variables and parameters needed to generate four futures price series for hogs. First, we discuss the state variables and parameters needed to generate in-sample live hog futures. Second, we discuss the state variables and parameters needed to generate out-of-sample live hog futures. Third, we discuss the state variables and parameters needed to generate out-of-sample lean hog futures.

In-Sample Live Hog Futures

First, we estimated the ST/LT model with seasonal component for live hog futures as discussed in the empirical methods. we estimated the ST/LT model with varying dimensions of the measurement equation to fit the observations of live hog futures prices that were available as shown in figure 4. The parameter estimates from this model are reported in table A.1. These parameters and state variables were used to generate in-sample live hog futures prices as discussed in the empirical methods.

Table A.1 Parameter Estimates of ST/LT model for live hogs from 12/07/1984 to 11/29/1996

Parameter	Definition	Estimate (Standard Error)
κ	Short-term mean reversion rate	1.89***(0.087)
σ_χ	Short-term volatility	24.1%***(0.010%)
λ_χ	Short-term risk premium	20.6%***(1.89%)
μ_ξ	Equilibrium drift rate	-0.733%(3.45%)
σ_ξ	Equilibrium volatility	12.9%***(0.562%)
μ_ξ^*	Equilibrium risk neutral drift rate	-1.14%(0.524%)
$\rho_{\xi\chi}$	Correlation of increments	-0.396***(0.053)
s_1	Standard deviation of error for measurement equation	0.002***(0.0001)
s_2	"	0.0000***(0.0000)
s_3	"	0.000***(0.0000)
s_4	"	0.000***(0.0000)

s_5	"	0.000***(0.0000)
s_6	"	0.000***(0.0000)
s_7	"	0.000***(0.0000)
β_{Jan}	Monthly Seasonal Variable	-0.041***(0.007)
β_{Feb}	"	0.011***(0.001)
β_{Mar}	"	-0.073***(0.007)
β_{Apr}	"	-0.029***(0.001)
β_{May}	"	-0.016***(0.003)
β_{Jun}	"	0.073***(0.001)
β_{Jul}	"	0.077***(0.001)
β_{Aug}	"	0.050***(0.001)
β_{Sep}	"	0.002(0.007)
β_{Oct}	"	-0.030***(0.001)
β_{Nov}	"	0.083***(0.007)

Note: *, **, and *** denote parameter estimates that are statistically different from zero at the 10, 5, and 1 percent levels, respectively.

Out-of-Sample Live Hog Futures

Second, we estimated the ST/LT model with futures for expiration in 1995 and earlier, dropping the last year of data, as discussed in the empirical methods. The parameters[6] and state variables estimated from this model were used to generate out-of-sample live hog futures prices as discussed in empirical methods and shown in figure 5.

Out-of-Sample Lean Hog Futures with Kalman Filter Model

Third, we estimated the additional parameters needed to generate hypothetical lean hog futures prices. The state variables and parameter estimates shown in table A.1 were used to generate the lean hog futures. The methods to generate hypothetical futures also require the relationship between ξ_t^H and ξ_t^E to be estimated, and the parameters of the process of ξ_t^H to be estimated. The results of stationarity and cointegration testing for live and lean spot prices are presented in table A.2. Both spot prices are non-stationary in levels because the null hypothesis of a unit root is not rejected in *ln*(price) for both prices and both statistics. On the other hand, the first differences of both prices are stationary because the null hypothesis is strongly rejected for both test statistics. Results of the coinegration test indicate that the two prices are cointegrated

[6] The parameter estimates from this model are not reported here because they were almost identical to the parameter estimates shown in table A.1.

because the residuals of the OLS regression of the two prices are stationary. Therefore, the ECM is used to estimate the relationship between the long term equilibrium price levels of the live and lean hog futures.

Table A.2 Augmented Dickey-Fuller Tests of Live Hog spot price and Lean Hog spot price for Stationarity and Cointegration

Price Level	Spot Price	Rho	Pr < Rho	Tau	Pr < Tau
ln(Price)	Live Hogs	0.069	0.699	0.573	0.839
	Lean Hogs	0.094	0.704	0.755	0.876
First Difference of *ln*(Price)	Live Hogs	-430.1	<.0001	-17.84	<.0001
	Lean Hogs	-580.2	<.0001	-22.65	<.0001
Test of Residuals of OLS regression for cointegration	Both	-65.4	<.0001	-6.07	<.0001

The estimated relationship between the long term equilibrium price levels is given by:

$$\xi_t^H = f\left(\xi_t\right) = 0.56645 + 0.93939\xi_t^E \,. \tag{A.1}$$

This relationship is used to derive all the long term equilibrium price levels of the hypothetical lean hog futures. The parameters that describe the process of ξ_t^H were estimated from the ST/LT model using only the lean hog index in the vector of observed futures as described in the empirical methods. The parameter estimates of the process of ξ_t^H are shown in table A.3. The parameter estimate for μ_ξ^H is not statistically different from zero. Therefore, μ_ξ^H was set equal to zero in the model to generate hypothetical lean hog futures.

Table A.3 ξ_t^H process parameter estimates

Parameter	Estimate (Standard Deviation)
μ_ξ^H	1.36% (6.62%)
σ_ξ^H	24.05%*** (1.15%)

Note: *, **, and *** denote parameter estimates that are statistically different from zero at the 10, 5, and 1 percent levels, respectively. The parameter estimate for μ_ξ^H is not statistically different from zero, therefore, μ_ξ^H was set to zero in the futures generation function.

The parameters needed from table A.1 and A.3, and the state variables calculated using the relationship shown in equation (A.1) were used in the model for hypothetical futures to generate the out-of-sample hypothetical lean hog futures prices.

Estimation of State Variables and Parameters Used to Generate BBCV Futures Prices

In the following section, we discuss the results from estimating the state variables and parameters needed to generate BBCV futures prices. First, we discuss the state variables and parameters needed to generate BBCV futures prices with the primary method. Second, we discuss the state variables and parameters needed to generate BBCV futures prices with the SUR method.

BBCV Futures with the Kalman Filter Model

The ST/LT model was estimated using a vector of 6 futures prices and the spot price, as shown in table 5.3. The seasonal model was estimated because cattle prices have a seasonal pattern that must be accounted for. The resulting parameter estimates are shown in table A.4.

Table A.4 Parameter Estimates of ST/LT model with seasonal component for live cattle prices

Parameter	Definition	Estimate (Standard Error)
κ	Short-term mean reversion rate	1.67 (0.079)
σ_{χ}	Short-term volatility	15.1% (0.676%)
λ_{χ}	Short-term risk premium	-3.52% (1.89%)
μ_{ξ}	Equilibrium drift rate	1.66% (2.36%)
σ_{ξ}	Equilibrium volatility	8.80% (0.339%)
μ_{ξ}^{*}	Equilibrium risk neutral drift rate	-4.03% (0.339%)
$\rho_{\xi\chi}$	Correlation of increments	-0.253 (0.056)
s_1	Standard deviation of error for measurement equation	0.001 (0.0000)
s_2	″	0.000 (0.0000)
s_3	″	0.000 (0.0000)
s_4	″	0.000 (0.0000)

s_5	″	0.000 (0.0000)
s_6	″	0.000 (0.0000)
s_7	″	0.000 (0.0000)
β_{Jan}	Monthly Seasonal Variable	0.013 (0.004)
β_{Feb}	″	0.011 (0.000)
β_{Mar}	″	0.035 (0.004)
β_{Apr}	″	0.014 (0.001)
β_{May}	″	0.018 (0.004)
β_{Jun}	″	-0.030 (0.001)
β_{Jul}	″	-0.032 (0.004)
β_{Aug}	″	-0.036 (0.001)
β_{Sep}	″	-0.018 (0.004)
β_{Oct}	″	-0.010 (0.001)
β_{Nov}	″	0.000 (0.004)

Note: Estimated with prices from 12/05/2003 to 1/27/2017.

Table A.5 Augmented Dickey-Fuller Tests of Live Cattle spot price and BBCV spot price for Stationarity and Cointegration

Price Level	Spot Price	Rho	Pr < Rho	Tau	Pr < Tau
Ln(Price)	Live Cattle	-4.766	0.4576	-1.77	0.3957
	BBCV	-6.074	0.3409	-1.90	0.3300
First Difference of Ln(Price)	Live Cattle	-579.5	0.0001	-22.62	<.0001
	BBCV	-430.6	0.0001	-17.85	<.0001
Test of Residuals of OLS regression for cointegration	Both	-110.6	0.0001	-7.76	<.0001

The methods to generate hypothetical futures also require the relationship between ξ_t^H and ξ_t^E to be estimated and the parameters of the process of ξ_t^H to be estimated. The results of stationarity and cointegration testing are presented in table A.5. Both spot prices are non-stationary in levels because the null hypothesis of a unit root is not rejected in *ln*(Price) for both prices and both statistics. On the other hand, the first differences of both prices are stationary because the null hypothesis is strongly rejected for both test statistics. The results of the cointegration test indicate that the two prices are cointegrated because the residuals of the OLS regression of the two prices are stationary. Therefore, the ECM is used to estimate the relationship between the long term equilibrium price levels of the live and lean hog futures.

The estimated relationship between the long term equilibrium price levels is given by:

$$\xi_t^H = f\left(\xi_t\right) = 1.01647 + 0.88728\xi_t^E \ . \qquad \text{(A.2)}$$

This relationship is used to derive all the long term equilibrium price levels of the hypothetical BBCV futures. The parameters that describe the process of ξ_t^H were estimated from the ST/LT model using only the BBCV index in the vector of observed futures as described in the empirical methods section. The parameter estimates of the process of ξ_t^H are shown in table A.6. The parameter estimate for μ_ξ^H is not statistically different from zero. Therefore, μ_ξ^H was set equal to zero in the model to generate hypothetical BBCV futures.

Table A.6 ξ_t^H process parameter estimates

Parameter	Estimate (Standard Deviation)
μ_ξ^H	7.141% (5.49%)
σ_ξ^H	12.343***% (0.836%)

These parameter estimates and the state variables obtained from the model estimation are used to derive hypothetical BBCV futures contracts for each live cattle futures contract for expiration between 2005 and 2017. The BBCV futures contracts prices derived have the same time of expiration and length of trading period as the live cattle futures contracts with the same month of expiration. This facilitates the comparison of both contracts as risk management tools.