Essays on beef cattle economics

by

Melissa Gale Short McKendree

B.S., University of Florida, 2011
M.S., Purdue University, 2013

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
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Abstract

The U.S. beef industry is comprised of multiple, vertically connected segments. Beginning at the cow-calf level, cattle move through the industry to backgrounding/stocker operations, feedlots, and then to beef packers. The beef produced then continues to move through the marketing channel from beef packers to wholesalers and on to multiple final consumer outlets. Each level of the beef industry has both distinct and related economic issues. This dissertation contains three essays on beef cattle economics. Essay 1 focuses on price and animal health risk management at the feedlot level. Essays 2 and 3 explore how upstream demand changes impact primary beef suppliers.

The objective of Essay 1 is to determine if feedlot operators manage price risk and animal health risk as two separate and independent risks or if they manage them jointly. The animal health attribute of interest is purchasing feeder steers from a single known source versus an auction with unknown background. The output price risk mitigation tools are futures contracts, forward contracts, other, and accept cash price at time of sale. Primary data is collected using an online survey administered to feedlot operators. Participants are placed in forward looking, decision making scenarios utilizing a split-sample block design. Evidence of a relationship between animal health risk and output price risk management is mixed.

Ricardian rent theory (RRT) is tested in Essay 2 to determine if complete pass-through occurs from fed cattle and corn prices to feeder cattle prices. Monthly price data from December 1995 to December 2016 is used. Based on RRT, surplus rents should pass through the market to the holder of the scarcest resource. In cattle markets, feeder calves are the scarcest, widely traded resource and thus gains and losses at the feedlot theoretically pass-through to feeder cattle prices. The hypothesized pass-through rates suggested by RRT is calculated using monthly

production data from the *Focus on Feedlots* data series. The regression pass-through estimates are tested against the hypothesized RRT pass-through. In many models, the estimated pass-through rate is statistically greater than the RRT hypothesized pass-through rate. Thus, when fed cattle or corn prices change, these changes are more than fully passed to cow-calf producers through the feeder cattle price. Evidence is found of asymmetric pass-through during times of herd expansion versus contraction.

Essay 3 provides a quantification of how changes in retail and export beef demand are transmitted to different members of the beef industry. Understanding how information is transmitted from primary consumer demand through the supply chain is key for long-term prosperity of the U.S. cattle industry. However, empirical applications quantifying how demand signals are transmitted through vertically connected industries are limited. Using both naïve and forward looking price expectations, a four equation system of inverse demand and supply equations for live and feeder cattle is estimated. Using retail and export beef demand indices, the impacts of 1% change in retail or export demand on live cattle and feeder cattle prices are quantified.

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Table of Contents

List of Figures

List of Tables

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Dedication

To my amazing support system of family and friends, especially Buddy, Mom, Dad, and my grandparents

Chapter 1 - Introduction

The U.S. beef industry is composed of multiple, vertically connected segments with unique and related economic issues (Figure 1.1). Cows mother and rear calves in the cow-calf sector. The bovine gestation is nine months. After the calf is born it remains with its mother until weaning, around six to ten months of age. After weaning, steer calves are either retained by cow-calf operations, adding additional weight before being sold to a feedlot, or sold to a stocker and backgrounder operation. Heifer calves can be also retained by cow-calf operations for breeding, either to expand herd size or replace existing breeding stock.

At stocker and backgrounder operations, calves are put on pasture or may be introduced to a forage-based growing diet in a drylot. Next, calves are sold to a feedlot operation at around 12 to 18 months of age, and are considered yearlings. The yearlings are fed a grain intensive diet, primarily composed of corn, at the feedlot and are housed in a pen with around 125 to 150 other yearlings. During the four to six months at the feedlot the animal will continue to gain weight until they are sold to a meat packing plant. Historically, harvest weight has been between 1,100 and 1,300 lbs, but has increased to around 1,400 lbs recently (Figure 1.2) (Livestock Marketing Information Center, 2017). After harvest, the meat and byproducts are processed and sold through multiple outlets. These outlets include domestic outlets such as grocery stores, restaurants, and institutions, as well as exports.

This dissertation is a collection of three essays related to important economic issues in the beef industry. Essay 1, “Management of multiple sources of risk in livestock production,” investigates if and what type of relationship (independent, substitutes, or complements) exists between feedlot operators’ decisions about output price and animal health risk mitigation strategies. Primary data is collected using an online survey of feedlot operators. The survey places producers in a forward looking mindset. Using a split-sample design, producers are either asked feeder cattle placement or output price hedging scenarios. The animal health risk mitigation strategy of interest is single sourced feeder steers versus steers comingled from multiple sources with unknown backgrounds (auction). The output price risk mitigation strategies considered are futures hedge, forward contract, accept cash price at time of sale, and other. A complementary relationship between animal health risk and output price risk mitigation strategies is found in feeder cattle purchasing scenarios. However, little evidence of a relationship is found between output price and animal health risk mitigation strategies in the output price risk hedging scenarios. Persistence of past output pricing behavior is evident. Potentially, the complementary relationship in feeder cattle procurement questions but not output oriented questions stems from the structure of the beef industry; there are more options when buying feeder cattle than when selling finished cattle.

Essay 2, "Testing Ricardian rent theory in the U.S. beef industry across time," focuses on the idea of fed cattle and corn price transmission to feeder cattle price. The objective is to determine if Ricardian rent theory holds in the U.S. beef industry by examining the pass-through rates from fed cattle to feeder cattle price and from corn to feeder cattle price. Monthly feedlot production data (placement weight, finished weight, feed conversion ratio, etc.) from *Focus on Feedlots* is used to estimate pass-through rates hypothesized by Ricardian rent theory. These hypothesized values are compared to actual pass-through rates from econometric regressions. Actual pass-through rates are investigated using futures prices and expected prices (incorporating basis). Additionally, given the many changes in the U.S. beef industry (e.g., increased finishing weights, U.S. recession, bovine spongiform encephalopathy (BSE) discovery, etc.), the robustness of pass-through rates across time are investigated. Pass-through asymmetry during times of fed cattle price increases and decreases, and during times of herd expansion and contraction are explored. Overall, pass-through rates are greater than 100%, and pass-through is asymmetric during times of herd expansion versus contraction. This large pass-through can benefit cow-calf producers when fed cattle prices increase, potentially from retail demand increases, or corn price decreases. However, adverse shocks, such as BSE, can be more than proportionally passed back to cow-calf operations.

Essay 3, "Impacts of retail and export demand on U.S. cattle producers," explores how changes in retail and export beef demand impact upstream members in the beef supply chain, in particular, feedlot operators and feeder cattle producers. Using both naïve and forward looking price expectations, a four equation system of inverse demand and supply equations for live cattle and feeder cattle is estimated. Using retail and export beef demand indices, the impacts of a 1% change in retail or export demand on live cattle and feeder cattle prices are quantified. A "what-if" analysis is completed to demonstrate how one index point and one standard deviation changes in retail and export demand impact these prices. Additionally, decompositions of predicted values demonstrates how quantity of live cattle supplied, retail demand, and export demand impacted the live cattle price during key time periods. Overall, essays 2 and 3 demonstrate the importance of understanding conceptually and numerically how changes in vertically and horizontally connected markets impact primary beef suppliers.

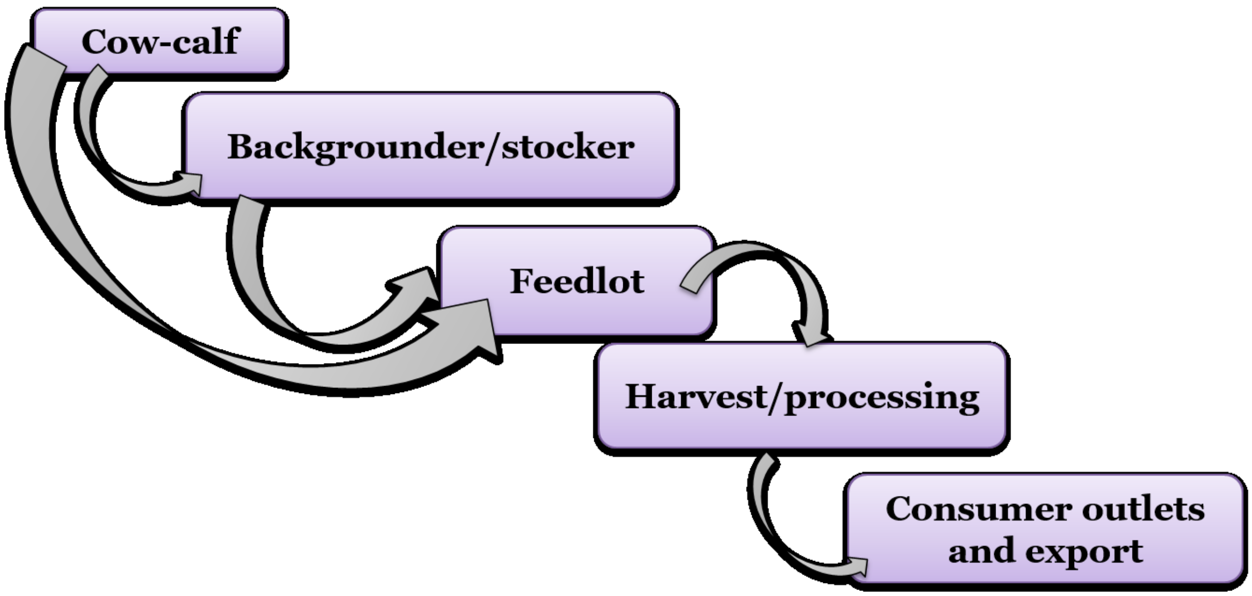

Figure 1.1 U.S. beef marketing chain

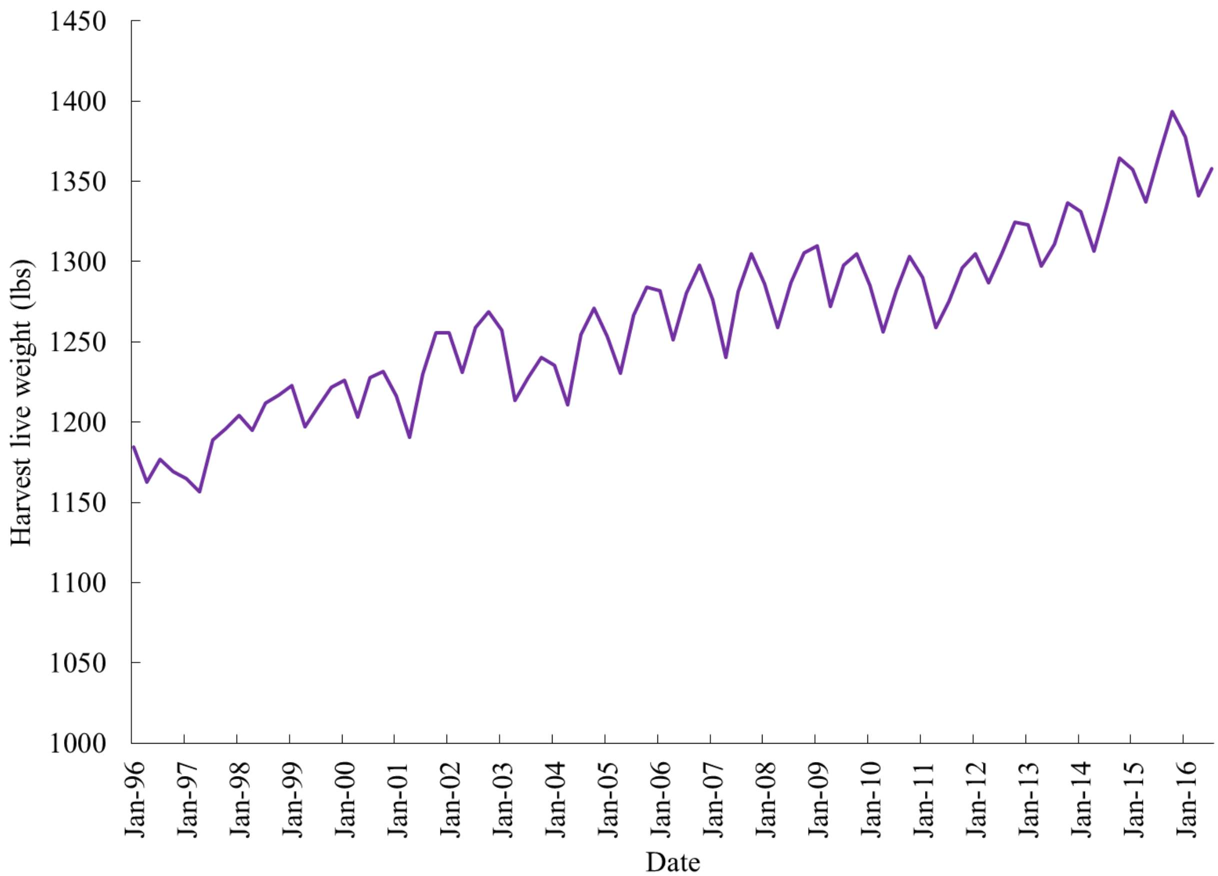

Figure 1.2 Historical live cattle harvest weight in lbs

References

Livestock Marketing Information Center (LMIC). *Livestock Marketing Information Center Spreadsheets*, http://www.lmic.info/members/spreadsheets. 2017.

Chapter 2 - Management of multiple sources of risk in livestock production

This issue of managing multiple types of risk is prevalent in agriculture. For example, Du, Ifft, Lu, and Zilberman (2015) look at the relationship between crop producers' use of marketing contracts and crop insurance. Similar to crop producers, cattle feedlot operators face multiple types of risk, which can impact profitability. Such risks include price, production, animal health, disease outbreaks, weather, business, and financial risk. How do feedlot operators and their team of experts make decisions in this risky environment? Researchers have largely focused on the role of futures and options markets to mitigate price risk from feeder cattle, live cattle, and corn prices (Tonsor & Schroeder, 2011; Hart, Babcock, & Hayes, 2001; Mark, Schroeder, & Jones, 2000; Schroeder & Hayenga, 1988). However, little work has examined relationships between different types of risk feedlot operators face and available risk mitigation strategies. In an example of the limited research on both price and animal health risk, Belasco, Taylor, Goodwin, and Schroeder (2009) developed an ex-ante model of price and yield risks associated with cattle feeding. They determined that both animal health and price risk have statistically significant impacts on the conditional mean and variability of profits. However, no study has investigated how feedlot producers actually view the management of multiple types of risk. To better understand tradeoffs and relationships between risk management decisions, our analysis will focus on the relationship between output price and animal health risk management.

Our objective is to determine if feedlot producers view/manage output price risk and animal health risk as two separate and independent risks or if they view them jointly. To accomplish this, we conduct a survey that places feedlot operators in forward looking, decision making scenarios. If producers approach risk jointly, understanding if mitigation strategies for output price risk and animal health risk are substitutes or complements is important. Knowing if and what kind of relationship exists between animal health and output price risk mitigation can inform the development of more complete risk mitigation strategies so producers can better manage their risk portfolio. As part of meeting this objective, we will also map out use of price risk and animal health risk mitigation strategies in the feedlot industry.

Whether cattle feedlot operators view output price and animal health risk independently or jointly is unknown. Operations have a fixed budget. Therefore, feedlot operators could decide to implement increased animal health risk mitigation strategies instead of hedging using futures market contracts (substitute relationship). Conversely, animal health and output price risk mitigation strategies could be complements. Animal health practices could decrease the uncertainty in production and therefore operators could better match their production to futures contracts, increasing the use of futures contracts. This could possibly help explain past "surprises" by analysts when producers have hedged price risk less than "expected" (Goodwin & Schroeder, 1994).

Goodwin and Schroeder (1994) and Belasco et al. (2009) state that price risk is one of the largest risks faced by producers. Feedlot operators face price risk for inputs, primarily feeder cattle and corn, and output prices, live cattle. Hedging alternatives, including forward contracts and futures contracts, exist to allow feedlot operators to manage price risk. However, feedlot operations do not hedge as much as many academic studies suggest they should (Moschini & Hennessy, 2001; Goodwin & Schroeder, 1994). There are likely multiple factors which contribute to lower than expected participation in hedging. One potential explanation examined in this study is if operators are making tradeoffs in their risk management decisions. For output price risk management we will focus on hedging of live cattle price using futures contracts, forward contracts, other programs, and accepting cash (spot market) price at time of sale.

In addition to output price risk, feedlot operators face animal health risks that extend beyond feed conversion and average daily gain. For instance, animal disease events may be rare but are often damaging if not devastating to operations that experience drastic reductions in output or spikes in production costs (Schroeder, Pendell, Sanderson, & McReynolds, 2015). Many factors contribute to the potential disease risk of cattle coming into a feedlot including "source, age, distance transported, previous health management, amount of comingling, shrink, and weather conditions" (Rambo, 2014). When feedlot operators are looking to place a lot of feeder cattle, they can buy the number of head desired from a single seller (i.e. a single farm) or assemble the required number of head from multiple sources (i.e. an auction). When placed in feedlots, cattle are faced with adapting to new environments, establishing a social hierarchy, and adjusting to a new diet (Rambo, 2014). Due to these and other factors, lots composed of feeder cattle purchased from multiple sources are considered a higher risk for animal disease than feeder cattle purchased from a single source (Rambo, 2014). Single source of origin will be the animal health risk mitigation practice of interest.

Conceptual model

Feedlot operator i will make decisions to maximize their expected utility, EU_i:

$$EU_i = E[U_i(w_{0,i} + \tilde{\pi}_i)] \tag{1}$$

where $w_{0,i}$ is initial wealth and $\tilde{\pi}_i$ is profit, a random variable (Moschini & Hennessy, 2001).[1] Profit for the total operation is the sum of profit per pen (b pens),

[1] Subscript i is dropped hereafter for notational convenience. A time subscript is omitted.

$$\tilde{\pi} = \sum_{b} \widetilde{\pi_b}. \quad (2)$$

Profit per pen of cattle is a function of input and output prices and quantities. However, when feedlot operators place cattle there is uncertainty about both prices and quantities. This uncertainty makes profit a random variable. Following Moschini and Hennessy (2001), profit can be written as:

$$\tilde{\pi} = PG(x; \tilde{e}) - rx - K \quad (3)$$

where P is output price, $G(x; \tilde{e})$ is a stochastic production function where realized output depends on the input vector x and a random variable $\tilde{e}$, r is a vector of input prices, and K is fixed costs. This framework can be adapted to feedlot operators' decision making under price and animal health risk. We consider two scenarios, allowing one risk type to vary while holding the other fixed.

First, consider how animal health production practices impact profit, holding live cattle price constant. A relationship between feeder cattle quantity placed, Q^{FC}, and live cattle quantity produced, Q^{LC}, exists. Additionally, the relationship between feeder cattle pounds placed and live cattle pounds at finishing will be a function of animal health production practices, $z = \{additional\ animal\ health\ practice\ (AH),\ standard\ practices\ (ST)\}$. For example, an additional animal health practice might be purchasing cattle from a single, known source. While cattle are being fed they can potentially get sick and therefore their final finish weight is uncertain. Additionally, due to death loss, the total number of finished head is uncertain. Thus, the production function depends on the specific practices used,

$$Q_{AH}^{LC} = f(Q_{AH}^{FC}, x_{AH}; \tilde{e}) \quad (4)$$

$$Q_{ST}^{LC} = g(Q_{ST}^{FC}, x_{ST}; \tilde{e}). \quad (5)$$

Potentially, due to factors such as seasonality and other feedlot characteristics, $f(.)$ and $g(.)$ could be related. Therefore, profit functions can be written as:

$$\widetilde{\pi_{AH}} = \widetilde{P^{LC}} * f(Q_{AH}^{FC}, x_{AH}; \tilde{e}) - \widetilde{P_{AH}^{FC}} * Q_{AH}^{FC} - rx_{AH} - K \quad (6)$$

$$\widetilde{\pi_{ST}} = \widetilde{P^{LC}} * g(Q_{ST}^{FC}, x_{ST}; \tilde{e}) - \widetilde{P_{ST}^{FC}} * Q_{ST}^{FC} - rx_{ST} - K \quad (7)$$

where P^{LC} is live cattle price per hundred weight (cwt) (finished cattle, output), P_z^{FC} is feeder cattle price per cwt, Q_z^{LC} is total cwts of cattle produced (output lbs), Q_z^{FC} is total cwts of feeder cattle purchased (input lbs), and x_z is a vector of other input quantities. Other inputs costs, including feed costs, veterinary costs, and labor, will vary by pen and production practices used specifically for that pen. Therefore, additional animal health practices impact profit through differences in premiums paid for feeder cattle, production costs, and live cattle lbs produced.

Now, consider how price risk management strategies impact profitability, assuming animal health practices remain constant. We assume operators are price takers. However, they can have some control over if/when they lock in input and output prices through hedging. A feedlot operator can hedge feeder cattle, live cattle, and corn prices using futures contacts, forward contracts, or other tools. Alternatively, the operator can decide to not hedge prices and accept cash prices at time of sale. Hedging allows producers to decrease price risk (uncertainty about prices) compared to accepting cash price at time of sale. Consider the formula,

$$net\ price = futures\ price + basis. \quad (8)$$

Hedging using futures contracts locks in the futures price component of equation (8) and only allows basis risk. Basis risk is usually less than cash price risk. Hedging using forward contracts often locks in both futures price and basis, eliminating all price risk.[2] Hedging protects

[2] Third party default risk is ignored.

producers from adverse price movements. However, one downfall of hedging with futures or forward contracts is producers cannot benefit from price movements in their favor. Thus, price risk management strategies impact input and output prices that directly impact profitability. For simplicity, assume feedlot operators only hedge live cattle (output price) and feeder cattle prices, or use cash markets, $h = \{hedged\ price\ (H),\ cash\ price (C)\}$. Then profit can be written as:

$$\widetilde{\pi_H} = \widetilde{P_H^{LC}} * G(Q^{FC}, x; \tilde{e}) - \widetilde{P_H^{FC}} * Q_{FC} - rx - K \quad (9)$$

$$\widetilde{\pi_C} = \widetilde{P_C^{LC}} * G(Q^{FC}, x; \tilde{e}) - \widetilde{P_C^{FC}} * Q_{FC} - rx - K. \quad (10)$$

Therefore, profit can vary based on differences in prices paid for inputs and received for outputs when using cash markets only versus hedging.

Futures contracts are standardized meaning they have a set delivery date, quality, and quantity. The CME live cattle contract is for 40,000 lbs of finished cattle. Assume that, on average, the operator expects finished steers to weigh 1,400 lbs each. To almost fully hedge a pen of 150 steers (210,000 lbs) the feedlot operator would sell five live cattle contracts (covering approximately 143 steers) for six months in the future. However, what happens if cattle in the pen get sick and only finish at 1,250 lbs each? Now the five live cattle contracts cover 160 cattle each weighing 1,250 lbs. The pen is "over-hedged." The operator is now a speculator on ten cattle. A similar thought exercise can be completed for other hedging alternatives such as forward contracts.

One link between hedging output price risk and animal health production practices could be the expectation of total pounds of finished cattle. If there is a large variance in pounds produced per pen, then feedlot operators may be less likely to hedge because they cannot properly assess the number of futures contracts they should use or specifications they should agree to in a forward contract. If animal health production practices decrease the variability in finishing weight and death loss, then operators can make more informed output price hedging decisions. Thus, operators avoid adding risk associated with becoming a futures market speculator or not being able to meet forward contract agreements.

There can be a substitution, complementary, or no relationship between output price risk and animal health risk mitigation strategies. Risk mitigation strategies are not free and feedlot operations have a limited budget. A feedlot operator could decide the feedlot should only invest in animal health mitigation strategies instead of also managing output price risk. This would be an example of substitution. Alternatively, operators could view output price and animal health risk mitigation strategies as complements. Certain animal health risk mitigation strategies can decrease uncertainty about the pounds of animals produced. This decreased uncertainty will allow producers to make more informed hedging decisions. Additionally, there could be no relationship between feedlot operators' decisions regarding price risk mitigation and animal health risk mitigation strategies. Determining this relationship is a core component of our analysis. We hypothesize there is some relationship between output price risk and animal health risk mitigation strategies. However, to investigate this hypothesis we need to look at the individual feedlot operators' decision making process and past risk management behavior.

Data collection

Primary data was collected from feedlot operators using online surveys sent out via an anonymous email link. See Appendix A for full survey instrument. The survey was programmed using Qualtrics. Feedlots in Colorado, Iowa, Nebraska, Kansas, and Texas were targeted. These states comprise five of the eight states in the five market average price reported by the USDA and are home to 80% of cattle on feed at feedlots with 1000+ head capacity (U.S. Department of Agriculture [USDA], 2017a). Survey links were emailed to members/subscribers by the Colorado Livestock Association, Iowa Cattlemen's Association, Kansas Livestock Association, Nebraska Cattleman, Texas Cattle Feeders Association, and Feedlot Magazine. The authors did not have access to the email lists of the participants as the organizations sent the link themselves. Therefore we do not know the total number of operations who received an invitation to complete the survey. Additionally, an operation could have received an invitation from multiple sources (i.e. their state association and Feedlot Magazine). However, the "prevent ballot box stuffing" option was used in Qualtrics to prevent participants from taking the survey more than once. The survey launched on January 19, 2017 and ended on February 14, 2017.[3] In addition to the core choice experiment, data on operator and operation demographics, past risk management, and views on risk were collected.

There were 588 responses.[4] However, 232 participants whose operation did not include a feedlot and/or who did not make price risk or animal health risk management decisions were dismissed from the survey after questions 1 and 2. Additionally, 75 participants who qualified to continue, but did not answer any questions past question 13 were considered not usable. Thus, only 281 were usable responses for this analysis.

Summary statistics for all the useable responses are shown in Table 2.1. The average respondent age is 49 years old, with a minimum and maximum age of 23 and 85 years, respectively. Nearly half of the participants have at least a Bachelor's degree. Feedlot operators from Iowa comprise 50% of the sample, Nebraska 19%, Texas 10%, Kansas 6%, and Colorado

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[3] Colorado Livestock Association sent survey link on February 8. Feedlot Magazine sent survey link on January 19 and 26. Iowa Cattlemen's Association sent survey link on January 19 and 26. Kansas Livestock Association sent link on January 19 and 30. Nebraska Cattleman sent survey link on January 23 and 30. Texas Cattle Feeders Association sent survey link on January 24 and 30.

[4] Total distribution numbers are not known and therefore a response rate is not given.

5%. Nineteen percent of respondents are from medium sized operations (defined as having sold between 8,000 and 31,999 fed cattle in the last 12 months) and 16% from large operations (defined as having sold more than 32,000 fed cattle in the last 12 months). Just over 20% of participants are considered custom feeders owning less than 40% of their cattle.

To better understand participant's price expectations they were asked if they believed the August CME live cattle contract price would settle higher, lower or the same as today. Nearly 29% of participants think the August CME contract price will increase. Participants were asked a series of questions to gauge their risk aversion following the Global Risk-Attitude Construct (Pennings & Garcia, 2001). These variables collapse down to one factor via a factor analysis. Therefore, only one question, Q13.1, is included in our analysis. Participants are considered risk averse if they somewhat agree, agree, or strongly agree with the statement, "I usually like "playing it safe" (for instance, "locking in a price") instead of taking risks for market prices for fed cattle." Since single source feeder cattle purchases and fed cattle price hedging are of key interest, participants were asked about their past behaviors. Nearly 65% of participants have purchased single source calves before. On average, participants hedge 19% and 18% of their finished cattle using futures and forward contracts, respectively. However, these hedging percentages range from 0 to 100%.

Research methodology: Past behavior

Past feeder cattle procurement and output price hedging behavior can be used as a simple test of if a relationship between animal health risk (single source feeder cattle) and output price risk mitigation exists. Participants were asked the following questions:

Question 4: On average, what percentage of feeder cattle does your operation source from (should sum to 100%):

______ Traditional auction

______ Satellite/video auction

______ Purchased direct from seller (ranch)

______ Home raised from own cow-herd

______ Custom fed, so I did not buy or own animals

______ Other (please describe):

Question 8: In the past 12 months, what percentage of the following pricing methods did your operation use for marketing finished cattle (should sum to 100%):

______ Spot cash market

______ Forward contract or marketing agreement

______ Futures hedge

______ Options hedge

______ Livestock Risk Protection (LRP) Insurance

______ Livestock Gross Margin (LGM) Insurance

______ Other (please describe):

Using the answers to these two questions, Tobit models can be estimated to test if a relationship between past purchasing of feeder animals direct from seller and past output price hedging exists. Specifically, purchased direct from seller and spot cash market (no output price hedging) will be the main variables of interest. The two latent variables of interest (indicated with a * subscript), the percent of feeder cattle purchased direct from seller ($directseller_i^*$) and the percent of finished cattle marketed on the spot cash market ($spot_i^*$), can be modeled as:

$$directseller_i^* = \delta_1 spot_i + \boldsymbol{X}'_{direct,i}\boldsymbol{\beta}_{direct} + \varepsilon_{direct,i} \qquad (11)$$

$$spot_i^* = \delta_2 directseller_i + \boldsymbol{X}'_{spot,i}\boldsymbol{\beta}_{spot} + \varepsilon_{spot,i} \quad (12)$$

where the relationships between the latent variables and the observed variables are:

$$directseller_i = \begin{cases} directseller_i^* & if\ 0 \le directseller_i^* \le 100 \\ 0 & if\ directseller_i^* < 0 \\ 100 & if\ directseller_i^* > 100 \end{cases} \quad (13)$$

$$spot_i = \begin{cases} spot_i^* & if\ 0 \le spot_i^* \le 100 \\ 0 & if\ spot_i^* < 0 \\ 100 & if\ spot_i^* > 100. \end{cases} \quad (14)$$

In equations (11) and (12), δ_1 and δ_2 are the key coefficients of interest. $\boldsymbol{X}'_{S,i}$ (where $S = direct, spot$) is a vector of explanatory variables for each individual i (e.g. operation size, risk preferences, etc.) and an intercept, $\boldsymbol{\beta}_S$ are coefficient estimate vectors, and $\varepsilon_{S,i} \sim N(0, \sigma_S^2)$. Equations (11) and (12) are modeled individually with maximum likelihood. The cmp command in Stata is used to estimate all models (Roodman, 2011).

Results and discussion: Past behavior

Tobit coefficient estimates and average marginal effects for the historical purchase of single source feeder cattle are shown in Table 2.2. Model 1 is the base model, including only an intercept and past percent of finished animals marketed on the spot market. Model 2 adds large operation, risk aversion, and custom feeder dummy variables as additional controls. The spot marketing coefficients and average marginal effects are statistically significant and similar in models 1 and 2. The 0.09 spot market average marginal effect in model 2 means that when finished cattle marketed on the spot market increases by 1%, the percent of feeder cattle purchased directed from seller decreases by 0.09%. Thus, those who purchase single source feeder animals were more likely to also use some sort of output price risk hedging instead of not hedging (accepting the spot cash price at time of sale). Additionally, in model 2, larger operations purchased 8.73% more of their feeder animals direct from the seller than smaller operations.

A relationship is also present between purchasing feeder cattle direct from seller and output price risk in models 3 and 4 (Table 2.3). The direct from seller marginal effect in model 4, -0.17, indicates that a 1% increase in feeder animals purchased direct from seller decreases the number of head sold in the spot market by 0.17%. This is the similar to the relationship found in models 1 and 2, however, larger in magnitude. Additionally, larger operations and risk averse producers marketed about 22% less of their finished animals on the spot market only.

These simple regressions of past behavior and average marginal effects confirm that a relationship exists between animal health risk (purchasing feeder animals directly from seller) and output price risk mitigation strategies (spot market versus hedging). Overall, there is a negative relationship between single source feeder animal purchases and spot marketing. Therefore, there is a positive relationship between single source procurement and using some sort of output price risk mitigation strategy (the opposite of spot market only). Additionally, the relationship is larger in magnitude when explaining output price risk mitigation by direct from seller feeder cattle procurement than when explaining feeder cattle procurement by past output price risk mitigation. Therefore, this relationship is worth further investigating and the decision under consideration (feeder cattle procurement or output price hedging) is important when documenting the relationship.

Research methodology: Choice experiment

The simple regressions of past behavior suggest a relationship between animal health and output price risk mitigation might exist. However, these simple regressions do not control for other factors that might be considered in producers risk mitigation decisions. For example, source premium (cost of input control), basis (cost of output price control), CME price (cost of output price control), and the type of output price risk hedging strategy (forward contracts, futures hedge, spot market, etc.) were not accounted for. In order to better understand feedlot operators' decision making regarding risk and to control for other information that might enter into a producers' decision making a choice experiment was conducted. Past studies of cattle producers that utilized surveys, including choice experiments, were successful in finding results consistent with market observations (Schulz & Tonsor, 2010; Schumacher, Schroeder, & Tonsor, 2012). In order to assess if price risk and animal health risk mitigation strategies are viewed as independent and separate or jointly, a split-sample choice design was utilized as the core information source for this study.

To assess individual feedlot operators' decision making process, operators were placed in a realistic decision making mindset where they were making decisions and forming expectations around events that will happen in the future. They were asked to make decisions as if it were February 15, 2017 for feeder animals being placed in March 2017 with an expected August 2017 closeout. A seven-block design (Table 2.4) was utilized to test key hypotheses by comparing responses across scenarios to isolate differences of central interest, similar to Tonsor, Schroeder, and Lusk (2013). The animal health, feeder cattle procurement practice of interest was known single source feeder steers versus feeder steers of unknown background. The live cattle output price risk management strategies were futures hedge, forward contract, other, or accept cash price at sale. An additional difference across designs is how the expected hedge basis was presented. The futures hedge basis was unambiguous (e.g. -$1.00/cwt) or ambiguous (e.g. 35% chance of being less than -$1.00/cwt and a 65% chance of being greater than -$1.00/cwt) (Di Mauro & Maffioletti, 2004). Basis ambiguity was included to try to understand how producers form their price expectations and to see how basis uncertainty might alter their risk mitigation decisions.

Each participant was randomly assigned to one of the seven blocks.[5] Blocks fall into two broad categories consistent with the initial assessment of past behavior: feeder placement or output price hedging oriented. Blocks 1-2 consisted of two scenarios about placing a lot of feeder steers, one where no output pricing information is given (question 11; Q11) and one where potential output pricing information is provided as an information shock (question 12; Q12). Responses from Q11 and Q12 can be compared to test our core hypothesis. See Figure 2.1 for an example of block 2 where information about forward contracts being offered is shown in Q12.

Blocks 4-7 include one scenario were the participant was asked how many of the 150 head purchased they would place in each of the four output pricing strategies. Blocks 4 and 5 are the base blocks were no information on the source of feeder cattle was given. However, in blocks 6 and 7 participants were told the steers were purchased from a single source and given a random premium paid (information shock). See Figure 2.2 for an example of block 7. Additionally, blocks 5 and 7 have ambiguous fed cattle basis for futures hedges. By comparing responses across blocks we can gain an understanding of if/how producers alter decisions when animal health and price risks are individually versus jointly examined. In particular, marginal effects across blocks 4 and 6 (non-ambiguous basis), and blocks 5 and 7 (ambiguous basis) can be compared.

Hypothetical bias is a concern when collecting data using surveys. Tonsor and Shupp (2011) found that including cheap talk scripts yield more reliable willingness to pay results in

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[5] Blocks 1, 2, 4, 5, 6 and 7 will be the primary focus of this study. Block 3 is not used.

consumer surveys. Therefore, before answering the choice questions participants were presented with these instructions, "*The following two questions look similar but importantly are different. Please complete both questions carefully. Research studies have found people overstate their willingness to pay in hypothetical situations, such as a survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.*" for blocks 1 to 2 and, "*Research studies have found people overstate their willingness to participate in hypothetical situations, such as a survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.*" for blocks 4 to 7. Lusk and Schroeder (2004) found that although total willingness to pay was overstated in hypothetical choice experiments, marginal willingness to pay was not statistically different across hypothetical and actual payment scenarios. Thus, hypothetical bias concerns are mitigated since our core hypotheses tests depend on net differences across blocks.

Values of key variables n the choice design were randomly drawn for each participant from a range selected to match current market conditions. The source premium shown ranged from $1.00 to $10.00/cwt, the CME live cattle contract price from $95.00 to $110.00/cwt (consistent with the market as of January 9th, 2017), all basis numbers ranged from $-5.00 to $5.00/cwt (consistent with historical basis numbers from Livestock Marketing Information Center (LMIC) (2017)), and the random percent for the ambiguous basis scenario ranged from 1 to 99%.

Econometrically, systems of Tobit models are utilized because the dependent variables (either quantity of feeder head purchased, or quantity of head placed in each output price risk strategy) are continuous but censored between 0 and 150. Using these methods, coefficient estimates, and, of more central interest, marginal effects can be calculated and compared across designs to identify if relationships exist between animal health risk mitigation and output price risk mitigation.

Feeder cattle placement scenarios (blocks 1-2)

For blocks 1 and 2, the two latent variables of interest (indicated with a * subscript), the number of head purchased when output pricing information is not shown ($Q11head_i^*$) and the number of head purchased when potential output price information is shown ($Q12head_i^*$), can be modeled as:

$$Q11head_i^* = \boldsymbol{X}'_{Q11,i}\boldsymbol{\beta}_{Q11} + \varepsilon_{Q11,i} \tag{15}$$

$$Q12head_i^* = \boldsymbol{X}'_{Q12,i}\boldsymbol{\beta}_{Q11} + \varepsilon_{Q12,i} \tag{16}$$

where the relationships between the latent variables and the observed variables are:

$$Q11head_i = \begin{cases} Q11head_i^* & if\ 0 \le Q11head_i^* \le 150 \\ 0 & if\ Q11head_i^* < 0 \\ 150 & if\ Q11head_i^* > 150 \end{cases} \tag{17}$$

$$Q12head_i = \begin{cases} Q12head_i^* & if\ 0 \le Q12head_i^* \le 150 \\ 0 & if\ Q12head_i^* < 0 \\ 150 & if\ Q12head_i^* > 150. \end{cases} \tag{18}$$

In equations (15) and (16), $\boldsymbol{X}'_{Qk,i}$ (where $k = 11, 12$) is a vector of information given in the question (e.g., source premium, CME price, basis) and explanatory variables for each individual i (e.g. operation size, risk preferences, etc.), $\boldsymbol{\beta}_{Qk}$ are coefficient estimate vectors, and $\varepsilon_{Qk,i} \sim N(0, \sigma_{Qk}^2)$.[6] Equations (15) and (16) are modeled jointly with maximum likelihood. The

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[6] Therefore, we are assuming that participants used the information given to them in the question for the source premium, CME price, expected basis, etc. when they answered the question and did not bring in their own expert information. For example, a participant could have been given a -$3.50/cwt expected basis in the question. However, their historical local basis could be $1.50/cwt. We assume that the producers used -$3.50/cwt given when responding.

error terms $\varepsilon_{Q11,i}$ and $\varepsilon_{Q12,i}$ are specified following a bivariate normal distribution with a zero mean, standard deviations σ^2_{Q11} and σ^2_{Q12}, and correlation ρ. By estimating these equations jointly we can test if unobservable factors are impacting the number of head purchased in each question. If ρ is zero then the equations can be estimated independently (Cornick, Cox, & Gould, 1994).

Output price risk hedging scenarios (blocks 4 to 7)

For blocks 4 to 7 the latent variables of interest are the number of head placed in each output price risk management strategy out of the 150 feeder steers purchased: futures hedge ($FutHedge_i^*$), forward contract ($ForwardCont_i^*$), other ($Other_i^*$), and spot market at time of sale ($Spot_i^*$). The number of head in the four output price risk management tools must sum to 150. A multivariate system can be modeled as:

$$FutHedge_i^* = \boldsymbol{X}_i'\boldsymbol{\beta}_{FutHedge} + \varepsilon_{FutHedge,i} \tag{19}$$

$$ForwardCont_i^* = \boldsymbol{X}_i'\boldsymbol{\beta}_{\text{ForwardCont}} + \varepsilon_{ForwardCont,i} \tag{20}$$

$$Other_i^* = \boldsymbol{X}_i'\boldsymbol{\beta}_{\text{Other}} + \varepsilon_{Other,i} \tag{21}$$

$$Spot_i^* = \boldsymbol{X}_i'\boldsymbol{\beta}_{\text{Spot}} + \varepsilon_{Spot,i} \tag{22}$$

where the relationships between the observed and latent variables are:

$$FutHedge_i = \begin{cases} FutHedge_i^* & if\ 0 \le FutHedge_i^* \le 150 \\ 0 & if\ FutHedge_i^* < 0 \\ 150 & if\ FutHedge_i^* > 150 \end{cases} \tag{23}$$

$$ForwardCont_i = \begin{cases} ForwardCont_i^* & if\ 0 \le ForwardCont_i^* \le 150 \\ 0 & if\ ForwardCont_i^* < 0 \\ 150 & if\ ForwardCont_i^* > 150 \end{cases} \tag{24}$$

$$Other_i = \begin{cases} Other_i^* & if\ 0 \le Other_i^* \le 150 \\ 0 & if\ Other_i^* < 0 \\ 150 & if\ Other_i^* > 150 \end{cases} \tag{25}$$

$$Spot_i = \begin{cases} Spot_i^* & if\ 0 \leq Spot_i^* \leq 150 \\ 0 & if\ Spot_i^* < 0 \\ 150 & if\ Spot_i^* > 150. \end{cases} \tag{26}$$

In equations (19), (20), (21), and (22), $\boldsymbol{X}_i'$ is a vector of information given in the scenario (e.g., source premium, CME price, expected basis) and explanatory variables for each individual i (e.g. past output pricing behavior, etc.), $\boldsymbol{\beta}_m$ (where $m = FutHedge, ForwardCont, Other, Spot$) are coefficient estimate vectors, and $\varepsilon_{m,i} \sim N(0, \sigma_m^2)$. Since the four dependent variables sum to 150, only three equations (19, 20, and22) are estimated jointly. When modeled jointly, the error terms $\varepsilon_{FutHedge,i}$, $\varepsilon_{\text{ForwardCont},i}$ and $\varepsilon_{\text{Spot},i}$ are specified following a multivariate normal distribution with a zero mean, standard deviations $\sigma_{FutHedge}^2$, $\sigma_{\text{ForwardCont}}^2$ and σ_{Spot}^2, and correlation ρ_{mn}.

Feedlot operators vary in their experience with alternative marketing methods as well as in relationships with entities who buy their finished cattle. These factors likely not only effect observed selections in our survey, but are endogenous to our decisions of central interest. Accordingly, the system of equations above can be extended as:

$$FutHedge_i^* = \boldsymbol{X}_i'\boldsymbol{\beta}_{FutHedge} + \gamma_{1,FutHedge}PastHedge_i + \gamma_{2,FutHedge}PastForward_i + \varepsilon_{FutHedge,i} \tag{27}$$

$$ForwardCont_i^* = \boldsymbol{X}_i'\boldsymbol{\beta}_{\text{ForwardCont}} + \gamma_{1,\text{ForwardCont}}PastHedge_i + \gamma_{2,\text{ForwardCont}}PastForward_i + \varepsilon_{ForwardCont,i} \tag{28}$$

$$Spot_i^* = \boldsymbol{X}_i'\boldsymbol{\beta}_{\text{Spot}} + \gamma_{1,\text{Spot}}PastHedge_i + \gamma_{2,\text{spot}}PastForward_i + \varepsilon_{Spot,i} \tag{29}$$

$$PastHedge_i = \boldsymbol{Z}_i'\boldsymbol{\delta}_{\text{PastHedge}} + \varepsilon_{PastHedge,i} \tag{30}$$

$$PastForward_i = \boldsymbol{Z}_i'\boldsymbol{\delta}_{PastForward} + \varepsilon_{PastForward,i} \tag{31}$$

where $PastHedge_i$ and $PastForward_i$ are variables indicating percent of past fed cattle that were marketed using futures hedge and forward contracts (question 8 in the survey). $\boldsymbol{Z}_i'$ is a vector explanatory variables, and γ and δ are parameter vectors to be estimated.

Results and discussion: Choice experiment

Summary statistics by block are shown in Table 2.1. There were 40 responses for block 1, 41 for block 2, 42 for block 3, 36 for block 4, 42 for block 5, 41 for block 6 and 38 for block 7.

Purchasing feeder cattle (CV1 and CV2)

Bivariate model results from block 1 (CV1) are in Table 2.5. There are 40 respondents in CV1. Recall, the difference between Q11 and Q12 is participants were presented additional information (an information shock) on potential output pricing information (live cattle CME price and expected local basis) in Q12. The statistically significant ρ indicates there is a relationship between Q11 and Q12 residuals in each model. Thus, Q11 and Q12 should be estimated jointly. Model A is the base model with explanatory variables only for the information shown. The source premium coefficients in Q11 and Q12 are negative and statistically significant as expected indicating that the willingness to purchase feeder cattle decreases as the source premium increases. Additionally the source premium coefficient in Q12 is smaller in absolute terms than in Q11, indicating that sensitivity to the source premium is smaller whenever output hedging information is given.

Other alternative models with additional explanatory variables (e.g. dummy variables for operation size, custom feeder, if the August CME price is expected to increase, risk aversion, and if they have purchased single source cattle before) and interaction terms (CME * source premium and basis * source premium) are explored. Based on likelihood ratio tests, the preferred model for CV1 is model B, which includes additional interaction terms in Q12. The source premium and CME price, and the source premium and expected basis interaction terms are statistically significant indicating a relationship between incoming cattle purchasing and the potential output price hedging information mentioned. Interaction terms make the coefficients difficult to interpret, therefore, feeder cattle demand curves (using mean values for included explanatory variables) from model B are plotted for Q11 and Q12 in Figure 2.3. When output pricing information is shown the demand for feeder cattle is more inelastic (steeper). Thus operators are less sensitive to an increase in the source premium when output hedging information is given.

Models C and D combine the CME price and basis into an expected price (expected price=expected basis + CME price). Model C is the base model and model D is the preferred model when using expected price. Overall, the results from models C and D are similar to models A and B.

When using Tobit models, the marginal effects within the censored bounds are of main interest. Average marginal effects for models A to D are shown in Table 2.6. Focusing on model B, the source premium marginal effect in both Q11 and Q12 are negative. A $1.00/cwt increase in the source premium decreases the number of feeder steers purchased (from a maximum of 150) by 13.52 head and 6.41 head in Q11 and Q12, respectively. These marginal effects are statistically different from zero and from each other ($\chi^2(1) = 9.33, p - value = 0.002$). Thus, whenever the CME price and expected basis information are shown, participants are less sensitive to single source premiums. The CME price and expected basis marginal effects are both positive with the expected basis marginal effect being statistically different than zero. When the expected basis increases by $1.00/cwt, head purchased increases by approximately five.

Plots of the marginal effects with 95% confidence bands for model B are shown in Figure 2.4 to Figure 2.9. Q11 and Q12 source premium marginal effects at different values are shown in Figure 2.4 and Figure 2.5. In both Q11 and Q12, the marginal effect of a $1.00/cwt increase in the source premium decreases in absolute terms as the source premium increases, but is statistically different from zero. Additionally, the Q11 source premium marginal effect is greater in absolute terms than the Q12 source premium marginal effects. The decreased sensitivity to the source premium with the output hedging information shock aligns with the demand curve in Q12 being more inelastic than in Q11.

Marginal effect plots are also needed because of continuous interaction terms. At lower values of CME price ($96.00/cwt to around $99.00/cwt) the source premium marginal effect is not different than zero (Figure 2.6). However, as the CME price increases, the source premium marginal effect increases in absolute terms. This could suggest that at lower CME prices, feedlots are not purchasing single source cattle due to tighter profit margins or potentially not even placing cattle at all. However at higher CME prices, and thus more appealing profit margins, more cattle are placed overall and a $1.00/cwt increase in the source premium has a larger effect on head placed. The same general story is also evident in source premium's marginal effect at different levels of expected basis (Figure 2.7).

CME price's marginal effect at different levels of source premium is shown in Figure 2.8. At lower source premiums, a $1.00/cwt increase in the CME price increases the number of head purchased. However, at premiums greater than $4.00/cwt, a $1.00/cwt increase in the CME price does not increase the feeder steers purchased. The expected basis marginal effect at different values of source premium is greater than the CME price marginal effect, but still exhibits a decreasing pattern (Figure 2.9). Potentially, this difference exists because the CME price is generally more variable than basis. In other words, a \$1.00/cwt change in the CME price is more likely to occur than a \$1.00/cwt increase in the expected basis. Overall, the marginal effect plots indicate a relationship between source premium and shown fed cattle futures hedging information.

Model results for block 2 (CV2) are shown in Table 2.7. There are 41 respondents in CV2. Forward contract information (CME live cattle price and offered basis) is the information shock in Q12. Model E is the base model with CME price and forward contract information as two separate variables and model G is the base model when using expected price. Based on likelihood ratio tests, models F and H are preferred to models E and G, and interaction terms are not needed. The statistically significant ρ indicates there is a relationship between the errors of Q11 and Q12 in each model and thus Q11 and Q12 should be estimated jointly. Focusing on model F, the source premium coefficient is negative and significant in Q11 and Q12. Furthermore, these two coefficients are statistically different from one another ($\chi^2(1) = 5.11, p - value = 0.02$). The forward contract basis coefficient is positive and significant. The effect of explanatory variables are somewhat different across Q11 and Q12. In Q11, medium and large feedlots purchase fewer single source steers relative to smaller feedlots. Additionally, custom feeders purchase more single source steers. In Q12, those who think the August CME live cattle contract price is going to increase purchased more single source feeder steers.

The coefficient estimates from model F are used to plot single source feeder cattle demand curves for Q11 and Q12 (Figure 2.10). As in CV1, the Q11 demand curve, when no output price hedging information is given, is more elastic, while the Q12 demand curve, when output price hedging information is given, is more inelastic. Therefore, producers are less sensitive to an increase in source premium when forward contracting information is given than when it is not.

The average marginal effects accounting for censoring in models E, F, G, and H are shown in Table 2.8. The source premium marginal effect is negative in all equations and models. The source premium marginal is statistically different across Q11 and Q12 in models F ($\chi^2 = 4.80, p - value = 0.03$) and H, but not models E and H. In the preferred model, model F, the source premium average marginal effect is nearly 13 head in Q11, but six head in Q12 when forward contract information is given. This is consistent with the Q12 demand curve being more inelastic. In Q12, the average marginal effect on the forward contract basis is 6.50 and statistically different from zero. The CME average marginal effect is not significant. If participants believe the August CME live cattle contract price will increase, they purchase almost 35 more head than those who believe the price will decrease or stay the same.

The average marginal effect plots for model F are shown in Figure 2.11 to Figure 2.14. The source premium average marginal effects plots for Q11 and Q12 are different (Figure 2.11 and Figure 2.12). The 95% confidence bands do not cross zero in Q11 (Figure 2.11). Additionally, the source premium marginal effect has a decreasing effect as source premium increases. In Q12, the 95% confidence bands are wide at lower values of source premium (Figure 2.12). However, the same decreasing marginal effect as in Q11 is generally exhibited. The CME marginal effects are not different than zero at all CME values investigated (Figure 2.13). On the other hand, the forward contract basis average marginal effect is different than zero for all basis numbers investigated (Figure 2.14). At weaker basis levels, the average marginal effect of increasing basis by \$1.00/cwt is smaller than at stronger basis levels. However, the marginal effect increases at a decreasing rate.

To determine if the effects of source premium, CME price, and basis are different when information is given on futures hedge versus forward contracts, the 95% confidence intervals for similar models can be compared. For example, the source premium marginal effect confidence interval from model B can be compared to the source premium marginal effect confidence interval from model F. When comparing the confidence intervals on source premium, CME price, and expected basis across CV1 and CV2, all confidence intervals overlap. Therefore, the marginal effects when the information is presented as a futures hedge are the same as when the information is presented as a forward contract.

Discussion of core hypotheses

The coefficient estimates, demand curve plots, and average marginal effects in CV1 and CV2 can collectively be used to discuss the relationship between incoming cattle risk and output price risk. First, the significant interaction terms in models B and D suggest there is a relationship between single source premium and output hedging information shown.

Economists often classify the relationship between goods as substitutes or complements. Generally, substitutes have a positive cross price elasticity and complements have a negative cross price elasticity. In consumer literature, increasing consumption of either good decreases income. However, in this case, source premium and expected basis or CME price have opposite impacts on the feedlot profitability. Therefore, the traditional notions of substitutes and complements have to be revised in this application.

Investigating the demand curves and average marginal effects, there is evidence of a complementary relationship. Finding that the demand curves for Q11, when no output pricing information is given, are more elastic than when output price hedging information (Q12) is given supports this conclusion. Additionally, the marginal effects plots point to a complementary relationship. Consider the impact of an increase in the CME price and source premium on profitability. An increase (decrease) in the CME price or a decrease (increase) in the source premium would increase (decrease) profit per head. Given that the marginal effect of source premium increases in absolute terms when the CME price increases suggests a complementary relationship between animal health risk and output price risk management for futures hedging and forward contracting. The same thought exercise can be completed for an increase in expected basis. Overall, the output hedging information shocks decrease the sensitivity to an increase in source premium.

In consumer choice studies, willingness to pay estimates vary depending on the number and mix of attributes shown (Pozo, Tonsor, & Schroeder, 2012; Gao & Schroeder, 2009). Therefore, we recognize that simply having more information presented in Q12 (potential output price hedging information) than Q11 could influence the source premium coefficients and marginal effects. However, the identified relationship between source premium and output price hedging information is rational. If output prices are considered strong, then more feedlots will be interested in placing feeder steers and then potentially consider paying a premium for single source steers. By purchasing single source steers, producers reduce uncertainty on the animals' performance which in turn increases the likelihood of actually receiving higher output prices. Conversely, if output prices are weak, then feedlots will place fewer cattle and potentially ignore single source cattle premiums. The significant interaction terms in block 1 Q12 and marginal effect interaction plots support this conclusion.

Output pricing (CV4 to CV7)

In the output oriented blocks, blocks 4 and 5 are the base blocks where no information is given on feeder cattle source. Blocks 6 and 7 include an information shock that the feeder steers are from a single source and give a random source premium.

No sourcing information given (CV4 and CV5)

In CV4 and CV5, feedlot operators are asked which output pricing strategies they would implement for a lot of 150 steers purchased on February 15th for March placement. No information is given on the feeder cattle source. The difference between CV4 and CV5 is the way basis information was presented for futures hedging. In CV4 a non-ambiguous basis is given, while an ambiguous basis is given in CV5.

Pooled model results with a block dummy variable and interaction terms are shown in Table 2.9. There are 78 usable responses when the two blocks are combined. The CV4 block dummy and interactions are jointly insignificant ($\chi^2(12) = 13.01, p - value = 0.37$). Therefore the ambiguous basis (versus non-ambiguous presentation) did not impact head placed under each output pricing strategy in blocks 4 and 5. Looking at the ρ estimates, the equations need to be estimated jointly, including the past behavior ($\rho_{3,4}, \rho_{2,5}, \rho_{3,5}, \rho_{4,5}$). This confirms expectations of past hedging behavior endogeneity. In the past hedging and forward contracting equations, custom feeders place fewer head under futures hedges, and risk averse producers place more head under both futures hedging and forward contracts.

For the main three equations, the average marginal effects for each block are of main interest (Table 2.10). The margins are decomposed margins for each block. For example, the margins for block 4 come only from treating those in block 4 as if they were in block 4 and those who were in block 5 only as if they were in block 5. Comparing the decomposed marginal effects across blocks 4 and 5, none of the average marginal effects across CV4 and CV5 are statistically different from each other. For example, in the futures hedge equation, the CME price marginal effect confidence interval is [-3.40, 3.36] for CV4 and [-2.08, 4.57] for CV5. Since these two confidence intervals overlap, they are considered not statistically different.

Many of the average marginal effects are insignificant. A $1.00/cwt increase in forward contract basis increases head placed under a forward contract by 2.53 head in CV4. For spot market, an increase in the CME price by $1.00/cwt decreases head sold by about two. Past forward contract percentage has a significant positive impact on the head placed in forward contracts and a significant negative impact on head sold in the spot market. For each 1% increase in cattle placed under a forward contract in the past, almost one more head is placed under a forward contract in CV4 and CV5, and over one head less in the spot market.

Since feedlot operators are professionals, they are likely very familiar with current market conditions. Therefore, participants could use their outside knowledge when answering the survey questions. No information is given in the survey about base feeder cattle price. Thus, the CME feeder cattle futures price, sourced from LMIC (2017), for the day the participant took the survey is added as an explanatory variable.[7] Model J results including feeder cattle futures price are in Table 2.11. Overall, model J results are similar to model I results. The feeder cattle coefficients are significant in the futures hedge and spot market equations. Additionally, the feeder cattle futures price marginal effect is significant and positive for futures hedging and spot market (Table 2.12). The other decomposed average marginal effects are robust to model I.

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[7] Likelihood ratio tests were used to determine that the current CME feeder futures price was not significant in CV1 and CV2.

However, the CME marginal effect is significant and positive for forward contract usage and negative for spot market. Persistence of past output pricing behavior is still present.

Single source information given (CV6 and CV7)

In CV6 and CV7, participants are informed that feeder steers came from a single source and gave the premium paid (information shock). As with CV4 and CV5, the difference between CV6 and CV7 is the ambiguous expected futures hedge basis in CV7. The pooled model results for CV6 and CV7 (model K) are found in Table 2.13. There are 78 participants combined in these two blocks. Unlike CV4 and CV5, the CV6 block dummy variable and interactions are jointly significant ($\chi^2(15), p - value = 0.003$). The significant ρ coefficients confirms the five equations need to be estimated jointly.

Decomposed average marginal effects (treating CV6 as CV6 and CV7 as CV7) for CV6 and CV7 are shown in Table 2.14. Except for the forward contract basis marginal effect in the spot market equation, the marginal effects in CV6 and CV7 are not statistically different from one another. Therefore, the ambiguous versus not ambiguous basis presentation had little impact on marginal effects. A $1.00/cwt increase in the forward contract basis decreases head sold in the spot market by three. Past output pricing behavior has the largest impact. A 1% increase in past futures hedging percent increases the head placed under a futures hedge by over one, and decreases spot market head by over one. Additionally, a 1% increase in past forward contracting percent increases head placed under a forward contract by about one head and decreases head under spot market pricing by about one head.

The source premium marginal effects can be used as a within block test of the relationship between animal health and output price risk mitigation. A $1.00/cwt increase in source premium increases head placed in a futures hedge by 2.55 and decreases head sold in the spot market by 2.69. Therefore, there is some evidence of a relationship between animal health and output price risk mitigation. However, all of the source premium marginal effects 95% confidence intervals overlap.

Feeder cattle futures price on the day the participant took the survey is an additional explanatory variable in model L (Table 2.15). The coefficient estimates are fairly robust across models K and L. However, of the new variables, only the feeder futures and CV6 interaction in the futures hedge equation is statistically significant. Decomposed marginal effects for model L are in Table 2.16 and are robust to average marginal effects from model K. Of the additional feeder cattle futures marginal effects, the marginal effect in CV7 for the futures hedge equation is statistically significant and negative. Thus, a $1.00/cwt increase in the feeder cattle futures price decreases the number of head placed under a futures contract by over two head. The source premium marginal effect is positive and significant in CV6 futures hedge, and negative and significant in CV7 spot market.

Discussion of core hypotheses

To test the core hypothesis that a relationship between incoming cattle risk and output price risk exists, the 95% confidence intervals from the decomposed average marginal effects are compared across the base blocks and those with the single source information shock.[8] Specifically, CV4 decomposed average marginal effects are compared to analogous CV6 decomposed average marginal effects (both blocks have non-ambiguous basis), and CV5 to CV7 (both blocks have ambiguous basis). Only one difference in confidence intervals for the CME

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[8] Schenker and Gentleman (2001) found that comparison of 95% confidence intervals is more conservative than standard methods of significance testing when the null hypothesis is true and falsely rejects the null hypothesis more frequently when the null hypothesis is false.

price, expected hedge basis, forward contract basis, past futures hedging percent, and past forward contracting percent in parallel equations is found (compare model I marginal effects to model K marginal effects). The marginal effects for forward contract basis in the spot market equation in CV5, [0.02, 6.36], and CV7, [-5.65,-1.00] are different. Therefore, there is little evidence that the single source information shock changes the marginal effects of the output hedging information. However, recall that the source premium marginal effect is significant in the futures hedge and spot market equations in models K and L. These source premium marginal effects indicate that when source premium increases more cattle are placed under futures hedges and fewer cattle marketed on the cash market. However, the marginal effect is only around 2.50 head for a $1.00/cwt increase in source premium in select blocks.

Multiple explanations for little evidence of a relationship between incoming cattle health risk and output pricing strategies could exist. First of all, the hypothetical nature of the survey and small sample cannot be ignored. Our findings would suggest that incoming cattle characteristics do not impact output hedging decision much (at least the source of cattle in our experiment). Potentially, feedlot operators largely ignore incoming cattle characteristics because the decision is already made, likely reflecting pre-existing business relationships, and cannot be changed. Thus, it is a sunk decision and not considered moving forward. Alternatively, persistence of past behavior and existing relationships with fed cattle buyers was present. There could be a high cost in switching output pricing or output risk management strategies. This could be a reason for little evidence of animal health risk mitigation information impacting output hedging decisions. In the U.S. there are approximately 734,000 operations with beef cows (LMIC, 2017), nearly 30,000 feedlots (just over 2,000 with 1,000+ head capacity) (USDA, 2017a), and 650 beef packing plants, 179 of which harvest more than 1,000 head (USDA, 2017b). Therefore, there are more options to buy feeder cattle than to sell these cattle once finished. This would support our finding of a relationship between incoming cattle and output pricing risk in the feeder cattle purchasing equations but a minimal relationship in the output pricing questions.

Conclusion and implications

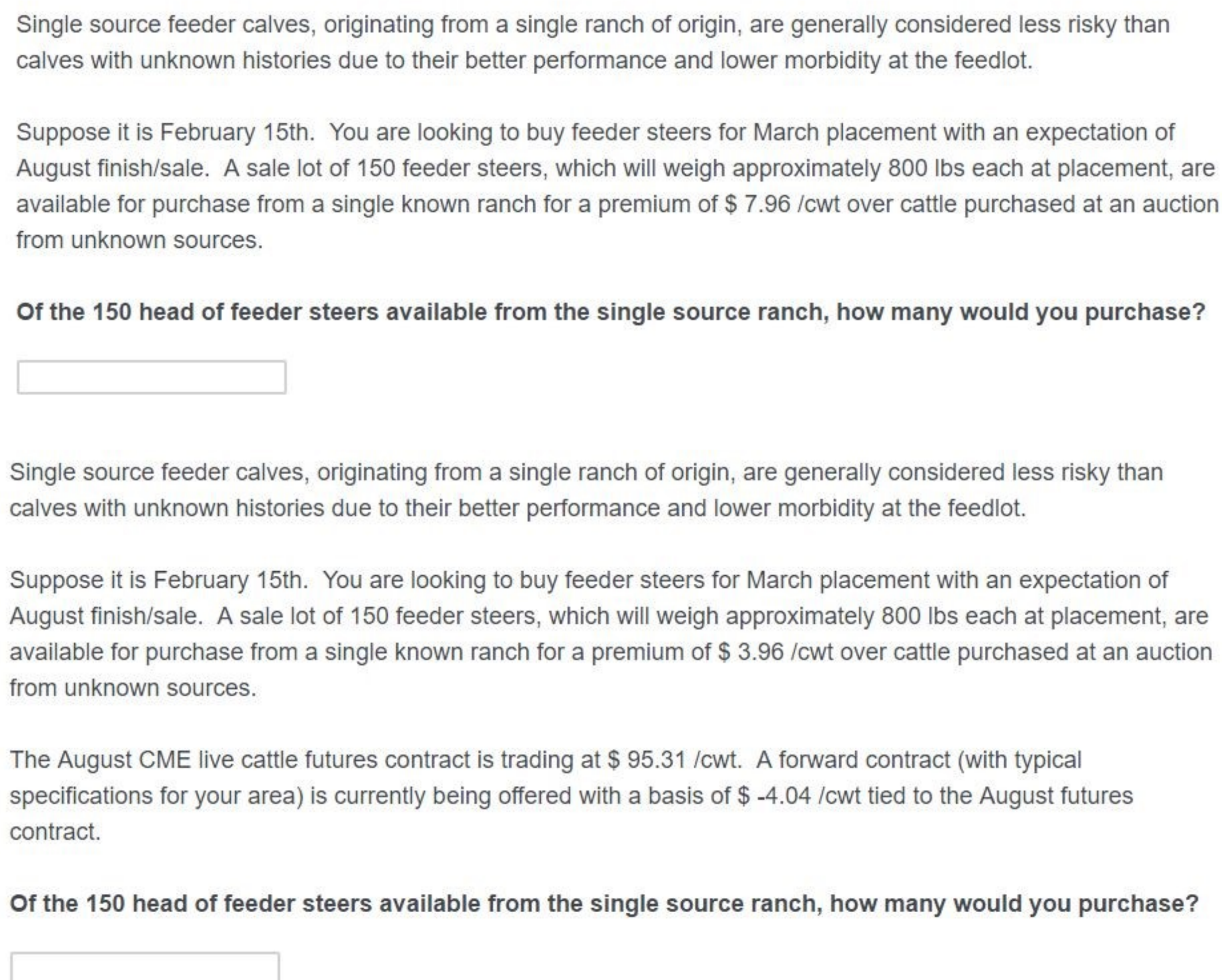
To the best of our knowledge, this was the first study seeking to understand feedlot operators' decision making regarding both animal health and output price risk management. The objective was to determine if feedlot operators view/manage these two risks jointly or independently. The animal health practice of interest was single source steers while the output price risk hedging strategies were futures contacts, forward contracts, other, and accept cash price at time of sale. An online survey was utilized to collected primary data from feedlot operators about their use of risk management tools, operation characteristics, views on risk mitigation, and demographic characteristics. A split-sample choice experiment was core to our analysis, placing feedlot operators in a forward-looking mindset to better understand their risk management decision making. Blocks 1 to 2 asked operators feeder steer procurement oriented questions. Blocks 4 to 7 were output pricing oriented scenarios.

Simple Tobit models of past feeder cattle procurement and output hedging identified a negative relationship between past purchases of feeder animals from a single source and use of spot markets. Therefore, a positive relationship is implied between animal health risk and output price risk mitigation. The split-sample choice experiment allows for a deeper understanding of this relationship.

Using blocks 1 and 2 evidence of a complementary relationship between willingness to pay a source premium and output pricing information was found. Willingness to purchase single source cattle was more inelastic when output pricing information was shown, for both futures hedging and forward contracts. Additionally, interaction terms between source premium and output pricing information were significant in block 1. The average marginal effect plots indicate a higher sensitivity to increases in source premium at higher output prices. Additionally, the CME and basis marginal effects were more sensitive at lower values of source premium. Given that the source premium marginal effect increases in absolute terms when the CME price or expected basis increases suggests a complementary relationship between animal health risk and shown output price risk information. This complementary relationship could be one reason why producers do not hedge output price risk as much as academics think they should. Potentially, if more single source cattle were available, or offered at a lower premium, producers would increase their use of output price hedging. Potentially, since there is less uncertainty in single source feeder steers performance in the feedlot (e.g., finish weight, death loss, etc.), producers can more confidently match their production to futures and forward contract specifications.

Little evidence of a relationship was found between information on feeder cattle source and output pricing risk mitigation strategies in blocks 4 to 7. Most of the average marginal effects for the hedging variables were the same across blocks that did and did not include single source information. However, some of the source premium marginal effects were significant in blocks that included single source information. A $1.00/cwt increase in source premium increased head placed under a futures hedge by about 2 head, and decreased head placed in the spot market by about 2 head. Potentially, these findings suggests that feedlot operators view the feeder cattle purchase as a “sunk decision” when deciding how to manage output price risk. Therefore, producers only consider another risk mitigation strategy when that decision is still applicable. Additionally, there was strong evidence of persistent behavior in output price hedging. This could be the result of existing relationships with cattle buyers and the relatively limited number of outlets to sell finished cattle. Potentially this persistence also stems for unfamiliarity with other output pricing strategies and high switching cost. The small relationship between single source information and output pricing strategies could also be a function of the hedging strategies considered. In the hedging options, no distinction was made regarding cattle quality. Conceivably, single source cattle might grade better at harvest and receive quality premiums (for those using grid pricing), however, this was not accounted for in our hedging scenarios.

Moving forward, there are multiple potential extensions of this study. Other animal health practices such as weaning and preconditioning certifications could be investigated instead of single source premium. Furthermore, other members of the beef marketing chain, like cow-calf producers, could approach mitigation of multiple risks differently than feedlot operators. Additionally, the concept of tradeoffs between input and output types of risk mitigation can be extended to any livestock species and non-livestock crops.


Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot.

Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800 lbs each at placement, are available for purchase from a single known ranch for a premium of $ 7.96 /cwt over cattle purchased at an auction from unknown sources.

Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot.

Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800 lbs each at placement, are available for purchase from a single known ranch for a premium of $ 3.96 /cwt over cattle purchased at an auction from unknown sources.

The August CME live cattle futures contract is trading at $ 95.31 /cwt. A forward contract (with typical specifications for your area) is currently being offered with a basis of $ -4.04 /cwt tied to the August futures contract.

Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Figure 2.1 Block 2 example

Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot.

Suppose it is February 15th. You just purchased a lot of 150 feeder steers weighing approximately 800 lbs each for March placement with an expectation of August finish/sale. The steers were sourced from a single known ranch for a premium of $ 7.96/cwt over cattle purchased at an auction from unknown sources.

The August CME live cattle futures contract is trading at $ 95.31 /cwt (CME contract is for 40,000lb of live cattle).

How many head would you place under each of the following output pricing strategies?

A forward contract (with typical specifications for your area) with a basis of $ -4.04 /cwt tied to the August futures contract.	0	head
A futures hedge where the expected local August basis has a 54% chance of being less (weaker) than $ 2.13, and a 46% chance of being greater (stronger) than $ 2.13.	0	head
Other output pricing strategy (e.g., options, Livestock Risk Protection, formula pricing, etc.)	0	head
I would accept the local cash price at time of sale in August	0	head
Total	0	head

Figure 2.2 Block 7 example

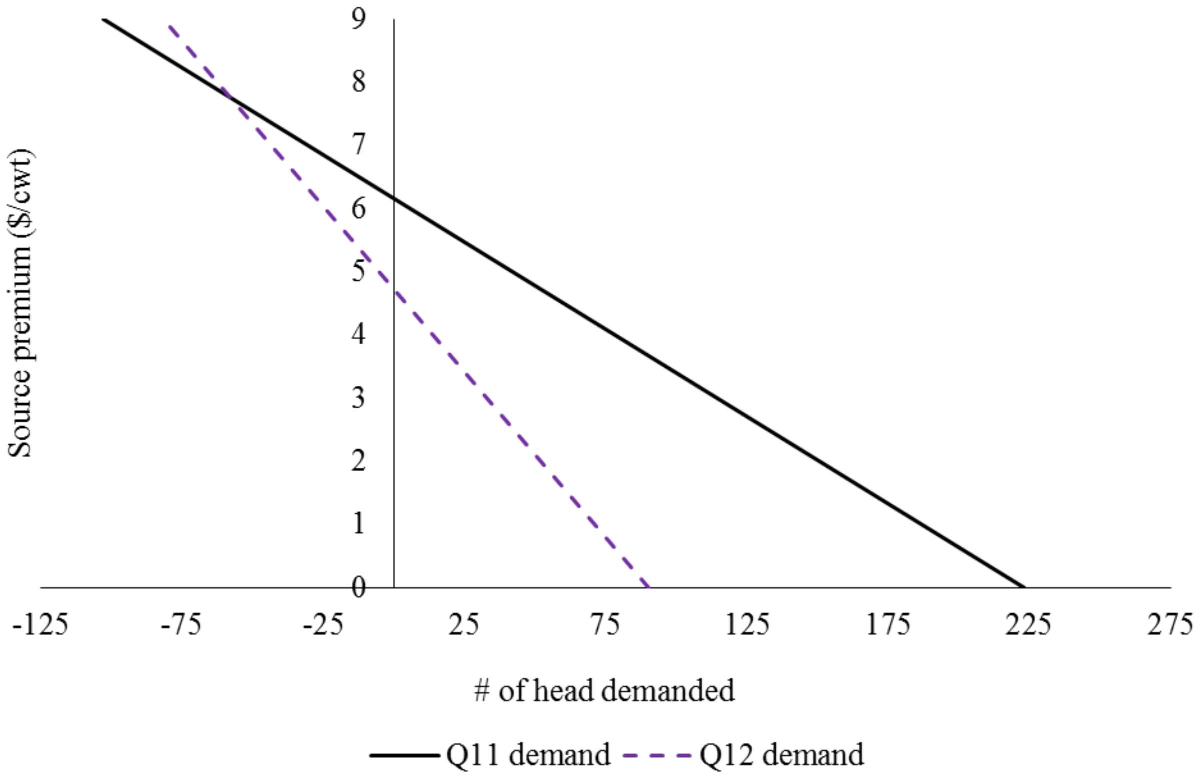


Figure 2.3 Single source feeder cattle demand curves for model B

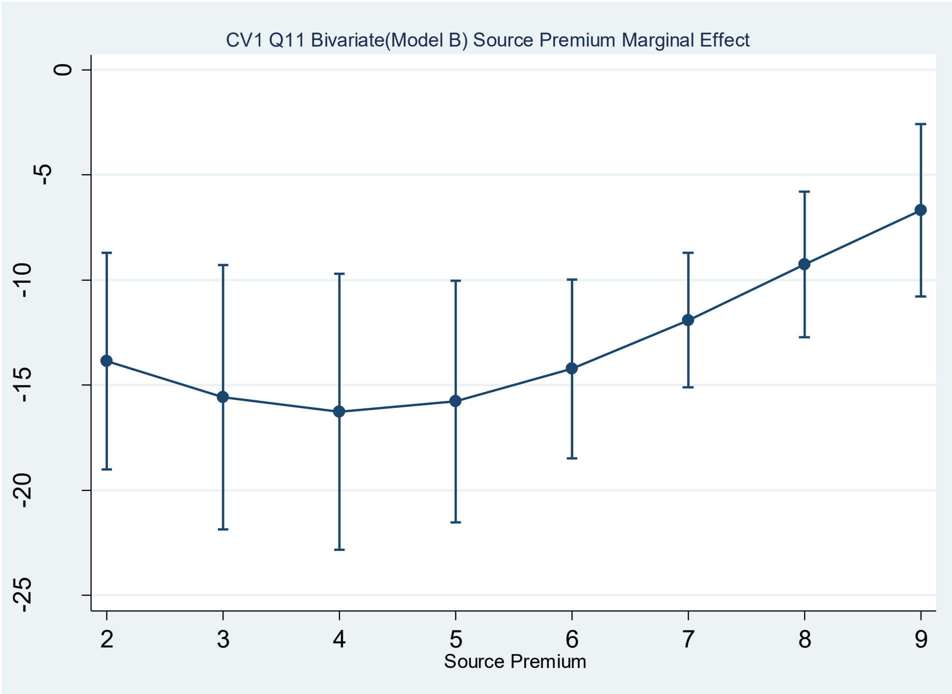


Figure 2.4 CV1 Q11 (Model B) source premium marginal effect

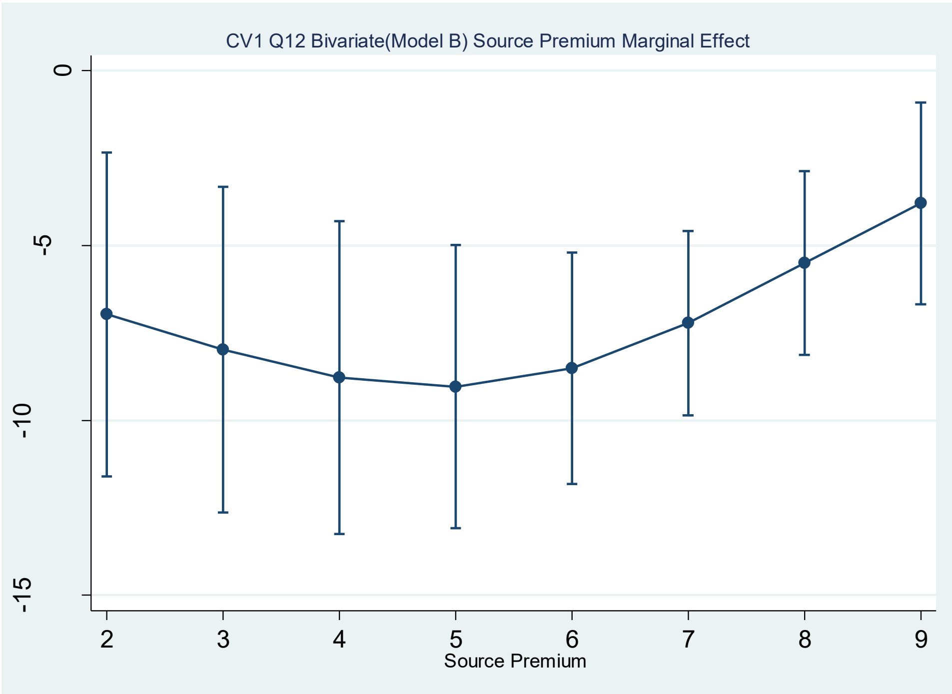


Figure 2.5 CV1 Q12 (Model B) source premium marginal effect

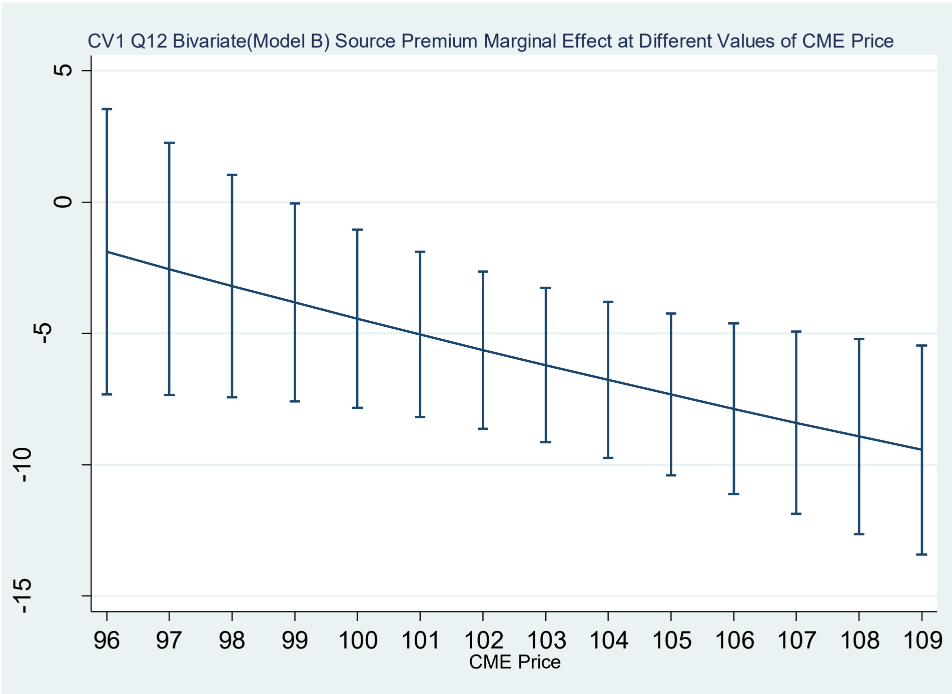


Figure 2.6 CV1 Q12 (Model B) source premium marginal effect at different values of CME price

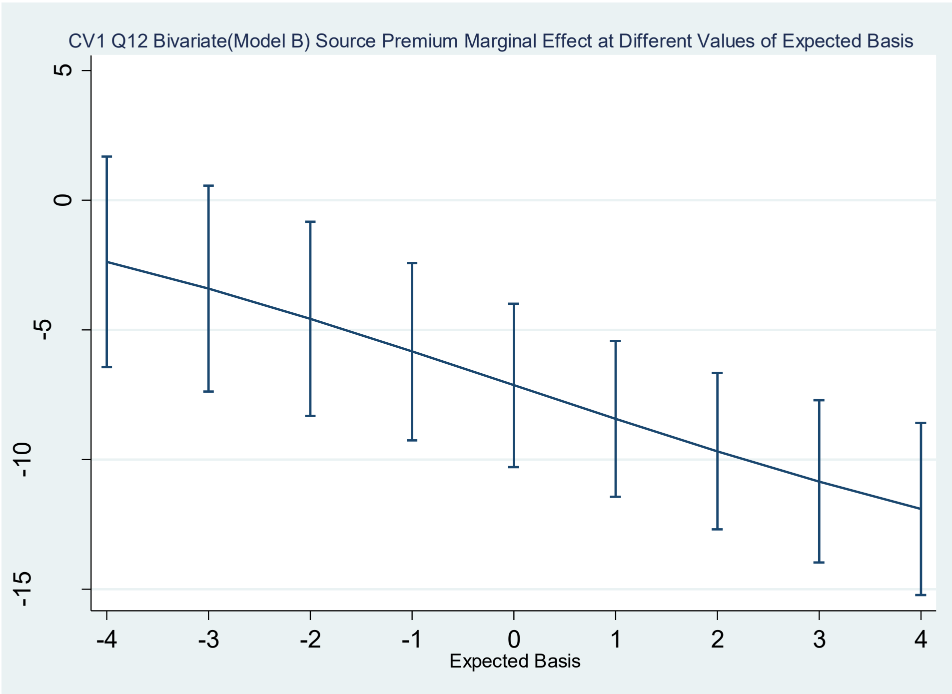


Figure 2.7 CV1 Q12 (Model B) source premium marginal effect at different values of expected basis

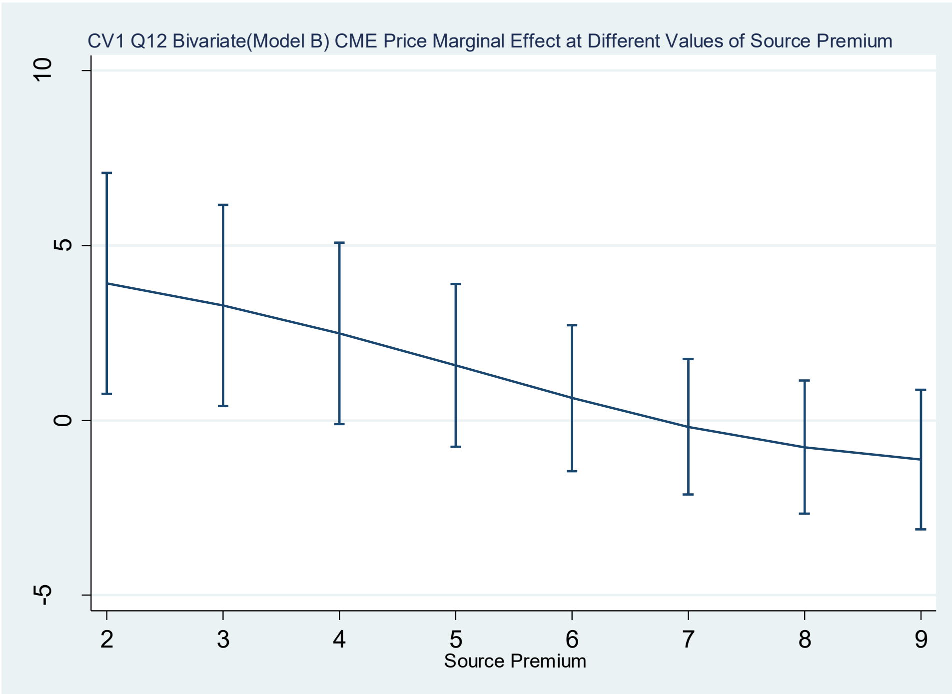


Figure 2.8 CV1 Q12 (Model B) CME price marginal effect at different values of source premium

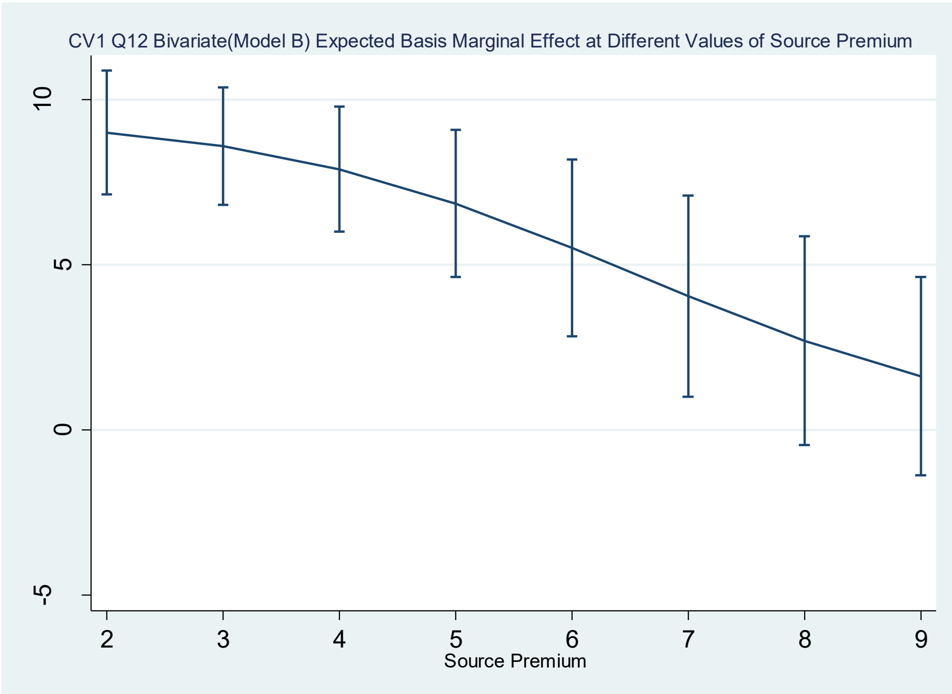


Figure 2.9 CV1 Q12 (Model B) expected basis price marginal effect at different values of source premium

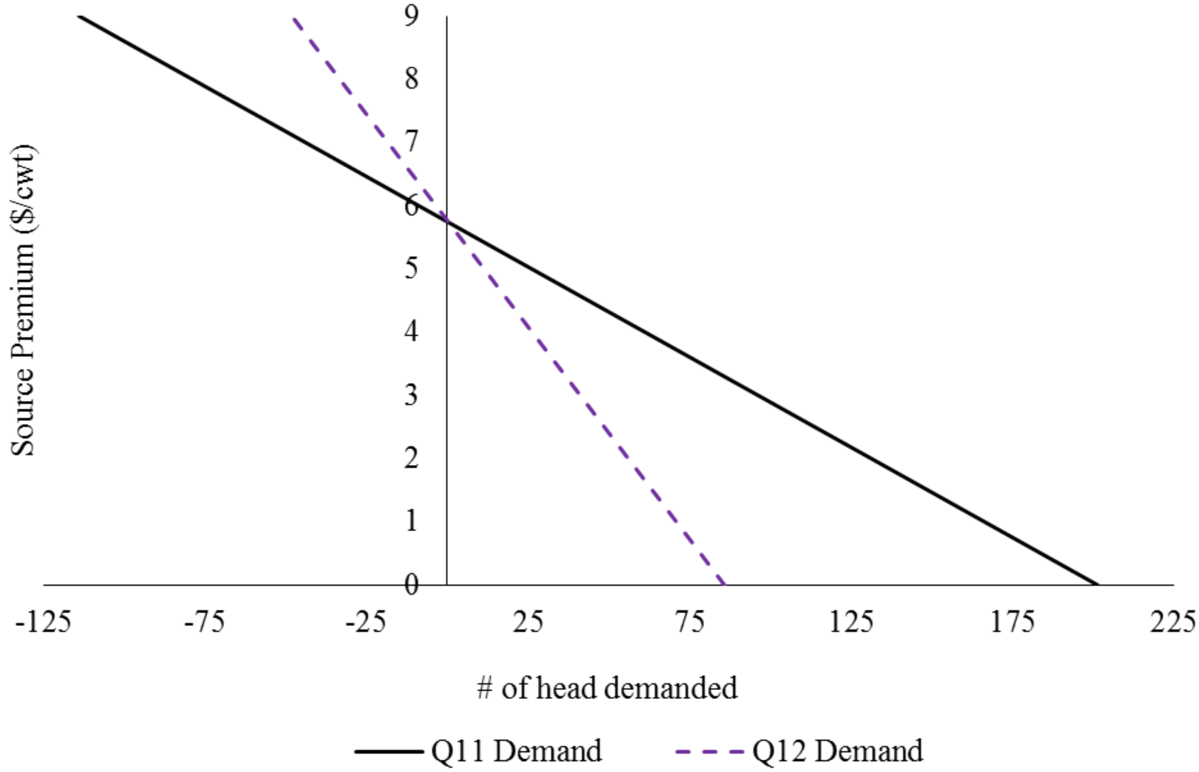


Figure 2.10 Single source feeder cattle demand curves from model F

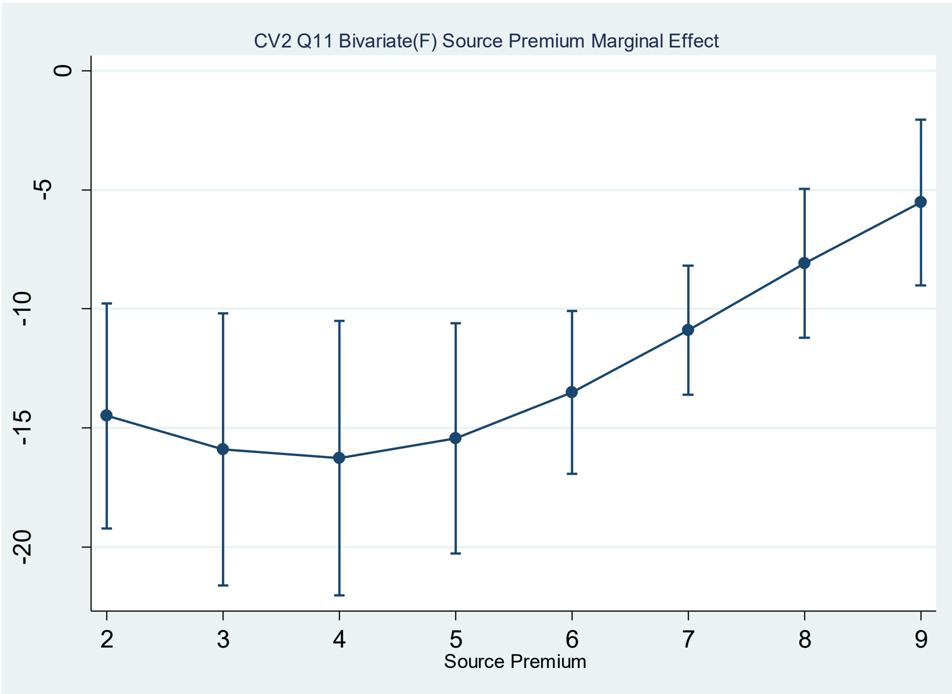


Figure 2.11 CV2 Q11 (Model F) source premium marginal effect

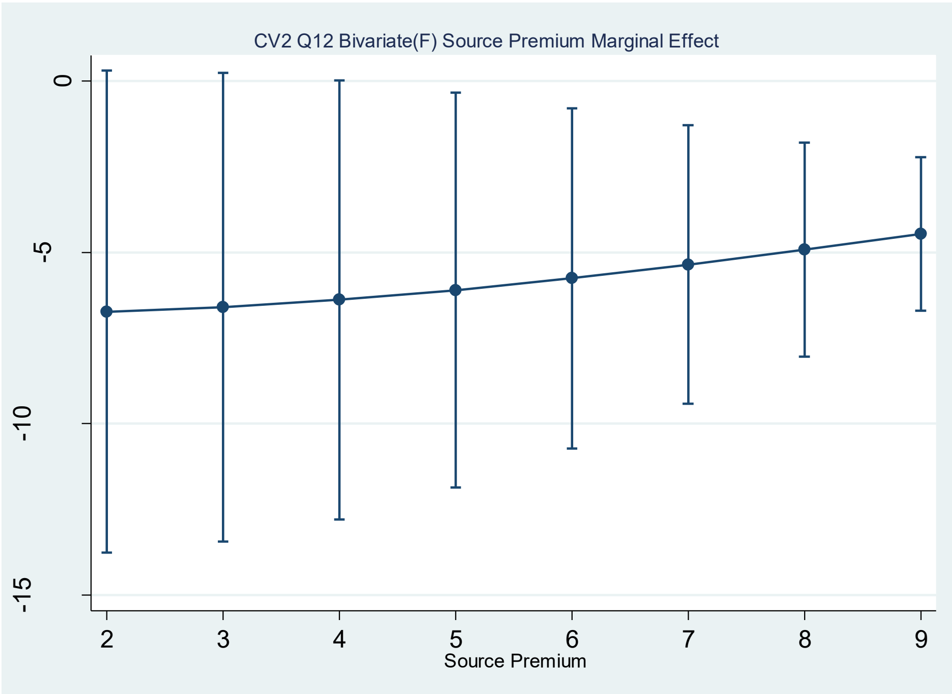


Figure 2.12 CV2 Q12 (Model F) source premium marginal effect

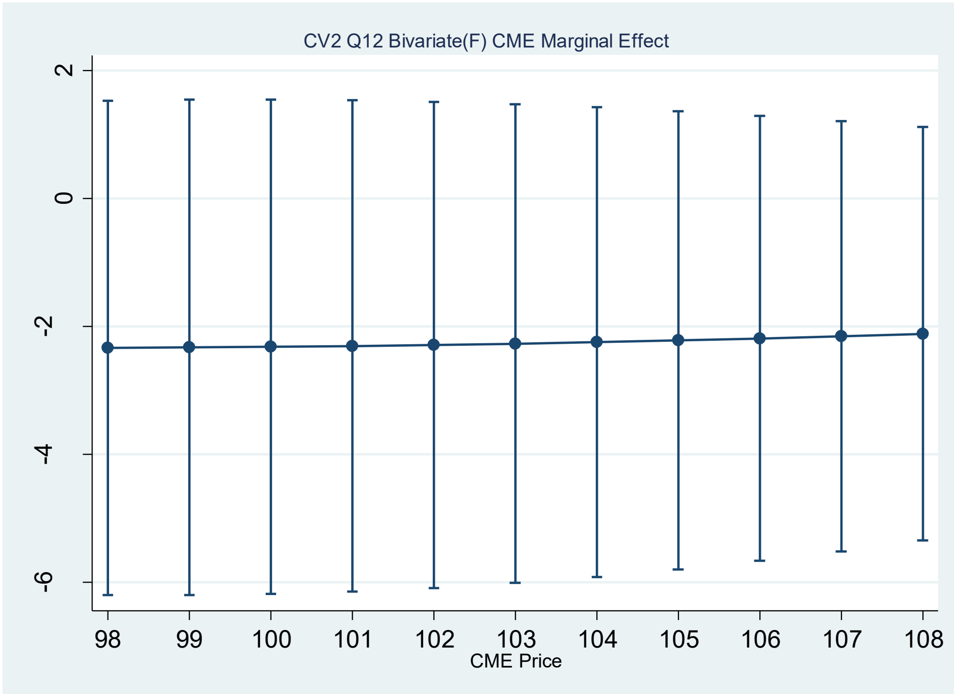


Figure 2.13 CV2 Q12 (Model F) CME price marginal effect

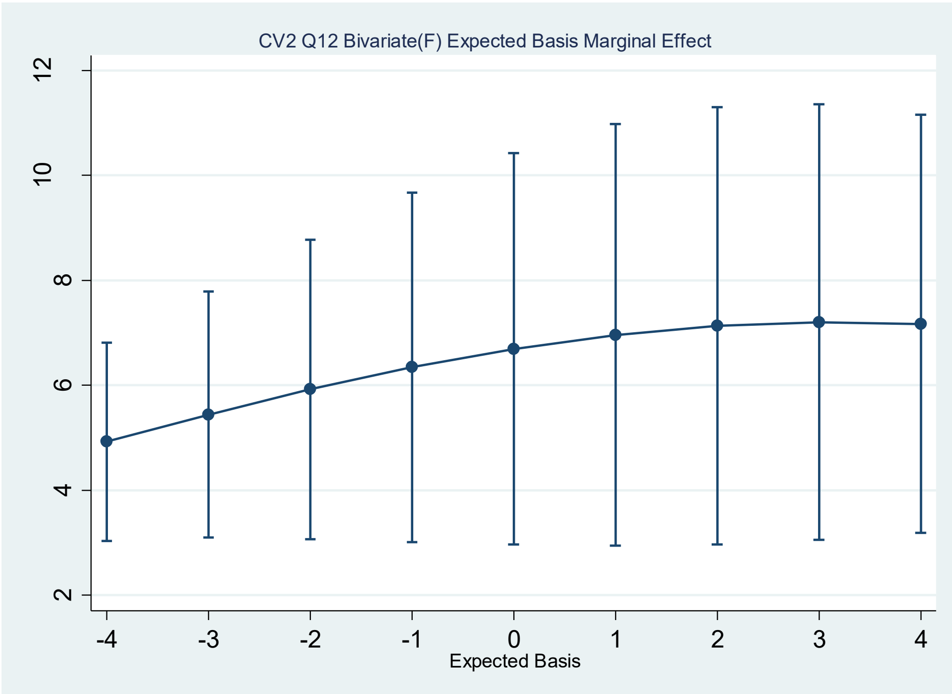


Figure 2.14 CV2 Q12 (Model F) expected basis marginal effect

Table 2.1 Summary statistics

	Full sample	V1	V2	V3	V4	V5	V6	V7
Number of observations	281	40	41	42	36	42	41	38
Age (years)	49.16	51.60	49.17	46.31	49.58	49.59	50.83	46.75
Bachelor's degree	49.47%	40.00%	60.98%	45.24%	44.44%	42.86%	56.10%	57.89%
TX	10.32%	12.50%	14.63%	7.14%	8.33%	11.90%	12.20%	5.26%
NE	18.86%	22.50%	17.07%	19.05%	22.22%	14.29%	21.95%	15.79%
IA	49.47%	47.50%	51.22%	40.48%	44.44%	61.90%	46.34%	55.26%
CO	5.34%	5.00%	7.32%	4.76%	5.56%	2.38%	4.88%	7.89%
KS	6.41%	2.50%	4.88%	11.90%	11.11%	0.00%	9.76%	5.26%
Cattle sold- medium	18.51%	10.00%	29.27%	16.67%	19.44%	14.29%	14.63%	26.32%
Cattle sold- large	15.66%	15.00%	14.63%	21.43%	16.67%	14.29%	14.63%	13.16%
Custom feeders	21.35%	12.50%	19.51%	26.19%	22.22%	23.81%	17.07%	26.32%
August contract increase	28.83%	35.00%	34.15%	23.81%	25.00%	23.81%	34.15%	26.32%
Purchased single source before	56.58%	52.50%	56.10%	57.14%	61.11%	69.05%	51.22%	50.00%
Risk averse	64.77%	70.00%	63.41%	66.67%	63.89%	66.67%	63.41%	60.53%
Past futures hedge percent	18.50%	19.00%	20.98%	17.41%	15.83%	17.62%	20.20%	18.68%
Past forward contract percent	17.78%	14.23%	21.76%	24.86%	17.50%	14.88%	14.08%	15.92%

Table 2.2 Historical direct from seller coefficient estimates and average marginal effects (N=278)

	Model 1 coefficient	Model 1 average marginal effects	Model 2 coefficient estimates	Model 2 average marginal effects
Spot marketing percent	-0.16***	-0.10***	-0.14**	-0.09**
	(0.06)	(0.04)	(0.07)	(0.04)
Cattle-sold large			14.20***	8.73***
			(5.36)	(3.22)
Risk averse			-4.02	-2.47
			(4.61)	(2.83)
Custom feeder			-5.88	-3.61
			(5.50)	(3.37)
Intercept	20.86***		21.37***	
	(3.78)		(5.86)	
Sigma	34.64***		34.30***	
	(2.05)		(2.05)	
SBC	1955.37		1964.70	
Log- likelihood	-969.24		-965.47	
Predicted correlation	0.15		0.18	

Table notes: Robust standard errors in (). * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 2.3 Historical spot marketing of finished cattle coefficient estimates and average marginal effects (N=278)

	Model 3 coefficient estimates	Model 3 average marginal effects	Model 4 coefficient estimates	Model 4 average marginal effects
Direct seller percent	-0.29**	-0.21**	-0.23**	-0.17**
	(0.12)	(0.09)	(0.11)	(0.08)
Cattle-sold large			-31.39***	-22.69***
			(7.10)	(4.97)
Risk averse			-30.80***	-22.26***
			(4.90)	(3.30)
Custom feeder			3.46	2.50
			(6.68)	(4.82)
Intercept	57.67***		77.75***	
	(3.64)		(4.07)	
Sigma	45.20***		40.96***	
	(1.73)		(1.85)	
SBC	2554.13		2522.27	
Log- likelihood	-1268.62		-1244.25	
Predicted correlation	0.15		0.44	

Table notes: Robust standard errors in (). * p<0.10, ** p<0.05, *** p<0.01

Table 2.4. Split-sample design

Block	**1**		**2**		**3**		**4**	**5**	**6**	**7**
	Q11	**Q12**	**Q11**	**Q12**	**Q11**	**Q12**				
Placement oriented	X	X	X	X	X	X				
Output pricing oriented							X	X	X	X
Single source premium	X	X	X	X	X	X			X	X
Output pricing options shown										
CME price		X		X		X	X	X	X	X
Expected local basis		X					X		X	
Ambiguous local basis						X	X	X	X	X
Forward contract basis				X				X		X

Table 2.5 CV1 model coefficient estimates

Model	A		B		C		D	
	Q11	Q12	Q11	Q12	Q11	Q12	Q11	Q12
Source premium	-33.00***	-25.58***	-36.22***	224.52*	-32.57***	-27.00***	-34.52***	232.45*
	(7.89)	(6.08)	(7.42)	(123.28)	(8.30)	(6.27)	(7.69)	(127.87)
CME price		-0.47		16.05**				
		(3.10)		(8.00)				
Expected hedge basis		13.97***		31.18***				
		(4.56)		(9.59)				
Source premium * CME price				-2.38**				
				(1.19)				
Source premium * Expected hedge basis				-2.60*				
				(1.55)				
Expected price- hedge						4.91**		21.75**
						(2.43)		(8.88)
Source premium * Expected price-hedge								-2.48**
								(1.22)
Intercept	206.30***	179.18	223.10***	-1545.77*	203.94***	-378.57	214.08***	-2134.64**
	(35.81)	(317.71)	(32.81)	(834.54)	(37.65)	(255.71)	(34.29)	(940.84)
Sigma	122.87***	108.32***	125.76***	96.8***	121.85***	120.89***	123.19***	111.88***
	(18.43)	(16.96)	(19.21)	(15.90)	(18.13)	(18.78)	(18.27)	(18.86)
Rho	0.75***		0.78***		0.72***		0.74***	
	(0.08)		(0.08)		(0.12)		(0.11)	
N	40		40		40		40	
SBC/BIC	513.33		515.78		515.04		515.36	
Pseudo-loglikelihood	-240.07		-237.60		-242.76		-241.08	

Table notes: Robust standard errors in (). * p<0.10, ** p<0.05, *** p<0.01

Table 2.6 CV1 average marginal effects

Model	A		B		C		D	
	Q11	Q12	Q11	Q12	Q11	Q12	Q11	Q12
Source premium	-12.75***	-7.77***	-13.52***	-6.41***	-12.68***	-7.83***	-13.19***	-6.71***
	(2.19)	(1.49)	(1.88)	(1.44)	(2.34)	(1.52)	(2.05)	(1.58)
	[-17.04, -8.46]	[-10.68, -4.85]	[-17.21, -9.83]	[-9.24, -3.59]	[-17.26, -8.10]	[-10.81, -4.84]	[-17.20, -9.18]	[-9.80, -3.62]
Statistically different	Yes		Yes		Yes		Yes	
CME price		-0.14		0.88				
		(0.94)		(0.94)				
		[-1.99, 1.70]		[-0.95, 2.72]				
Expected hedge basis		4.24***		5.11***				
		(1.35)		(1.11)				
		[1.59, 6.89]		[2.94, 7.28]				
Expected price- hedge						1.42**		2.51***
						(0.69)		(0.72)
						[0.06, 2.78]		[1.11, 3.91]

Table notes: Standard errors are reported in (). 95% confidence intervals reported in []. * p<0.10, ** p<0.05, *** p<0.01. Yes in statistically different line means that the source premium marginal effect in Q11 is statistically different than the source premium marginal effect in Q12 at the .10 level.

Table 2.7 CV2 model coefficient estimates

Model	E		F		G		H	
	Q11	Q12	Q11	Q12	Q11	Q12	Q11	Q12
Source premium	-25.10***	-14.12	-35.06***	-14.86*	-24.42***	-15.27*	-34.93***	-14.65*
	(6.84)	(9.69)	(6.34)	(7.64)	(7.34)	(9.22)	(7.21)	(7.89)
CME price		-3.09		-5.38				
		(4.86)		(4.55)				
Forward contract basis		12.63**		16.01***				
		(5.61)		(4.93)				
Expected price-forward contract						3.85		4.64
						(3.30)		(3.45)
Cattle sold- medium			-126.36***	41.01			-133.87***	26.97
			(35.93)	(45.73)			(40.68)	(41.27)
Cattle sold- large			-134.91**	-32.16			-133.34**	-14.54
			(53.33)	(48.04)			(55.15)	(52.29)
Custom feeders			161.27***	32.91			164.79***	46.52
			(34.57)	(43.49)			(37.00)	(41.47)
August contract increase			-18.22	84.00**			-21.10	62.44*
			(31.75)	(37.19)			(31.28)	(35.91)
Risk adverse			10.18	21.31			16.52	9.81
			(29.63)	(35.46)			(29.67)	(37.36)
Purchased single source before			-14.33	33.93			-15.90	35.77
			(33.86)	(39.05)			(32.41)	(40.46)
Intercept	151.78***	406.24	237.10***	567.27	149.70***	-310.87	237.29***	-460.68
	(31.54)	(500.28)	(42.73)	(471.38)	(33.76)	(341.77)	(43.03)	(365.10)
Sigma	111.82***	108.84***	93.41***	103.47***	109.72***	110.95***	89.65***	103.42***
	(16.91)	(15.03)	(17.17)	(16.03)	(15.94)	(14.61)	(16.34)	(14.43)
Rho	0.52***		0.76***		0.41**		0.61***	
	(0.17)		(0.12)		(0.17)		(0.18)	
N	41		41		41		41	
SBC/BIC	605.34		620.45		605.50		625.26	
Pseudo-log likelihood	-285.96		-271.23		-287.89		-275.50	

Table notes: Robust standard errors in (). * p<0.10, ** p<0.05, *** p<0.01

Table 2.8 CV2 average marginal effects

Model	E		F		G		H	
	Q11	Q12	Q11	Q12	Q11	Q12	Q11	Q12
Source premium	-9.65***	-6.12	-12.80***	-6.04**	-9.59***	-6.79*	-13.03***	-6.45*
	(1.73)	(3.85)	(1.33)	(2.90)	(1.93)	(3.72)	(1.49)	(3.31)
	[-13.03, -6.27]	[-13.67, 1.43]	[-15.41, -10.19]	[-11.73, -0.34]	[-13.36, -5.81]	[-14.08, 0.50]	[-15.94, -10.11]	[-12.94, 0.04]
Statistically different	No		Yes		No		Yes	
CME price		-1.34		-2.19				
		(2.09)		(1.78)				
		[-5.43, 2.75]		[-5.68, 1.30]				
Forward contract basis		5.47**		6.50***				
		(2.15)		(1.73)				
		[1.26, 9.68]		[3.11, 9.90]				
Expected price-forward contract						1.71		2.04
						(1.42)		(1.47)
						[-1.08, 4.51]		[-0.84, 4.93]
Cattle sold- medium			-39.19***	16.93			-41.46***	12.09
			(10.08)	(19.19)			(10.24)	(18.83)
			[-58.95, -19.42]	[-20.67, 54.54]			[-61.52, -21.39]	[-24.81, 48.98]
Cattle sold- large			-40.94***	-12.63			-41.38***	-6.30
			(11.88)	(18.10)			(12.11)	(22.21)
			[-64.22, -17.65]	[-48.11, 22.85]			[-65.11, -17.64]	[-49.83, 37.24]
Custom feeders			59.93***	13.86			61.94***	21.54
			(12.69)	(18.90)			(12.36)	(19.57)
			[35.06, 84.80]	[-23.17, 50.90]			[37.72, 86.17]	[-16.83, 59.90]
August contract increase			-6.54	34.81**			-7.71	28.55*
			(11.41)	(14.65)			(11.42)	(16.31)
			[-28.90, 15.82]	[6.09, 63.52]			[-30.08, 14.67]	[-3.41, 60.52]
Risk averse			3.69	8.65			6.09	4.32
			(10.80)	(14.43)			(10.93)	(16.54)
			[-17.46, 24.85]	[-19.62, 36.93]			[-15.33, 27.51]	[-28.09, 36.73]
Purchased single source before			-5.25	13.74			-5.95	15.55
			(12.45)	(15.65)			(12.20)	(17.32)
			[-29.65, 19.15]	[-16.93, 44.42]			[-29.87, 17.97]	[-18.40, 49.49]

Table notes: Standard errors are reported in (). 95% confidence intervals reported in []. * p<0.10, ** p<0.05, *** p<0.01.

Table 2.9 Model I coefficient estimates

	Futures Hedge	Forward Contract	Spot	Past hedging percent	Past forward contract percent
CME price	2.96	-1.22	-1.51		
	(4.02)	(5.51)	(2.91)		
CME price * CV4	-3.02	11.07	-4.40		
	(6.01)	(8.12)	(4.15)		
Expected hedge basis	2.54	-6.84	1.22		
	(5.88)	(7.96)	(4.01)		
Expected hedge basis * CV4	-0.12	16.72	2.55		
	(8.47)	(11.39)	(5.18)		
Forward contract basis	-3.62	-0.75	8.57**		
	(5.21)	(6.79)	(4.28)		
Forward contract basis * CV4	6.51	11.92	-4.17		
	(7.82)	(8.86)	(5.79)		
Past futures hedging percent	1.26	0.37	-2.05		
	(1.66)	(3.08)	(1.69)		
Past forward contract percent	0.57	3.79*	-3.60***		
	(1.38)	(2.27)	(0.99)		
CV4	297.10	461.41	461.41		
	(612.38)	(424.90)	(424.90)		
Cattle sold- large				4.07	10.17
				(12.97)	(10.35)
Risk averse				11.07*	17.66***
				(5.74)	(5.40)
Custom feeder				-16.89***	12.70
				(4.55)	(8.91)
Intercept	-329.20	-3.02	267.47	11.69***	1.08
	(406.53)	(556.82)	(291.52)	(3.64)	(3.25)
Sigma	94.27***	143.45***	109.13***	24.93***	28.5***
	(10.95)	(38.96)	(23.11)	(2.78)	(3.02)
		Rho m2	**Rho m3**	**Rho m4**	**Rho m5**
Rho 1n		-0.56**	-0.04	0.14	-0.06
		(0.25)	(0.35)	(0.54)	(0.51)
Rho 2n			-0.67***	0.00	-0.66*
			(0.18)	(0.66)	(0.37)
Rho 3n				0.06	0.77***
				(0.46)	(0.20)
Rho 4n					-0.31***
					(0.07)
Rho 5n					
N	78				
SBC/BIC	2950.75				
Pseudo-loglikelihood	-1359.92				

Table notes: Robust standard errors are reported in (). * p<0.10, ** p<0.05, *** p<0.01.

Table 2.10 Model I decomposed average marginal effects

	Futures Hedge		Forward Contract		Spot	
	CV4	CV5	CV4	CV5	CV4	CV5
CME price	-0.02	1.24	2.23	-0.25	-2.22**	-0.56
	(1.72)	(1.70)	(1.39)	(1.12)	(1.02)	(1.09)
	[-3.40, 3.36]	[-2.08, 4.57]	[-0.49, 4.95]	[-2.44, 1.94]	[-4.22, -0.21]	[-2.70, 1.58]
Expected hedge basis	0.97	1.07	2.24	-1.40	1.41	0.46
	(2.54)	(2.47)	(1.70)	(1.75)	(1.36)	(1.49)
	[-4.00, 5.94]	[-3.78, 5.92]	[-1.11, 5.58]	[-4.83, 2.02]	[-1.24, 4.07]	[-2.46, 3.37]
Forward contract basis	1.16	-1.52	2.53*	-0.16	1.65	3.19**
	(2.27)	(2.23)	(1.47)	(1.40)	(1.52)	(1.62)
	[-3.30, 5.61]	[-5.89, 2.85]	[-0.36, 5.41]	[-2.91, 2.60]	[-1.34, 4.63]	[0.02, 6.36]
Past futures hedging percent	0.50	0.53	0.08	0.08	-0.77	-0.76
	(0.62)	(0.64)	(0.71)	(0.65)	(0.52)	(0.57)
	[-0.71, 1.72]	[-0.72, 1.78]	[-1.30, 1.47]	[-1.20, 1.35]	[-1.79, 0.26]	[-1.88, 0.35]
Past forward contract percent	0.23	0.24	0.86**	0.78***	-1.35***	-1.34***
	(0.57)	(0.60)	(0.35)	(0.26)	(0.44)	(0.37)
	[-0.89, 1.35]	[-0.94, 1.42]	[0.16, 1.55]	[0.27, 1.28]	[-2.21, -0.49]	[-2.06, -0.62]

Table notes: Standard errors are reported in (). 95% confidence intervals reported in []. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 2.11 Model J coefficient estimates

	Futures Hedge	Forward Contract	Spot	Past hedging percent	Past forward contract percent
Feeder futures	9.45*	-4.54	8.81*		
	(5.20)	(7.51)	(4.69)		
Feeder futures * CV4	-0.21	-2.37	-11.44*		
	(7.84)	(9.56)	(5.92)		
CME price	3.14	-1.64	-0.81		
	(3.95)	(5.32)	(3.01)		
CME price * CV4	-3.97	11.82	-4.37		
	(5.74)	(8.03)	(4.24)		
Expected hedge basis	3.54	-7.69	3.25		
	(5.73)	(7.76)	(4.06)		
Expected hedge basis * CV4	-0.55	17.04	0.12		
	(8.09)	(11.60)	(5.14)		
Forward contract basis	-4.71	-0.87	8.74**		
	(4.97)	(6.71)	(4.24)		
Forward contract basis * CV4	10.20	10.36	-5.41		
	(7.72)	(9.14)	(6.02)		
Past futures hedging percent	1.43	0.59	-1.77		
	(1.92)	(3.18)	(1.77)		
Past forward contract percent	0.26	3.91*	-3.91***		
	(1.58)	(2.36)	(1.06)		
CV4	418.29	-895.27	1918.61**		
	(1174.51)	(1468.34)	(843.65)		
Cattle sold- large				3.04	10.44
				(13.42)	(9.98)
Risk averse				11.42*	17.54***
				(5.86)	(5.35)
Custom feeder				-16.73***	12.78
				(4.96)	(8.78)
Intercept	-1548.66*	614.07	-928.34	11.59***	1.10
	(838.00)	(1081.62)	(704.84)	(3.69)	(3.23)
Sigma	90.03***	144.33***	112.41***	24.93***	28.49***
	(9.48)	(40.15)	(26.79)	(2.78)	(3.02)
		Rho m2	**Rho m3**	**Rho m4**	**Rho m5**
Rho 1n		-0.62**	0.01	0.06	0.06
		(0.27)	(0.46)	(0.67)	(0.63)
Rho 2n			-0.68***	-0.03	-0.66*
			(0.22)	-0.66*	(0.38)
Rho 3n				-0.04	0.83***
				(0.46)	(0.16)
Rho 4n					-0.31***
					(0.07)
Rho 5n					
N	78				
SBC/BIC	2967.00				
Pseudo-loglikelihood	-1354.98				

Table notes: Robust standard errors are reported in (). * p<0.10, ** p<0.05, *** p<0.01.

Table 2.12 Model J decomposed average marginal effects

	Futures Hedge		Forward Contract		Spot	
	CV4	CV5	CV4	CV5	CV4	CV5
Feeder futures	3.71	3.95*	-1.55	-0.93	-0.99	3.27*
	(2.37)	(2.14)	(1.33)	(1.56)	(1.48)	(1.76)
	[-0.93, 8.34]	[-0.25, 8.15]	[-4.16, 1.06]	[-3.98, 2.13]	[-3.88, 1.91]	[-0.17, 6.71]
CME price	-0.33	1.31	2.28*	-0.34	-1.94*	-0.30
	(1.62)	(1.67)	(1.35)	(1.08)	(1.01)	(1.12)
	[-3.52, 2.85]	[-1.96, 4.58]	[-0.37, 4.92]	[-2.44, 1.77]	[-3.92, 0.04]	[-2.49, 1.89]
Expected hedge basis	1.20	1.48	2.09	-1.57	1.26	1.21
	(2.34)	(2.41)	(1.73)	(1.75)	(1.30)	(1.48)
	[-3.38, 5.78]	[-3.24, 6.20]	[-1.31, 5.49]	[-5.00, 1.86]	[-1.29, 3.81]	[-1.70, 4.11]
Forward contract basis	2.20	-1.97	2.13	-0.18	1.25	3.24**
	(2.31)	(2.16)	(1.51)	(1.38)	(1.67)	(1.59)
	[-2.33, 6.74]	[-6.20, 2.27]	[-0.84, 5.09]	[-2.88, 2.52]	[-2.02, 4.51]	[0.13, 6.35]
Past futures hedging percent	0.58	0.60	0.13	0.12	-0.66	-0.66
	(0.68)	(0.69)	(0.72)	(0.68)	(0.57)	(0.61)
	[-0.76, 1.91]	[-0.75, 1.95]	[-1.29, 1.55]	[-1.22, 1.46]	[-1.79, 0.46]	[-1.85, 0.54]
Past forward contract percent	0.10	0.11	0.88**	0.80***	-1.46***	-1.45***
	(0.65)	(0.68)	(0.37)	(0.26)	(0.46)	(0.39)
	[-1.17, 1.37]	[-1.22, 1.43]	[0.28, 1.32]	[0.15, 1.60]	[-2.37, -0.56]	[-2.22, -0.68]

Table notes: Standard errors are reported in (). 95% confidence intervals reported in []. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 2.13 Model K coefficient estimates

	Futures Hedge	Forward Contract	Spot	Past hedging percent	Past forward contract percent
Source premium	2.73	5.51	-8.17**		
	(8.03)	(8.60)	(3.94)		
Source premium *CV6	7.77	-21.98	4.14		
	(10.12)	(16.44)	(5.62)		
CME price	-2.28	10.91***	3.24		
	(3.69)	(3.92)	(2.20)		
CME price * CV6	3.64	-13.67**	-4.67		
	(4.75)	(6.01)	(2.87)		
Expected hedge basis	11.23*	-0.00	2.52		
	(6.17)	(6.52)	(3.44)		
Expected hedge basis * CV6	-2.07	-31.51**	0.08		
	(8.93)	(12.85)	(5.00)		
Forward contract basis	11.09	7.40	-10.10***		
	(7.87)	(7.27)	(3.53)		
Forward contract basis * CV6	-22.50**	3.70	11.61**		
	(10.07)	(11.81)	(5.56)		
Past futures hedging percent	4.88*	-0.68	-4.08***		
	(2.51)	(3.70)	(1.50)		
Past forward contract percent	-0.85	4.36	-3.26		
	(3.45)	(6.53)	(2.54)		
CV6	-417.46	1444.65**	494.53*		
	(500.92)	(632.04)	(296.38)		
Cattle sold- large				16.02*	14.26
				(8.43)	(15.56)
Risk averse				16.87***	4.83
				(6.43)	(9.18)
Custom feeder				-6.99	9.08
				(5.55)	(8.65)
Intercept	150.33	-1286.97***	-132.84	5.83**	13.47***
	(376.41)	(451.47)	(233.02)	(2.60)	(4.61)
Sigma	138.17	132.77	111.48***	23.46***	31.71***
	(85.51)	(171.49)	(37.85)	(2.79)	(2.98)
		Rho m2	**Rho m3**	**Rho m4**	**Rho m5**
Rho 1n		-0.36	-0.38	-0.76***	0.41
		(1.02)	(0.70)	(0.22)	(0.69)
Rho 2n			-0.59	0.25	-0.73
			(0.45)	-0.73	(0.84)
Rho 3n				0.41	0.55
				(0.66)	(0.67)
Rho 4n					-0.36***
					(0.06)
Rho 5n					
N	78				
SBC/BIC	2939.14				
Pseudo-loglikelihood	-1341.05				

Table notes: Robust standard errors are reported in (). * p<0.10, ** p<0.05, *** p<0.01.

Table 2.14 Model K decomposed average marginal effects

	Futures Hedge		Forward Contract		Spot	
	CV6	CV7	CV6	CV7	CV6	CV7
Source Premium	2.55*	0.69	-2.41	0.92	-1.35	-2.69**
	(1.38)	(2.00)	(1.78)	(1.83)	(1.51)	(1.31)
	[-0.15, 5.25]	[-3.23, 4.61]	[-5.90, 1.08]	[-2.68, 4.51]	[-4.30, 1.60]	[-5.25, -0.13]
CME price	0.33	-0.58	-0.40	1.82	-0.48	1.07
	(0.80)	(0.99)	(0.71)	(2.63)	(0.73)	(0.74)
	[-1.23, 1.90]	[-2.52, 1.37]	[-1.79, 0.98]	[-3.33, 6.97]	[-1.90, 0.95]	[-0.39, 2.52]
Expected hedge basis	2.22	2.84	-4.61	-0.00	0.87	0.83
	(1.58)	(1.75)	(3.57)	(1.09)	(1.24)	(1.15)
	[-0.88, 5.33]	[-0.59, 6.27]	[-11.60, 2.39]	[-2.13, 2.13]	[-1.56, 3.30]	[-1.43, 3.09]
Forward contract basis	-2.77	2.80	1.62	1.23	0.50	-3.33***
	(1.81)	(2.34)	(1.41)	(2.23)	(1.61)	(1.19)
	[-6.31, 0.77]	[-1.77, 7.38]	[-1.15, 4.39]	[-3.14, 5.60]	[-2.64, 3.65]	[-5.65, -1.00]
Past futures hedging percent	1.18***	1.23***	-0.10	-0.11	-1.36**	-1.34**
	(0.34)	(0.30)	(0.47)	(0.49)	(0.68)	(0.55)
	[0.52, 1.85]	[0.65, 1.82]	[-1.03, 0.83]	[-1.07, 0.84]	[-2.70, -0.03]	[-2.42, -0.27]
Past forward contract percent	-0.21	-0.21	0.64	0.73***	-1.09*	-1.07
	(0.79)	(0.82)	(0.44)	(0.11)	(0.61)	(0.72)
	[-1.75, 1.34]	[-1.81, 1.38]	[-0.22, 1.50]	[0.51, 0.94]	[-2.29, 0.11]	[-2.48, 0.33]

Table notes: Standard errors are reported in (). 95% confidence intervals reported in []. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 2.15 Model L coefficient estimates

	Futures Hedge	Forward Contract	Spot	Past hedging percent	Past forward contract percent
Feeder futures	-10.47	-5.80	7.54		
	(6.48)	(8.63)	(4.79)		
Feeder futures * CV6	17.04**	1.40	-5.99		
	(7.90)	(10.59)	(5.88)		
Source premium	-1.13	4.16	-8.22**		
	(7.95)	(7.85)	(3.64)		
Source premium *CV6	11.67	-19.08	3.81		
	(9.94)	(15.15)	(5.41)		
CME price	-2.82	11.33***	3.34		
	(3.57)	(4.02)	(2.25)		
CME price * CV6	3.89	-13.76**	-4.83		
	(4.62)	(5.91)	(2.96)		
Expected hedge basis	9.89*	-0.49	4.05		
	(5.81)	(6.63)	(3.42)		
Expected hedge basis * CV6	-1.39	-30.06**	-1.65		
	(8.87)	(13.55)	(4.94)		
Forward contract basis	12.95	6.88	-10.60***		
	(8.32)	(7.21)	(3.64)		
Forward contract basis * CV6	-24.48**	2.84	12.35**		
	(10.26)	(11.47)	(5.64)		
Past futures hedging percent	5.22	-0.60	-4.24***		
	(3.50)	(3.10)	(1.56)		
Past forward contract percent	-1.96	3.94	-3.10		
	(5.16)	(5.17)	(2.69)		
CV6	-2632.32**	1261.65	1277.65		
	(1060.11)	(1411.89)	(779.64)		
Cattle sold- large				17.45**	14.69
				(7.24)	(13.36)
Risk averse				15.84***	4.98
				(5.99)	(8.26)
Custom feeder				-7.96	8.70
				(6.11)	(8.75)
Intercept	1577.01*	-576.37	-1105.62*	6.35**	13.41***
	(953.99)	(1239.84)	(663.22)	(2.61)	(4.56)
Sigma	163.43	121.14	109.45***	23.51***	31.7***
	(157.93)	(125.71)	(34.34)	(2.87)	(2.95)
		Rho m2	**Rho m3**	**Rho m4**	**Rho m5**
Rho 1n		-0.44	-0.28	-0.79***	0.60
		(1.09)	(0.77)	(0.14)	(0.62)
Rho 2n			-0.55	0.21	-0.68
			(0.55)	-0.68	(0.84)
Rho 3n				0.47	0.49
				(0.70)	(0.77)
Rho 4n					-0.36***
					(0.06)
Rho 5n					
N	78				
SBC/BIC	2957.95				
Pseudo-loglikelihood	-1337.38				

Table notes: Robust standard errors are reported in (). * p<0.10, ** p<0.05, *** p<0.01.

Table 2.16 Model L decomposed average marginal effects

	Futures Hedge		Forward Contract		Spot	
	CV6	CV7	CV6	CV7	CV6	CV7
Feeder futures	1.47	-2.32*	-0.66	-1.05	0.53	2.48
	(1.19)	(1.34)	(0.85)	(2.54)	(1.10)	(1.56)
	[-0.86, 3.80]	[-4.95, 0.31]	[-2.32, 1.00]	[-6.02, 3.92]	[-1.63, 2.68]	[-0.58, 5.53]
Soure premium	2.36*	-0.25	-2.24	0.75	-1.49	-2.70**
	(1.30)	(1.78)	(1.66)	(1.56)	(1.53)	(1.24)
	[-0.19, 4.90]	[-3.74, 3.24]	[-5.50, 1.01]	[-2.31, 3.82]	[-4.49, 1.51]	[-5.13, -0.27]
CME price	0.24	-0.63	-0.37	2.05	-0.50	1.10
	(0.72)	(0.83)	(0.71)	(2.55)	(0.76)	(0.76)
	[-1.18, 1.65]	[-2.25, 1.00]	[-1.76, 1.02]	[-2.95, 7.05]	[-2.00, 1.00]	[-0.39, 2.59]
Expected hedge basis	1.90	2.19	-4.59	-0.09	0.81	1.33
	(1.35)	(1.47)	(2.99)	(1.19)	(1.24)	(1.15)
	[-0.75, 4.55]	[-0.68, 5.06]	[-10.45, 1.27]	[-2.43, 2.25]	[-1.62, 3.25]	[-0.92, 3.58]
Forward contract basis	-2.58	2.87	1.46	1.25	0.59	-3.48***
	(1.66)	(2.14)	(1.30)	(2.08)	(1.61)	(1.24)
	[-5.83, 0.67]	[-1.34, 7.07]	[-1.09, 4.01]	[-2.84, 5.33]	[-2.57, 3.75]	[-5.92, -1.04]
Past futures hedging percent	1.17**	1.16***	-0.09	-0.11	-1.43*	-1.39**
	(0.48)	(0.40)	(0.42)	(0.46)	(0.74)	(0.62)
	[0.24, 2.10]	[0.38, 1.93]	[-1.01, 0.80]	[-0.91, 0.73]	[-2.89, 0.02]	[-2.60, -0.19]
Past forward contract percent	-0.44	-0.43	0.59	0.71***	-1.05	-1.02
	(1.05)	(1.01)	(0.38)	(0.12)	(0.67)	(0.74)
	[-2.49, 1.61]	[-2.41, 1.54]	[-0.16, 1.34]	[0.48, 0.94]	[-2.36, 0.26]	[-2.46, 0.43]

Table notes: Standard errors are reported in (). 95% confidence intervals reported in []. * p<0.10, ** p<0.05, *** p<0.01.

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Chapter 3 - Testing Ricardian rent theory in the U.S. beef industry across time

The U.S. cattle markets are characterized by extreme highs and lows. Recently, record high prices throughout the beef industry began in 2014 lasting through mid-2015 before quickly moving downward. This resulted in mixed short-run profitability outcomes between cow-calf and feedlot operations in 2015. Some economists estimate losses to feedlots of around \$500/head while cow-calf producers experienced historically high margins (Tonsor, 2016). Beyond immediate profitability implications, understanding how information from primary consumer demand is transmitted through price, throughout the supply chain is key for longer-term prosperity of the industry (Marsh, 2003; chapter 4). Furthermore, understanding these price transmissions from one part of the beef industry to another are key for long-term investment decisions. How do investments in generic advertising or prevention of food safety recalls geared towards enhancing retail beef demand impact cow-calf producers and feedlot operators? Is one group affected differently than another? How do changes in feed prices impact cattle prices? Ricardian rent theory can be used to understand these price transmissions.

According to Ricardian rent theory, rents are bid up so the holder of the scarcest resource extracts the surplus (Ricardo, 1821). In Ricardo's application to land, land is in fixed supply (perfectly inelastic) and necessary for crop production, while farmers are plentiful. When corn price increases, farmers can benefit by harvesting more crops. However, to do this with fixed technology, farmers need more land. Thus, competitive farmers bid up land rental rates until the level of zero economic profit. Consequently, the benefits of crop price increases pass from the farmer to the land owner through higher rental rates. Additionally, although not called Ricardian rent theory, the economic incidence of government subsidies between landowners and farmers has been studied using a one output and two input framework (Floyd, 1965; Alston & James, 2002). In order for rents to fully accrue back to the landowner (or holder of the scarce resource), strict conditions must be met including a perfectly inelastic supply of the scare resource, and perfectly elastic supply of additional inputs or fixed proportions technology.

Studies such as Kirwan (2009), Kirwan and Roberts (2016), and Du, Hennessey, and Edward (2008) have empirically tested Ricardian rent theory in farmland rental rates or incidence of agricultural subsidies. Generally, less than 100% pass-through has been found. Although originally applied to land rental rates, the core notions of Ricardian rent theory and adjustments in valuations of the scarcest resource can be used to examine how price changes are transmitted through beef industry sectors.

The main objective of this study is to determine if Ricardian rent theory holds in the beef industry by examining the pass-through rates from fed cattle price to feeder cattle price, and from corn price to feeder cattle price. Given the conditions needed for Ricardian rent theory to hold, there are potential reasons why Ricardian rent theory may hold in the beef industry and competing reasons why it may not hold. In terms of the cattle industry, the supply of breeding stock and calves (young feeder cattle) are nearly fixed in the short run; the cattle gestation-period is nine months and steers are 18 to 22 months of age when harvested. Additionally, many feeder calves are sold at competitive auction markets where (at least in the long-term) feeder cattle buyers will likely not be willing to pay more than the difference between expected fed cattle (output) price and feedings costs (Zhao, Du, & Hennessey, 2011). Given that feeder cattle are in fixed supply, necessary for fed cattle production, and sold in competitive markets, sellers of feeder animals (cow-calf, backgrounder, and stocker operations) could receive “Ricardian rents” when changes in fed cattle and corn prices occur.[9] However, Ricardian rent theory might not hold in the beef industry because the cattle herd can expand and contract in the long run. Using annual data, Marsh (2003) estimated a long-run feeder cattle supply elasticity of 2.82. Therefore, in the very short run (month to month), feeder cattle supply is perfectly inelastic, but is not perfectly inelastic in the long-run. Furthermore, the corn market might not be perfectly elastic, so some rents could accrue to corn producers. Finally, a large amount of capital is required and asset fixity exists at the feedlot level. Additionally, feedlots have historically had excess capacity. For these reasons, feedlot operators may not behave as perfectly competitive profit maximizers. As an example, given entry-exit costs feedlots may rationally bid up feeder cattle prices as long as they are covering variable costs even if doing so results in an expected economic loss.

Zhao, Du, and Hennessy (2011) first tested if Ricardian rent theory held in the U.S. beef industry using time-series data from January 1979 to April 2004. Zhao, Du, and Hennessy (2011) found fed cattle futures price passes through 93% to feeder cattle futures price and corn price changes have a negative effect of 87% pass-through to feeder cattle futures price.

In the past decade, the U.S. cattle and agriculture industries have changed in many ways. These changes could influence the feedlot profit function or the objective function employed by feedlot operators, changing the beef industry price transmission and subsequently alter Ricardian rent theory conclusions. Technological introductions, such as beta-agonists, into the feedlot sector could influence tradeoffs made regarding feeder cattle and corn input decisions (Schroeder & Tonsor, 2011). Finishing weights of fed steers have increased from approximately 1225 lbs in

[9] Potentially, Ricardian rents could be held by seed stock owners rather than cow-calf producers. While data constraints may limit such assessments, future research is encouraged.

the 1990s to 1375 lbs since 2010 (Livestock Marketing Information Center [LMIC], 2016). Increased finishing weight means more pounds are added per animal translating to increased corn consumption per head. Thus, this increased finished weight and increased corn consumption changes the relative importance of feeder cattle and corn costs in the feedlot profit function and thus pass-through conclusions. At the same time, the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 increased ethanol demand and hence corn demand (McPhail, 2011). In 2012, the nominal corn price reached over $7.00/bushel.

The beef industry has been increasingly affected by globalization. The bovine spongiform encephalopathy (BSE) case in 2004 reduced U.S. beef trade to near zero for a period of time. Since the threat of BSE has declined, approximately 10% of beef is now being exported (Westcott, Hansen, & Stallings, 2016). Additionally, mandatory country of origin labeling for beef, requiring country of birth, raising, and processing to be labeled, took effect in 2009, but was repealed in 2015 (Schroeder, Tonsor, & Parcell, 2016). The macroeconomic effects of the U.S. recession from 2008 to 2009 also cannot be ignored. Due to these and other transformations throughout the industry, further investigation into Ricardian rent theory and price transmission is warranted. Given the aforementioned changes, the feedlot profit function could have changed over time, impacting Ricardian rent theory pass-through rates.

Beyond updating past work, the first contribution of this study is endogenously identifying structural breaks over time in the feeder cattle, fed cattle, and corn price relationships to see if conclusions about Ricardian rent theory are robust across time. Zhao, Du, and Hennessy (2011) found a structural break in the data in 2004 and hence did not use data past 2004. Therefore, an analysis of recent data and study of structural change is warranted. Data from the *Focus on Feedlots* series (LMIC, 2017) is used to update production assumptions used to calculate hypothesized pass-through rates from Ricardian rent theory. Specifically, the fixed weights of feeder and finished cattle, death loss percent, discount rate, and bushels of corn needed for feed are updated to reflect industry practices across time (Herrington & Tonsor, 2013). This is important as underlying price data reflect changing market supply and demand conditions that need to be accounted for in identifying appropriate hypothesized pass-through rates.

The second major contribution is incorporating basis into price expectations (*analysis B*).[10] Zhao, Du, and Hennessy (2011) used fed cattle and feeder cattle futures prices for price expectations. Using futures prices only assumes a zero expected basis. However, Kastens, Jones, and Schroeder (1998) found incorporating historical basis results in more accurate forecasts. The zero basis assumption is relaxed using cash Kansas feeder cattle price and expected fed cattle price, calculated using deferred futures contract values, Kansas cash fed cattle prices, and four-year historical average basis.

Ricardian rent theory is based on an inelastic short-run supply of feeder calves, but can potentially be used to draw long-run implications, since in the longer run, the cow herd, and hence feeder cattle supply, can expand and contract. The feedlot industry has excess capacity (Allen, 2014). Thus, feedlot operators could potentially try to incentivize cow-calf producers to increase the calf inventory through price transmissions. The third major contribution is investigating pass-through asymmetry in two ways. Pass-through from fed cattle and corn prices to feeder cattle prices could be different when fed cattle prices are increasing versus decreasing (*analysis C*). Second, pass-through rates from the feedlot sector to the cow-calf sector could be different during times of herd expansion and contraction (*analysis D*).

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[10] $basis = cash\ price - futures\ price$

Given these contributions, four analyses are completed. First, analysis A is conducted using feeder futures, fed cattle futures, and cash corn price data while simultaneously testing for structural breaks. Second, pass-through rates are examined using cash feeder cattle prices and expected fed cattle prices based upon deferred future contract values and historical basis patterns while also testing for structural breaks (analysis B). In analysis C, pass-through asymmetry in the fed cattle to feeder cattle price is studied during times of expected fed cattle price increases and decreases. Lastly, in analysis D, pass-through asymmetry during herd expansion and contraction is explored.

Applying Ricardian rent theory to the beef industry

Similar to Zhao, Du, and Hennessy (2011), the net present value of expected profit per head for a finished steer sold from a representative feedlot at time of placement (π_t) is:

$$\pi_t = \frac{E_t\left[P_T^{Fed}\right]W^{Fed}(1-D)}{1+r} - E_t[P_t^{Feeder}]W^{Feeder} - E_t[P_t^{Corn}]B^{Corn} - OC. \qquad (32)$$

Subscript t is time of placement and T represents the expected finishing time. A five month feeding horizon is assumed, and thus $T = t + 5$. $E_t[P_t^{Feeder}]$ is expected feeder cattle price at time t in dollars per hundredweight (cwt). $E_t\left[P_T^{Fed}\right]$ is expectation at time t of time T fed cattle price in dollars per cwt. W^{Feeder} and W^{Fed} are the steer's weight at placement and finishing in cwt, respectively. $E_t[P_t^{Corn}]$ is the expected corn price at time t in dollars per bushel (bu) and B^{Corn} is total corn bu fed.[11] All corn is assumed to be purchased at placement. D is death loss percent and r is the discount rate. OC represents other costs such as veterinary costs, marketing, transportation, etc. OC is assumed to be constant and relatively small.

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[11] $B^{Corn} = \frac{(W^{Fed} - W^{Feeder}) * (Feed\ conversion\ ratio)}{lbs\ of\ corn\ per\ bushel}$

Assuming profit is equal to a fixed K, the following hypotheses can be derived to test if Ricardian rent theory holds in the beef industry (Zhao, Du, & Hennessy, 2011). If Ricardian rent theory holds, then feeder cattle prices will be bid up or down when economic changes occur in cattle finishing. The first testable hypothesis, the 100% fed cattle to feeder cattle pass-through, is:

H_0^{Fed}: a dollar increase in expected fed cattle price, $E_t\left[P_T^{Fed}\right]$, affects the feeder cattle price, $E_t[P_t^{Feeder}]$ by:

$$\phi_1 = \frac{W^{Fed}(1-D)}{W^{Feeder}(1+r)}. \tag{33}$$

The second testable hypothesis, the 100% corn to feeder cattle pass-through, is:

H_0^{Corn}: a dollar increase in corn price, $E_t[P_t^{Corn}]$, affects the feeder cattle price, $E_t[P_t^{Feeder}]$ by:

$$\phi_2 = -\frac{B^{Corn}}{W^{Feeder}}. \tag{34}$$

Multiple assumptions are used to estimate equations (33) and (34). Monthly data, from December 1995 to December 2016, of feeder cattle weight, fed cattle weight, death loss percent, and feed conversion ratio are obtained from the *Kansas State University Focus on Feedlots* series (LMIC, 2017). Through the entire analysis, 56 lb of corn per bu is assumed. Quarterly observations from Q4 1995 to Q4 2016 for average annual interest rate for feeder livestock, non-real estate bank loans from the Kansas City Federal Reserve Bank, were used as the discount rate (Federal Reserve Bank of Kansas City, 2017).[12] The effective semi-annual discount rate is calculated using $[(1 + annual\ rate)^{1/2} - 1]$. The pass-through values hypothesized by

[12] To get monthly observations, quarterly values were assumed for each month in the quarter. For example, quarter 1 values were used for January, February, and March.

Ricardian rent theory, ϕ_1 and ϕ_2, are calculated for each month and averaged for the whole period under investigation. The hypothesized ϕ_1 and ϕ_2 from Ricardian rent theory (henceforth called RRT ϕ_1 and RRT ϕ_2) are tested against the pass-through estimates from the regression analyses. See Table 3.1 for the average values of assumptions and RRT ϕ_1 and ϕ_2 values. See Appendix B for RRT ϕ_1 and ϕ_2 descriptive statistics and plots.

Methodology and data

The static empirical model can be written as (similar to Zhao, Du, and Hennessy (2011)):

$$E_t[P_t^{Feeder}] = \alpha_0 + \beta_0 E_t\left[P_T^{Fed}\right] + \gamma_0 E_t[P_t^{Corn}] + \sum_{k=1}^{11} d_k m_k + \sum_{w=0}^{W} \tau_w time_t^w + \varepsilon_t \qquad (35)$$

where $E_t[P_t^{Feeder}]$ is the expected feeder cattle price at placement time t, $E_t[P_T^{Fed}]$ is the expectation at placement time t of the fed cattle price at time of sale T, and $E_t[P_t^{Corn}]$ is the expected corn price at time t. m_k are monthly placement dummies for January to November with $k \in \{1,2, \ldots 11\}$. $time_t$ is a time trend allowing up to $time_t^w$, where $w \in \{0, 1, 2, 3\}$, to be included in the model to capture other unobservable factors. ε_t is the estimated error term. α_0, β_0, γ_0, d_k and τ_w are parameters. The values of β_0 and γ_0 are compared to the hypothesized RRT ϕ_1 and ϕ_2 to test for 100% pass-through.

Data are monthly averages and prices are discovered and reported in the market with noise, thus a model specification allowing for possible dynamic effects is estimated. Equation (35) is extended dynamically as follows:

$$E_t[P_t^{Feeder}] = \alpha_0 + \sum_{i=0}^{p} \beta_i E_{t-i}[P_{T-i}^{Fed}] + \sum_{j=0}^{q} \gamma_j E_{t-j}[P_{t-j}^{Corn}] + \sum_{k=1}^{11} d_k m_k + \sum_{w=0}^{W} \tau_w time_t^w + \varepsilon_t \qquad (36)$$

where β_i and γ_j are the pass-through rate from a change in fed cattle and corn prices i or j periods earlier (Zhao, Du, & Hennessy, 2011). Following Campa and Goldberg (2006) and Zhao, Du, and Hennessy (2011), the instantaneous effect is given by the coefficient in the same period and the total effect of fed cattle and corn changes are the sum of the respective coefficients. These values are tested against hypothesized pass-through threshold values to see if Ricardian rent theory holds in the cattle industry. Therefore, RRT ϕ_1 is compared to $\sum_{i=0}^{p} \beta_i$ and RRT ϕ_2 is compared to $\sum_{j=0}^{q} \gamma_j$. Lag lengths (p and q) and trends included are determined by minimizing the SBC value in models that included consecutive lags and all monthly dummy variables. For the dynamic models, up to six lags of fed cattle and corn prices were considered.

Monthly data from December 1995 to December 2016 were collected from the Livestock Marketing Information Center (LMIC) (LMIC, 2017). After considering up to six possible lags in the models and data availability, data from May 1996 to December 2016 are used to facilitate comparisons across the analyses. All prices are deflated by the Consumer Price Index (CPI; 1982-1984=100; U.S. Bureau of Labor Statistics, 2017).

Using feeder and fed cattle futures prices (analysis A)

Following Zhao, Du, and Hennessy (2011), $E_t[P_t^{Feeder}]$ is the nearby Chicago Mercantile Exchange (CME) feeder cattle futures contract price at time t, $E_t[P_T^{Fed}]$ is the appropriate deferred CME fed cattle futures contract price at time t, and $E_t[P_t^{Corn}]$ is the cash corn price. [13]

A five month feeding period is assumed throughout. Accordingly, $E_t[P_T^{Fed}]$ is the nearby fed cattle contract price for the contract corresponding to five months in the future. For example, if a steer is placed in January, it is assumed to finish feeding in June, so the June futures price in

[13] This assumes a zero basis for both feeder and fed cattle prices.

January is used. However, if a steer is placed in February, it will finish feeding in July. There is no July futures contract and hence the August futures contract price in February is used.[14]

Figure 3.1 to Figure 3.3 graph the real nearby feeder cattle futures, deferred fed cattle futures, and cash corn price series from December 1995 to December 2016. Descriptive statistics of the deflated price series are in Table 3.2. The real feeder cattle futures price generally increased from 1994 to 2016 (Figure 3.1). The real feeder cattle futures price averaged \$46.43/cwt between 1996 and 2003, \$51.40/cwt between 2004 and 2010, and \$70.07/cwt between 2011 and 2016. A major increase in price and subsequent fall is evident between 2012 and 2016, reaching \$100.88/cwt at its peak. The real fed cattle futures price follows the same general pattern as the feeder futures price (Figure 3.2). Fed cattle futures deflated price was relatively consistent from 1994 to 2001, but began to vary more in 2002. A substantial price increase occurred from around \$40.00/cwt in early 2009 to just over \$71.00/cwt in November 2014 before continually falling to nearly \$42.00/cwt in 2016. Real corn price also generally increased from 1994 to 2016 (Figure 3.3). The largest run up in the real corn price, from \$1.56/bu to \$3.31/bu, occurred between June 2010 and August 2012.

Incorporating basis into expected fed cattle price (analysis B)

Using feeder and fed cattle futures prices for price expectations assumes an expected basis of zero. Assuming a zero basis, as in Zhao, Du, and Hennessy (2011), when forecasting is usually not accurate (Kastens, Jones, & Schroeder, 1998). This assumption is relaxed in two ways. Kansas feeder steer cash prices by weight and fed cattle prices were obtained from LMIC (2017). Kansas cash feeder steer prices are available beginning January 1992 for 500 to 599 lb,

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[14] Live cattle future contracts are traded for February, April, May, June, August, September, October, and December.

600 to 699 lb, 700 to 799 lb, and 800 to 899 lb animals. Feedlot placements by weight class (less than 600 lb, 600 to 699 lb, 700 to 799 lb, 800 lb plus) for Kansas are available beginning December 1995. Using the four steer prices and the percent of cattle placed by weight in that month, a real weighted feeder cattle cash price is constructed for $E_t[P_t^{Feeder}]$ (Figure 3.1).

Alternatively, $E_t[P_T^{Fed}]$ can be calculated using historical Kansas fed cattle basis and fed cattle futures price using:

$$basis = cash\ price - futures\ price \tag{37}$$

and

$$expected\ price = current\ deferred\ futures\ price + expected\ basis. \tag{38}$$

Kansas fed cattle cash prices are available beginning January 1990. Kastens, Jones, and Schroeder (1998) found that the most accurate method to use for price forecasting is deferred futures plus historical basis. A four year historical average basis for fed cattle is used for expected basis as suggested by Tonsor, Dhuyvetter, and Mintert (2004). Figure 3.2 shows the real expected fed cattle price series. The average real expected basis is -\$0.09/cwt (t-test against 0=-1.93), with a minimum and maximum of -\$1.37/cwt and \$3.07/cwt, respectively. Expected basis is seasonal with the highest basis usually occurring in December.

Using the weighted cash feeder cattle price for $E_t[P_t^{Feeder}]$ and expected fed cattle price for $E_t[P_T^{Fed}]$, equations (35) and (36) are estimated again and used to test Ricardian rent theory when considering basis.

Exploring pass-through asymmetry (analyses C and D)

Asymmetric pass-through is investigated in two ways: increasing versus decreasing fed cattle price and herd expansion versus contraction.

Asymmetric pass-through in times of fed cattle price increase versus decrease

To investigate pass-through asymmetry in times of fed cattle price increases versus decreases equation (36) can be rewritten as

$$E_t[P_t^{Feeder}] = \alpha_0 + \omega_0 Incr + \sum_{i=0}^{p} \beta_i E_{t-i}\left[P_{T-i}^{Fed}\right] + \sum_{i=0}^{p} \iota_i E_{t-i}\left[P_{T-i}^{Fed}\right] * Incr_t$$
$$+ \sum_{j=0}^{q} \gamma_j E_{t-j}\left[P_{t-j}^{Corn}\right] + \sum_{k=1}^{11} d_k m_k + \sum_{k=1}^{11} \delta_k m_k * Incr_t \qquad (39)$$
$$+ \sum_{w=0}^{W} \tau_w time_t^w + \sum_{w=0}^{W} \theta_w time_t^w * Incr_t + \varepsilon_t.$$

Two types of fed cattle price increases will be investigated. The first is a month-to-month change in $E_t\left[P_T^{Fed}\right]$, therefore $Incr_t = 1$ if $E_t\left[P_T^{Fed}\right] > E_{t-1}\left[P_{T-1}^{Fed}\right]$ and 0 otherwise. The second is year-over-year change in $E_t\left[P_T^{Fed}\right]$ where $Incr_t = 1$ if $E_t\left[P_T^{Fed}\right] > E_{t-12}\left[P_{T-12}^{Fed}\right]$ and 0 otherwise. See Figure 3.4 for a plot of the two fed cattle price increase dummy variables. Joint tests are conducted to determine if the increase interaction terms and intercept shifter are statistically significant.

To test Ricardian rent theory, RRT ϕ_1 is compared to $\sum_{i=0}^{p} \beta_i$ for the base (price decrease) fed cattle pass-through and to $\sum_{i=0}^{p} \beta_i + \sum_{i=0}^{p} \iota_i$ for the price increase pass-through. RRT ϕ_2 is compared to $\sum_{j=0}^{q} \gamma_j$ since there are no fed cattle price increase interactions with corn price.

Asymmetric pass-through in times of herd expansion versus contraction

Given the biological considerations in the beef industry, the cattle herd is fixed in the short run, but can expand and contract in the long-run. Therefore, signals of herd expansion and contraction may impact the short-run pass-through conclusions. The heifer percentage of feedlot placements can be used to measure herd expansion and contraction.[15] A lower than average heifer percent is considered a signal of herd expansion because more heifers are being held back by cow-calf producers as breeding stock. From 1996 to 2016, on average 37% of animals placed in U.S. feedlots were heifers. The percent of heifers placed is used instead of the number of heifers placed because the number placed confounds changes in herd size and seasonality.

To investigate asymmetry in pass-through during times of herd expansion versus contraction equation (36) can be rewritten as:

$$
\begin{aligned}
E_t[P_t^{Feeder}] = \alpha_0 + \psi_0 Expan_t + \sum_{i=0}^{p} \beta_i E_{t-i}\left[P_{T-i}^{Fed}\right] + \sum_{i=0}^{p} \zeta_i E_{t-i}\left[P_{T-i}^{Fed}\right] * Expan_t \\
+ \sum_{j=0}^{q} \gamma_j E_{t-j}\left[P_{t-j}^{Corn}\right] + \sum_{j=0}^{q} \kappa_j E_{t-j}\left[P_{t-j}^{Corn}\right] * Expan_t + \sum_{k=1}^{11} d_k m_k \\
+ \sum_{k=1}^{11} \chi_k m_k * Expan_t + \sum_{w=0}^{W} \tau_w time_t^w + \sum_{w=0}^{W} \rho_w time_t^w * Expan_t \\
+ \varepsilon_t.
\end{aligned}
\tag{40}
$$

Two different expansion variables will be investigated. The first is a measure of expansion over the last year where $Expan_t = 1$ if $\frac{\sum_{k=0}^{11} \%\, heifers\ placed_{t-k}}{12} < 37\%$ and 0 otherwise. The second is the year-over-year change in the percent of heifers placed where $Expan_t = 1$ if $\%\, heifers\ placed_t < \%\, heifers\ placed_{t-12}$ and 0 otherwise. See Figure 3.5 for plots of the two expansion dummy variables. Joint tests are conducted to determine if the expansion interaction terms and intercept shifter are statistically significant.

[15] Percent heifers placed $= \frac{number\ of\ heifers\ placed}{number\ of\ heifers\ placed + number\ of\ steers\ placed}$

To test Ricardian rent theory, RRT ϕ_1 is compared to $\sum_{i=0}^{p} \beta_i$ for the base (contraction) fed cattle pass-through and to $\sum_{i=0}^{p} \beta_i + \sum_{i=0}^{p} \zeta_i$ for the expansion fed cattle pass-through. RRT ϕ_2 is compared to $\sum_{j=0}^{q} \gamma_j$ for the base (contraction) pass-through and $\sum_{j=0}^{q} \gamma_j + \sum_{j=0}^{q} \kappa_j$ for the expansion corn pass-through.

Augmented Dickey Fuller tests

Augmented Dickey Fuller (ADF) tests with and without accounting for seasonality were conducted to test for nonstationary and unit roots (Table 3.3) (Dickey & Fuller, 1979). The null hypothesis of the ADF test is the data display one unit root. The minimum Schwarz Bayesian criteria (SBC) was used to select the appropriate lag length in all ADF tests.[16,17] ADF tests with seasonality include 11 monthly dummy variables. After accounting for seasonality all feeder and fed cattle prices are stationary, however, cash corn price is not stationary. To further investigate the non-stationarity of corn price, Zivot and Andrews (2002) unit root test was conducted which allows for one break in the intercept, linear trend or both at an unknown date (Pfaff, Zivot & Stigler, 2016) (Table 3.4). If seven or eight lags are used, the corn price is stationary. However, this result is not robust across all potential lag lengths. In the analysis, a model of mixed level and stationary variables does not make sense. Including variables with unit root does not bias coefficient estimates, but may impact standard errors (Pouliot and Sumer, 2014). All models are conducted with level variables, but residuals are checked for stationarity using ADF tests.

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[16] $SBC = n * \ln\left(\frac{SSE}{n}\right) + k * ln(n)$ where n is the number of observations, SSE is sum of squared errors, and k is the number of independent variables (including the intercept).

[17] Using simulated data Beal (2007) found the SBC measure out performed both Akaike's Information Criteria (AIC) and Bayesian Information Criteria (BIC) by correctly choosing the true model most consistently.

Misspecification tests

Models are initially estimated using ordinary least squares and then misspecification tests are conducted to check for normality, homoscedasticity, and independence following McGuirk, Driscoll and Alwang (1993). The D'Agostino third sample moment tests, the Anscombe and Glynn fourth sample moment test, and D'Agostino-Pearson K^2 omnibus tests are used to test for normality (Anscombe & Glynn, 1983; D'Agostino, Belanger, & D'Agostino, 1990). Static and dynamic homoscedasticity are examined using a RESET2 test and autoregressive conditional heteroscedasticity (ARCH) test, respectively. Independence is checked using the following auxiliary regression:

$$\widehat{\varepsilon_t} = \beta_0' \boldsymbol{X}_t + \Lambda' \widehat{\varepsilon_{t-1}} + \upsilon_t \tag{41}$$

where $\boldsymbol{X}_t$ is a $k \times 1$ vector of independent variables, ε_t is the residual from the original model and υ_t is the estimated residuals from the auxiliary regression (McGuirk, Driscoll & Alwang, 1993). If Λ is significant then independence is rejected. If homoscedasticity and/or independence are rejected, then generalized method of moments with the Newey-West correction on the errors terms is completed (Greene, 2003).[18]

Results and discussion

Analysis A: Using feeder and fed cattle futures prices

The static and dynamic model results when using feeder and fed cattle futures prices and cash corn are found in Table 3.5. The misspecification tests indicate that non-normality,

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[18] See http://support.sas.com/kb/40/098.html. The Newey-West standard error correction in SAS can be completed using proc model specifying GMM and kernel=(Bartlett, L+1, 0) in the fit statement. L is the maximum lag length determined by the researcher. We use L=12 because monthly data are used.

heteroscedasticity and autocorrelation are concerns in both models. Thus, Newey-West corrected standard errors are used and reported.

In the static model, the fed cattle pass-through is estimated to be 1.86. Thus, when the fed cattle futures price increases by $1.00/cwt, the feeder cattle futures price increases by $1.86/cwt, ceteris paribus. A pass-through greater than one is expected. The feeder steer price per cwt is generally higher than the fed steer price per cwt because of the differences in placement weight versus finished weight. In other words, the feeder animal weighs less so the feeder steer price per cwt is often higher because overall less pounds are being purchased than when purchasing a finished steer. The corn price pass-through estimate is -8.49, meaning when the corn price increases by $1.00/bu the feeder cattle futures price decreases by $8.49/cwt, ceteris paribus. The monthly dummy variables are also jointly statistically significant confirming seasonality in feeder cattle prices.

By minimizing the SBC value, the dynamic model with one fed cattle lag, zero corn lags and a linear time trend is preferred amongst all dynamic models examined and to the static model. The contemporaneous fed cattle pass-through is $1.44/cwt with a total pass-through of $1.88/cwt.[19] The corn pass-through is -$8.45/cwt. Both the fed cattle and corn pass-through to the feeder cattle price are robust across the static and dynamic models. The seasonal dummy variables are also jointly significant confirming seasonality in feeder cattle prices.

The tests of RRT ϕ_1, 1.59, and ϕ_2, -7.16, against the pass-through estimates from the regression analysis are in Table 3.6 and Table 3.7. First, p-values are reported from Chi- square tests of the coefficient estimates against the average pass-through value (a fixed value). The second tests are one-sided complete combinational tests (Poe, Giraud, & Loomis, 2005) which

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[19] Estimates may seem off because of rounding. Note only two decimal places are reported.

utilize the mean and standard deviation of the monthly ϕ calculations, relaxing the assumption of the hypothesized pass-through being fixed.[20]

The ϕ_1 pass-through is 117% and 118% of that hypothesized by Ricardian rent theory in the static and dynamic models, respectively. For all tests, we reject that the regression fed cattle pass-through is equal to that suggested by Ricardian rent theory, at a five percent significance level. Therefore, fed cattle futures price changes at the feedlot level are being passed onto cow-calf producers through the feeder cattle futures price at rates higher than suggested by Ricardian rent theory. The fed cattle pass-through calculations contrast those of Zhao, Du, and Hennessy (2011) from 1979 to 2004 that failed to reject 100% pass-through of fed cattle futures.

If fed cattle prices are increasing then this higher pass-through would be beneficial for cow-calf producers (harmful for feedlot producers), but if fed cattle prices are decreasing this is negative for cow-calf producers (beneficial to feedlot producers). Looking at fed cattle price changes in Figure 3.2, price generally increased, benefiting cow-calf producers. However, there are notable times of price decrease, especially from 2014 to 2016, where the greater than 100% pass-through benefited feedlot operators.

The ϕ_2 regression pass-through for the static and dynamic models are 119% and 118% of that hypothesized by Ricardian rent theory, respectively. For both the static and dynamic model, when using a fixed RRT ϕ_2, we reject that the pass-through values are the same as RRT ϕ_2, at a five percent significance level. When examining the combinational tests, at the five percent level, the estimated pass-through is greater than the RRT pass-through for the static model. However, we marginally fail to reject that the regression pass-through is different than the RRT

[20] 1,000 Krinsky-Robb bootstrapped estimates of each of the hypothesized ϕ and estimated pass-through values from the regression were completed. $H_0: regression\ pass-through > RRT\ \phi$

pass-through for the dynamic model. Zhao, Du, and Hennessy (2011) failed to reject 100% corn pass-through.

Over the past few decades, changes in technology, globalization and international trade such as MCOOL and BSE, macroeconomic events such as the U.S. recession, and competing feed corn uses such as ethanol, have likely impacted relationships between the feeder cattle, fed cattle, and corn prices. These changes can potentially alter pass-through conclusions. Therefore it is important to examine if structural breaks in the relationships between feeder cattle, fed cattle, and corn prices occur. If structural breaks are not considered, results for the full period may mask important industry changes, potentially making Ricardian rent theory conclusions inaccurate.

Two methods can be used to test for structural change. The Chow test is used if break dates are known (Chow, 1960). However, if breaks dates are not known and multiple break dates are possible, the Bai Perron (BP) test is used to simultaneously determine the number and timing of structural breaks (Bai & Perron, 2003; Twine, Rude, & Unterschultz, 2015). The BP test with a 15% trimming factor and a maximum of five possible structural breaks is utilized (Bai & Perron, 2003; Twine, Rude, & Unterschultz, 2015). The dynamic model BP test results are shown in Table 3.8. Based on the SupF(l+1|l) test, two structural breaks are not rejected in favor of three structural breaks and thus we conclude two breaks. The three regimes (R) are May 1996 to October 2006 (R1), November 2006 to April 2011 (R2), and May 2011 to December 2016 (R3). Structural break 1 occurs after the breaks identified by Zhao, Du, and Hennessy (2011) in 2004. However, Zhao, Du, and Hennessy (2011) conducted structural change tests on each individual data series, whereas the BP test is testing for differences in the whole coefficient vector of the model. The second regime corresponds with changes in the corn market due to ethanol demand, which may have impacted the relationship between corn and feeder cattle prices, and the U.S. recession. The second break date and initiation of the third regime correspond with the drought conditions experienced throughout portions of the U.S. from 2010 to 2012. Droughts result in higher corn prices, poor pasture conditions, and limitations on when feeder cattle can be retained outside of feedlots, thus potentially impacting feedlot input use and substitutions.

Given the results of the BP tests, a model with interaction terms and a shifter variable for the regimes is estimated as:

$$
\begin{aligned}
E_t[P_t^{Feeder}] = {} & \alpha_0 + \psi_0 R2_t + \lambda_0 R3_t + \sum_{i=0}^{p} \beta_i E_{t-i}[P_{T-i}^{Fed}] + \sum_{i=0}^{p} \zeta_i E_{t-i}[P_{T-i}^{Fed}] * R2_t \\
& + \sum_{i=0}^{p} \eta_i E_{t-i}[P_{T-i}^{Fed}] * R3_t + \sum_{j=0}^{q} \gamma_j E_{t-j}[P_{t-j}^{Corn}] + \sum_{j=0}^{q} \kappa_j E_{t-j}[P_{t-j}^{Corn}] \\
& * R2_t + \sum_{j=0}^{q} \varrho_j E_{t-j}[P_{t-j}^{Corn}] * R3_t + \sum_{k=1}^{11} d_k m_k + \sum_{k=1}^{11} \chi_k m_k * R2_t \qquad (42) \\
& + \sum_{k=1}^{11} \Gamma_k m_k * R3_t + \sum_{w=0}^{W} \tau_w time_t^w + \sum_{w=0}^{W} \rho_w time_t^w * R2_t \\
& + \sum_{w=0}^{W} \vartheta_w time_t^w * R3_t + \varepsilon_t
\end{aligned}
$$

where R1 is the base case, R2=1 if the date is between November 2006 and April 2011 and 0 otherwise, and R3=1 if the date is between May 2011 and December 2016 and 0 otherwise. See Table 3.9 for estimation results. The joint Chi-square tests indicated that each group of regime specific variables (interactions and shifters) are jointly statistically significant. Additionally, the relevant pass-through variables (fed cattle and corn coefficients) are jointly statistically significant for each regime. The misspecification tests reject normality, homoscedasticity, and independence. Thus, Newey-West standard errors are reported. The lower SBC value indicates that this model is preferred to both the static and dynamic models without structural break shifters.

In R1, the contemporaneous fed cattle pass-through is $1.38/cwt with the total R1 pass-through being $1.79/cwt. For R2, the contemporaneous pass-through is $0.99/cwt (1.38-0.39) and the total R2 pass-through is $1.45/cwt (1.38-0.39+0.40+0.05), the smallest fed cattle pass-through of the three regimes. The R3 contemporaneous fed cattle pass-through is $1.47/cwt (1.38 + 0.08) with a total R3 pass-through of $1.91/cwt (1.38+0.08+0.40+0.05). However, the R3 fed-cattle interactions are not individually statistically different from zero.

Test results comparing the pass-through regression estimates to RRT ϕ_1 for the specific regime are shown in Table 3.6 (the regime specific RRT ϕ_1s are in Table 3.1). For R1 and R3, tests reject 100% pass-through. Therefore, from May 1996 to October 2006 and from May 2011 to December 2016 fed cattle prices changes were being passed from feedlots to cow-calf producers through the feeder cattle futures price at levels greater than Ricardian rent theory suggests. During R1, the fed cattle price varied, but generally increased. Thus, the larger than hypothesized pass-through benefited cow-calf producers. During R3, there was an upward movement in price from 2011 to 2014, however, the price fell in 2015 and 2016. Therefore, the 117% pass-through benefited cow-calf producers initially, but then benefited feedlot operators in 2015 and 2016 who passed on more of the fed cattle price decrease. The R2 pass-through is 90% of the RRT ϕ_1, but is not statistically different from 100% in either the fixed or one-sided combinational tests. Therefore, during R2 price transmission between the cow-calf producers and feedlot operators was consistent with Ricardian rent theory.

The estimated corn pass-through is statistically different across regimes. The corn pass-through is -$5.35/cwt, -$7.80/cwt, and -$8.47/cwt in R1, R2, and R3. These estimates are 77%, 105% and 114% of the pass-through values suggested by Ricardian rent theory (Table 3.7). The R1 coefficient is statistically less than (in absolute terms) the RRT ϕ_2, while the R2 and R3 pass-through estimates are not statistically different than the RRT ϕ_2. In R1, the corn price generally decreased. Accordingly, a smaller percent of this cost saving was passed from the feedlot to the cow-calf producer than hypothesized by Ricardian rent theory.

Those who are skeptical of structural breaks tests may argue that the break(s) might be caused by omitted variables or an incorrectly specified model. Due to the misspecification test concerns and structural breaks in analysis A we consider different price expectations in analysis B.

Analysis B: Using weighted Kansas cash feeder and expected fed cattle prices

This analysis relaxes the zero basis assumptions in both feeder cattle and live cattle prices. In analysis 3, weighted Kansas cash feeder cattle and expected live cattle prices are used instead of futures prices.[21] Misspecification tests and estimation results from the static and dynamic model are shown in Table 3.10.

Misspecification tests indicate residuals are normal and stationary, but dynamic heteroscedasticity and autocorrelation are present in both the static and dynamic models. Therefore, Newey-West standard errors are reported. Estimated fed cattle and corn pass-through from the static model are $1.97/cwt and -$9.59/cwt, respectively. Seasonality is also present in the feeder cattle price. The feeder cattle price from January to September is higher than in

[21] A four year historical basis was used as expected fed cattle basis.

December (the base month), while October and November feeder cattle prices are discounted relative to December. Additionally, the linear trend is statistically significant and positive, indicating a continual increase in the weighted Kansas cash feeder cattle price over time.

The lower SBC value indicates the dynamic model is preferred to the static model. The preferred dynamic model includes one lag of the expected fed cattle price but no corn price lags. Seasonality and a positive linear trend are present in the feeder cattle price. The instantaneous fed cattle pass-through is \$1.58/cwt and the total pass-through is \$1.99/cwt. The total fed cattle estimated pass-through is compared to the RRT ϕ_1 in Table 3.6. The estimated pass-through is 125% of and statistically significantly greater than the hypothesized RRT pass-through. From 1996 to 2014 the expected fed cattle price generally increased (Figure 3.2). The fed cattle price increase combined with pass-through greater than 100% benefited cow-calf producers because feedlots were passing back a larger share of this price increase than hypothesized by Ricardian rent theory. However, from 2015 to 2016, fed cattle prices sharply declined, hurting cow-calf producers through lower than hypothesized feeder cattle prices.

The estimated corn pass-through from the dynamic model is -\$9.56/cwt (Table 3.10), which is 134% of the RRT ϕ_2 (Table 3.7). Both the Chi-square test against the fixed RRT ϕ_2 and the combinational tests, which allow for statistical variation in RRT ϕ_2, confirm the estimated pass-through is statistically larger than the hypothesized pass-through. From 1996 to 2006 and 2013 to 2016, corn price generally decreased (Figure 3.3) benefitting cow-calf producers through higher than expected feeder cattle prices. From 2006 to 2013, corn price increased harming cow-calf producers with lower than expected feeder cattle prices.

The BP test did not identify any structural breaks ($supF(1|0) = 31.91$, $Pr > supF(1|0) = 0.58$). This contrasts the results in analysis A where two structural breaks were identified. Therefore, accounting for local supply and demand conditions and basis expectations using a cash feeder cattle price and expected fed cattle basis in analysis B potentially eliminates some of the omitted variable and misspecification concerns from analysis A. Given that no breaks were identified and errors are normal in analysis B, it is preferred to analysis A. Weighted Kansas cash feeder and expected fed cattle prices will be used to investigate pass-through asymmetry in analyses C and D.

Analysis C: Asymmetric pass-through in times of fed cattle price increase versus decrease

Pass-through asymmetry when the fed cattle price increases versus decreases is investigated in two ways, month-to-month and year-over year price changes.

Month-to-month changes in fed cattle price

Estimation results for the static model including interaction terms for month-to-month fed cattle price increase are shown in Table 3.11. The static model was preferred to all other dynamic specifications. The errors are normal and stationary, however they are not homoscedastic or independent, so Newey-West standard errors are reported. The base case is fed cattle price decrease. All price increase interactions and shifters are jointly significant.

The fed cattle pass-through is \$2.04/cwt when fed cattle price decreases and \$1.96/cwt when prices increases. These estimates are 128% and 123% of the pass-through hypothesized by Ricardian rent theory (Table 3.6). Tests against a fixed and variable RRT ϕ_1 indicate the estimated pass-through for both price increase and decrease are statistically greater than the RRT ϕ_1. However, the fed cattle pass-through during price increases and price decreases are not statistically different from one another (Chi-square statistic=2.14, p-value= 0.14). Therefore, month-to-month changes in the fed cattle price do not impact the fed cattle pass-through.

The corn pass-through is -\$9.65/cwt which is 135% of the RRT ϕ_2 and statistically larger than the RRT ϕ_2 (Table 3.7). The pass-through is similar to that found in both the static and dynamic models presented in analysis B.

Seasonality is present and different when the fed cattle price decreases versus when it increases. The price increase and seasonality interactions are jointly significant, at a five percent significance level. All monthly dummy interactions with price increase except May and July are negative, indicating the price differences in these months relative to December are lower during price increases than price decreases.

Year-over-year changes in fed cattle price

Another potential way to investigate pass-through asymmetry is using year-over-year (YOY) changes in fed cattle price. The static and dynamic model results are shown in Table 3.12 and Table 3.13. The pass-through point estimates are similar across the two models. All increase variables are jointly significant at a five percent significance level. However, this conclusion seems to be driven by the trend and increase interactions; the pass-through and increases interactions, and the seasonality and increase interactions are not jointly significant at the five percent level.

Investigating the estimated fed cattle pass-through conclusions in Table 3.6, the base case estimated fed cattle pass-through is 118% of and statistically greater than RRTϕ_1 for both the dynamic and static models. For fed cattle price increases, the estimated pass-through is 112% in both static and dynamic models, but not statistically different from RRTϕ_1, at a five percent significance level. However, the estimated fed cattle pass-through during price increases and decreases are not statistically different from each other (Chi-square statistic=0.58, p-value=.45).

The corn pass-through conclusions are mixed across the static and dynamic models. When comparing the -\$8.62/cwt and -\$8.68/cwt estimated pass-through estimates to a fixed RRT ϕ_2, both are statistically different from RRT ϕ_2 (Table 3.7). However, in the combinatorial tests where RRT ϕ_2 has statistical variability, the estimated corn pass-through in the static model is not statistically different from the RRT ϕ_2. Conversely, the estimated pass-through from the dynamic model is statistically greater than RRT ϕ_2, at a five percent significance level. Overall, the evidence is mixed regarding pass-through asymmetry during fed cattle price increases versus decreases.

Analysis D: Asymmetric pass-through in times of herd expansion versus contraction

Pass-through asymmetry during herd expansion versus contraction is investigated in two ways, average expansion over the last year and year-over year changes in heifer percentage.

Average expansion over the last year

The static and dynamic estimation results with expansion over the last 12 months interactions (expansion A12) are shown in Table 3.14 and Table 3.15. Errors in both models are normal and stationary. Newey-West errors are reported due to heteroscedasticity and autocorrelation concerns.

The dynamic model is preferred to the static model due to the lower SBC value, with conclusions being similar. In the dynamic model, the expansion A12 interactions and shifter are jointly significant (Table 3.15). The fed cattle contraction instantaneous pass-through is \$1.38/cwt with a total pass-through of \$1.92/cwt. During expansion, the instantaneous pass-through is \$1.42/cwt with a total pass-through of \$1.94/cwt. These pass-through estimates are 121% and 122%, and are both statistically greater than the RRT ϕ_1 (Table 3.6). However, the contraction and expansion estimates are not statistically different from each other (Chi-square statistic=0.04, p-value=0.84). Additionally, the expansion and contract fed cattle pass-through values are similar to the dynamic pass-through in Analysis B ($1.99, 125%).

The contraction and expansion corn pass-through estimates are -$7.43/cwt (104%) and -$12.55/cwt (175%), which are statistically different from each other (Chi-square statistic=6.44, p-value=0.01) (Table 3.7). The contraction pass-through is not statistically different than RRT ϕ_2, however, the expansion pass-through is statistically greater than the RRT ϕ_2. Thus, there is evidence of asymmetry in corn pass-through during herd expansion versus contraction. Potentially, this indicates that during times of expansion when there are fewer heifers in the feedlot, different input substitutions are being made by feedlot operators between corn and feeder cattle in the production of fed cattle.

In order to assess who benefits and who loses during times of expansion or contraction we need to understand price changes in fed cattle and corn over these time periods. Figure 3.6 plots the expansion A12 dummy against fed cattle and corn prices. Using the expansion A12 measure, the most recent contraction phase was from July 2009 to December 2012. Over this period both the fed cattle and corn price increased. The fed cattle price increase was positive for cow-calf producers because the 121% pass-through means that the feeder cattle price increased more than hypothesized by Ricardian rent theory. During contraction the corn pass-through is not different than that hypothesized by Ricardian rent theory. Therefore, this increased corn cost is passed to cow-calf producers through lower feeder cattle prices at expected rates. Overall, cow-calf producers benefited over this time period relative to what Ricardian rent theory would suggest.

Since January 2013 the cattle herd has been expanding when using the expansion A12 measure. From January 2013 to November 2014, fed cattle prices increased and then fell through 2016. The 122% pass-through would have benefited cow-calf producers and harmed feedlots during 2013 and 2014. The opposite would be true during 2015 and 2016. From 2013 to 2016 the corn price generally decreased. Coupled with the expansion A12 corn pass-through of 175%, this corn price decrease benefits cow-calf producers. Overall, from 2013 to 2014, cow-calf producers benefited from the larger than expected pass-through at feedlot operators expense. The impact from 2015 to 2016 is ambiguous.

Year-over-year change in heifer percentage as measure of expansion

The static and dynamic models with expansion year-over-year (expansion YOY) interactions are shown in Table 3.16 and Table 3.17. Errors in both models are stationary, but they are not normal, homoscedastic, or independent. Newey-West standard errors are reported. All expansion YOY variables are jointly significant in the static and dynamic models.

The conclusions across the static and dynamic models are similar. The dynamic model is preferred to the static model because of the lower SBC value. In the dynamic model, the total contraction fed cattle pass-through is \$1.73/cwt (instantaneous pass-through is \$1.47/cwt) and the total expansion pass-through is \$2.17/cwt (instantaneous pass-through is \$1.55/cwt). The contraction 109% fed cattle pass-through is not statistically different from the RRT ϕ_1, but the expansion 137% pass-through is statistically greater than the RRT ϕ_1. The contraction and expansion fed cattle pass-through estimates are also statistically different from each other (Chi-square statistic=11.16, p-value=0.0008). Thus, the fed cattle pass-through is asymmetric in the expansion YOY model.

The corn pass-through is -\$7.93/cwt during contraction and -\$10.05/cwt during expansion (Table 3.17). As with the fed-cattle pass-through, the estimated corn pass-through is not statistically different than the RRT ϕ_2 during contraction, but is statistically different during expansion (Table 3.7). The contraction and expansion pass-through estimates are also statistically different from one another (Chi-square statistic=4.41, p-value=0.04). Therefore, in times of YOY expansion more of fed cattle and corn price changes are being passed back to the cow-calf producers through the feeder cattle price than in YOY contraction.

Figure 3.7 plots the expansion YOY dummy against fed cattle and corn prices. During contraction YOY, the most recent and longest was July 2006 to June 2010, both the fed cattle and corn price changes passed through to the feeder cattle price as expected. However, during expansion YOY the fed cattle and corn pass-through estimates are greater than 100%. Generally from July 2010 to March 2016, the cattle herd was expanding based on the expansion YOY variable. During this time the real fed cattle price increased until November 2014, benefiting cow-calf producers. However, from November 2014 to March 2016 the real fed cattle price decreased substantially, hurting cow-calf producers through lower than hypothesized feeder cattle prices. Over this expansion time period the real fed cattle price generally increased, from $43.51/cwt in July 2010 to $51.57/cwt in March 2016, benefiting cow-calf producers. Real corn price varied from $1.60/bu in July 2010 up to $3.31/bu in August 2012 and down to $1.50/bu in March 2016. The more than 100% pass-through from corn to feeder cattle prices benefited feedlot producers from July 2010 to August 2012, but cow-calf producers from September 2012 to March 2016. However, over the whole 2010 to 2016 expansion period the corn price decreased, benefiting cow-calf producers. Therefore, over this expansion time period cow-calf producers benefited from the corn and fed cattle price changes more than Ricardian rent theory suggests.

Conclusion

This study examines whether Ricardian rent theory holds in the U.S. beef industry by investigating how changes in fed cattle and corn prices are transmitted to the feeder cattle price. Based on Ricardian rent theory, surplus rents should pass through the market to the holder of the scarcest resource. In the cattle markets, feeder calves are the scarcest, widely traded resource and thus gains and losses at the feedlot should be passed through to feeder cattle prices. Monthly data from 1996 to 2016 were used in four analyses. In analysis A, CME futures market feeder and fed cattle prices were used. Two structural breaks were found. Thus a model with regime specific pass-through interactions was estimated. In analysis B, the strong zero basis expectation was relaxed by using weighted Kansas cash feeder cattle price and an expected fed cattle price incorporating a four-year historical average basis. In analyses C and D asymmetric pass-through was explored. Asymmetry in pass-through when fed cattle price increases was introduced in analysis C using two different price increase interaction terms, month-to-month and year-over-year. In analysis D, testing for pass-through asymmetry was conducted when the cattle herd was expanding versus contracting using an average expansion variable for the past year and a year-over-year expansion variable.

One-hundred percent pass-through suggested by Ricardian rent theory between fed cattle and corn with feeder cattle prices were calculated using monthly production data primarily from the *Focus on Feedlots* data series. The regression pass-through estimates were tested against a fixed RRT pass-through, and against a pass-through with statistical variation. In many models, the estimated pass-through was statistically greater than the RRT hypothesized pass-through. Thus, when fed cattle or corn prices change, these changes are more than fully passed to cow-calf producers through the feeder cattle price. The larger than expected pass-through estimates are consistent with the divergent profitability outcomes between cow-calf operations and feeding operations recently. Both cow-calf producers and cattle feeders experienced historically high returns in 2014. However, in 2015 and 2016, average net returns for finished steers ranged from -$100 to -$500 per head (Tonsor, 2016). At the same time, cow-calf returns were around $300 per cow (LMIC, 2016). However, these divergent returns cannot be sustained long term. Near zero long run economic profit in the cow-calf and feedlot sectors is expected in a competitive market (Mark, Schroeder, & Jones, 2000; Pendell, Kim, & Herbel, 2015).

Conclusions regarding whether cattle markets are "broken" is sensitive to the assumptions in the model and the approach used to test Ricardian rent theory. For example, in analysis A, Ricardian rent theory was not rejected in all regimes tests while in analysis B Ricardian rent theory was rejected. Thus, an important contribution of our study is that the incorporation of basis into price expectations is key for accurate analysis. When a zero basis was assumed (analysis A), two structural breaks were found. However, when using weighted cash feeder cattle and expected fed cattle price with a four-year historical average basis (analysis B), no structural breaks were found. Potentially, the differing structural break conclusions are being driven by basis and expectations, instead of differences in true underlying feeder cattle, fed cattle, and corn price relationships.

Pass-through asymmetry was tested for fed cattle price increases and decreases, and for cattle herd expansion and contraction. Overall, there was little evidence for asymmetric pass-through when fed cattle price is increasing or decreasing. However, there was evidence that pass-through was asymmetric during times of herd expansion versus contraction. Corn pass-through was different for expansion and contraction in both the average expansion over the last 12 months and the year-over year models. The pass-through was not statistically different then that hypothesized by Ricardian rent theory during herd contraction, when calves are more plentiful. Conversely, during expansion when there are fewer heifers in the feedlot, the corn pass-through was statistically greater than the hypothesized Ricardian rent theory pass-through. This could be a signal of different input substitutions during expansion and contraction. The fed cattle pass-through in expansion and contraction was only different from each other in the year-over-year model, but not in the average over the last 12 months model. However, in the average herd expansion model, both during times of expansion and contraction the fed cattle pass-through was statistically greater than the Ricardian rent theory pass-through.

Overall, our results suggest that Ricardian rent theory does not perfectly hold in the U.S. beef industry. Oftentimes a pass-through greater than 100% was found. Potential reasons for this include:

1. The production data from *Focus on Feedlots* is from a small survey of feedlots in KS. Thus, if this data is not representative of actual feedlot production then the hypothesized Ricardian rent theory conclusions would be incorrect and bias our conclusions.
2. Expected prices are used that assume nothing about risk preferences or alternative marketing of fed cattle. Therefore, if producers forward contract their cattle, for example, our expected prices could not reflect the producers' actual expected prices and would bias pass-through conclusions.
3. There is a biological lag in beef production. Therefore, there might be differences in short run versus long run pass-through values.
4. Feedlot operations may not be behaving as perfectly competitive profit maximizers because of excess capacity and asset fixity. Therefore, the feedlot profit function

used to derive the hypothesized pass-through conclusions and subsequent pass-through conclusions would be incorrect. In the original application to farmland, landowners owned the only scarce resource (land). However, potentially both cow-calf producers (calves, genetics) and feedlots (feedlots are only used for one purpose, finishing livestock) own scarce resources.

Cow-calf producers should consider the potential implications of greater than 100% pass-through from fed cattle and corn prices. In vertical markets, anything that increases retail beef demand will subsequently increase fed cattle price. These benefits will be more than proportionally passed to cow-calf producers. However, if retail demand decreases, potentially from a change in tastes and preferences or a food safety shock, price decreases would also be more than proportionally passed to cow-calf producers. Considering the horizontal corn and feeder cattle markets, the large corn pass-through, especially during expansion, could indicate a higher degree of input substitutability between corn and feeder cattle. Potentially, if corn price increases and these higher feed costs result in adversely lower feeder cattle prices, cow-calf producers could consider delaying sale or even retaining ownership of the steer through slaughter. Generally, cow-calf producers cannot react as quickly to shocks. Therefore, cow-calf producers should not only follow current events and changes at the retail beef demand level but also the horizontal feed markets to understand the potential ramifications on feeder cattle prices, and ultimately revenue, they receive.

Moving forward, other sectors of the beef complex, such as seed stock (bulls, cow-calf pairs and bred heifers), can be included if data are available. An additional extension would be examining other key beef production states to see if conclusions hold across states. Future work could also look into a more complex feedlot profit functions due to asset fixity and excess capacity.

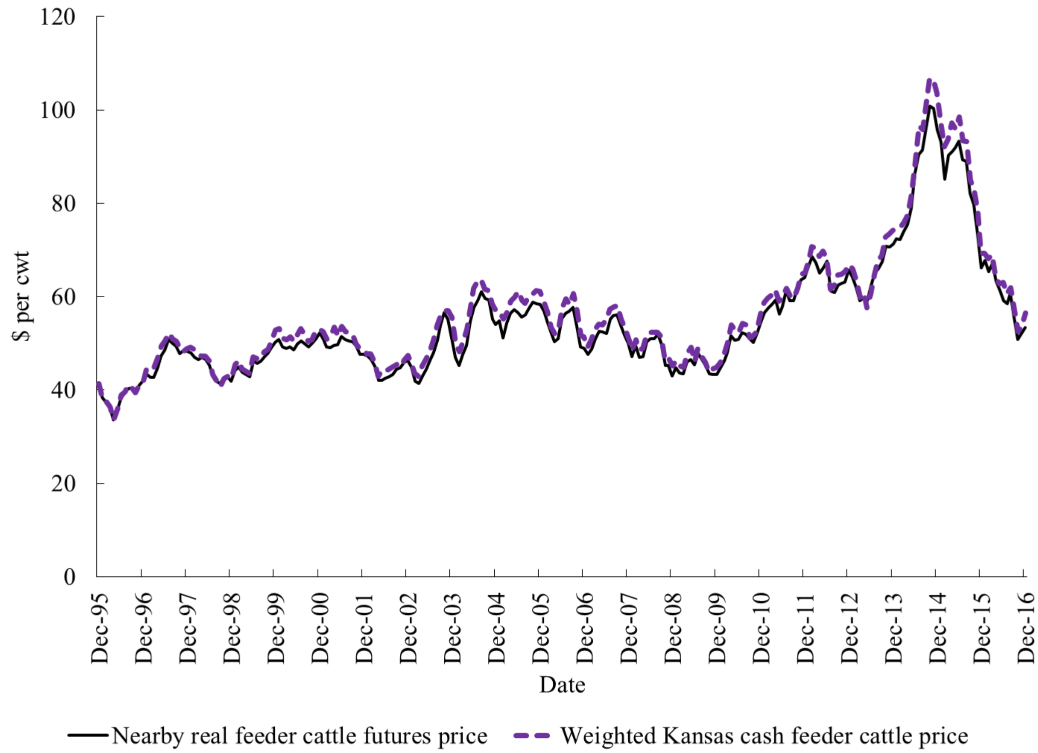


Figure 3.1 Monthly real nearby feeder cattle futures price ($/cwt) and real Kansas cash weighted feeder cattle price ($/cwt) from December 1995 to December 2016

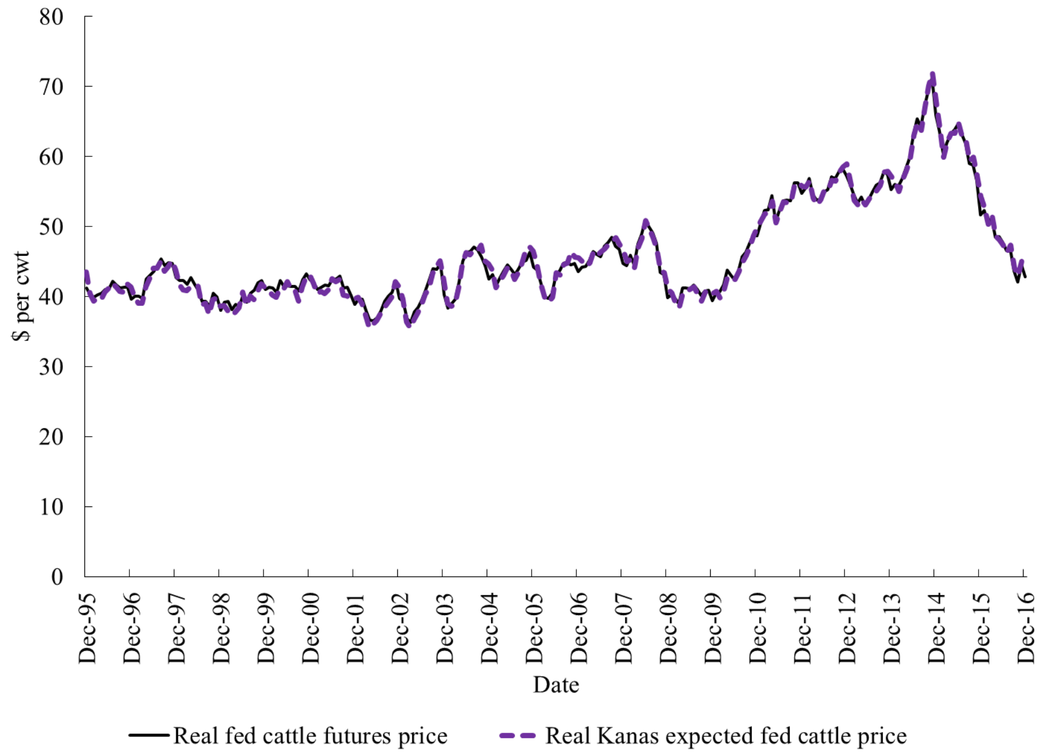


Figure 3.2 Monthly real fed cattle futures price (zero basis) ($/cwt) and real expected Kansas fed cattle price ($/cwt) from December 1995 to December 2016

Figure 3.3 Monthly real cash corn price ($/bu) from December 1995 to December 2016

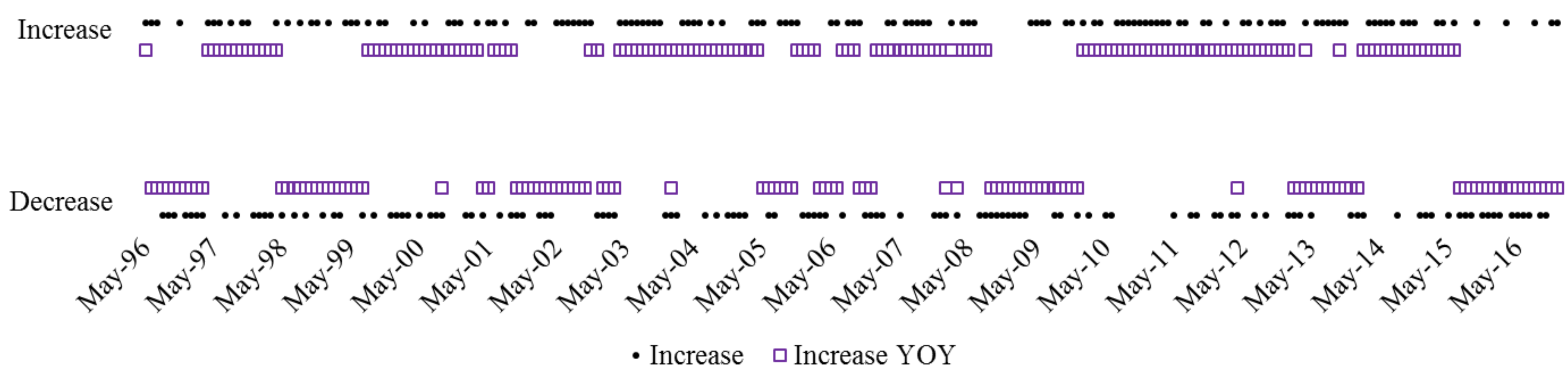


Figure 3.4 Fed cattle price increase month-to-month and year-over-year (YOY) dummy variables

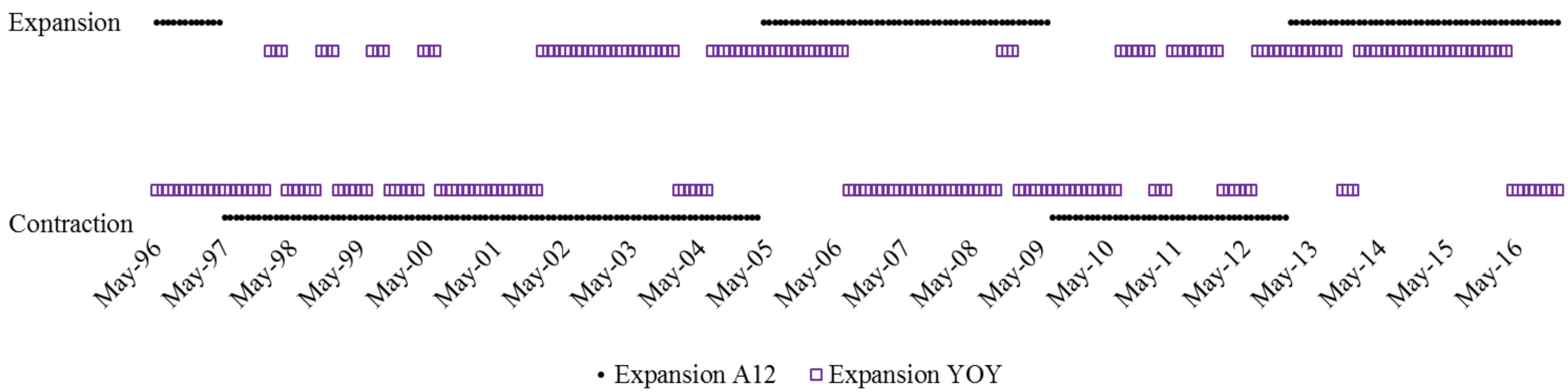


Figure 3.5 Expansion average over last year (A12) and expansion year-over-year (YOY) dummy variables

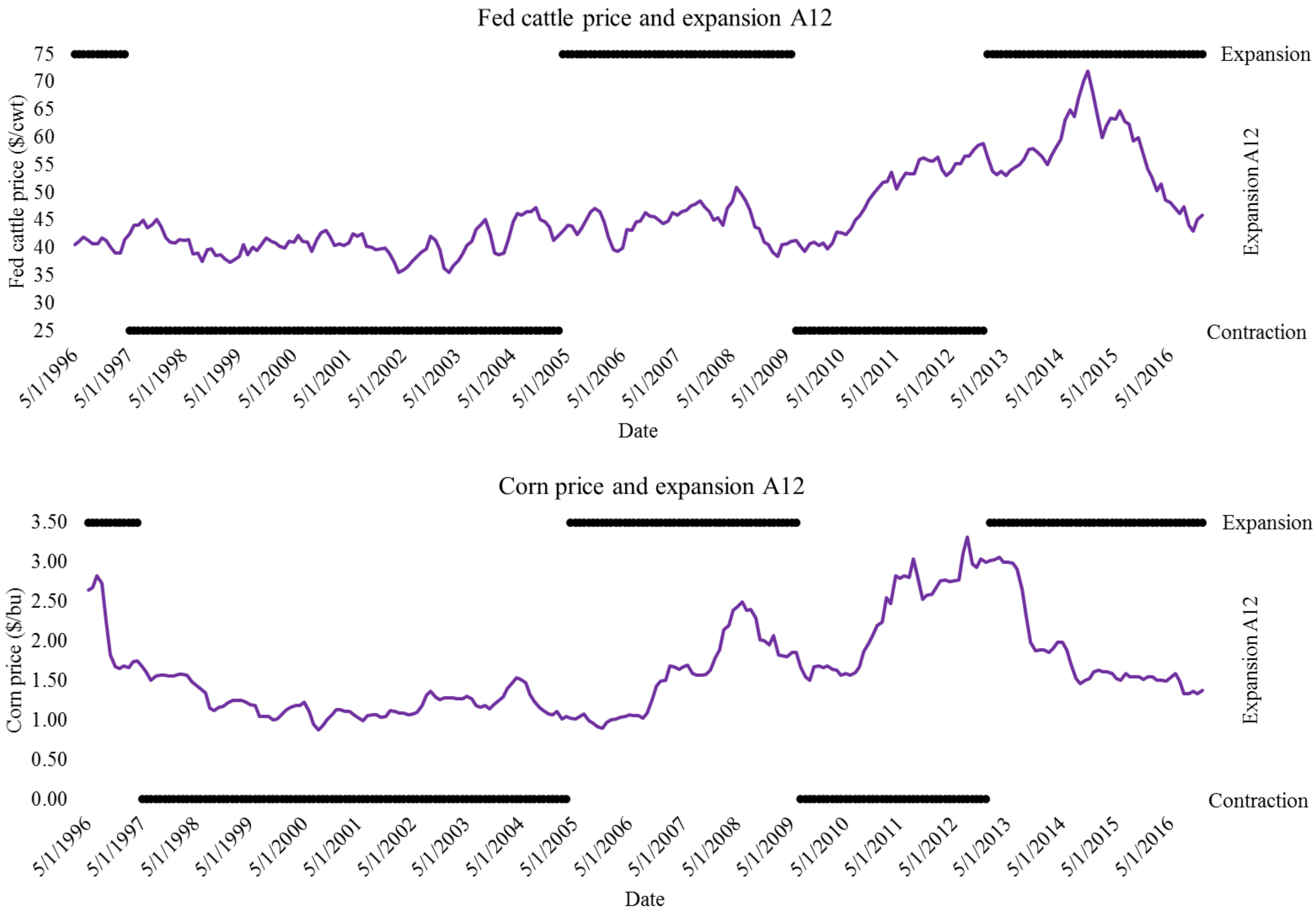
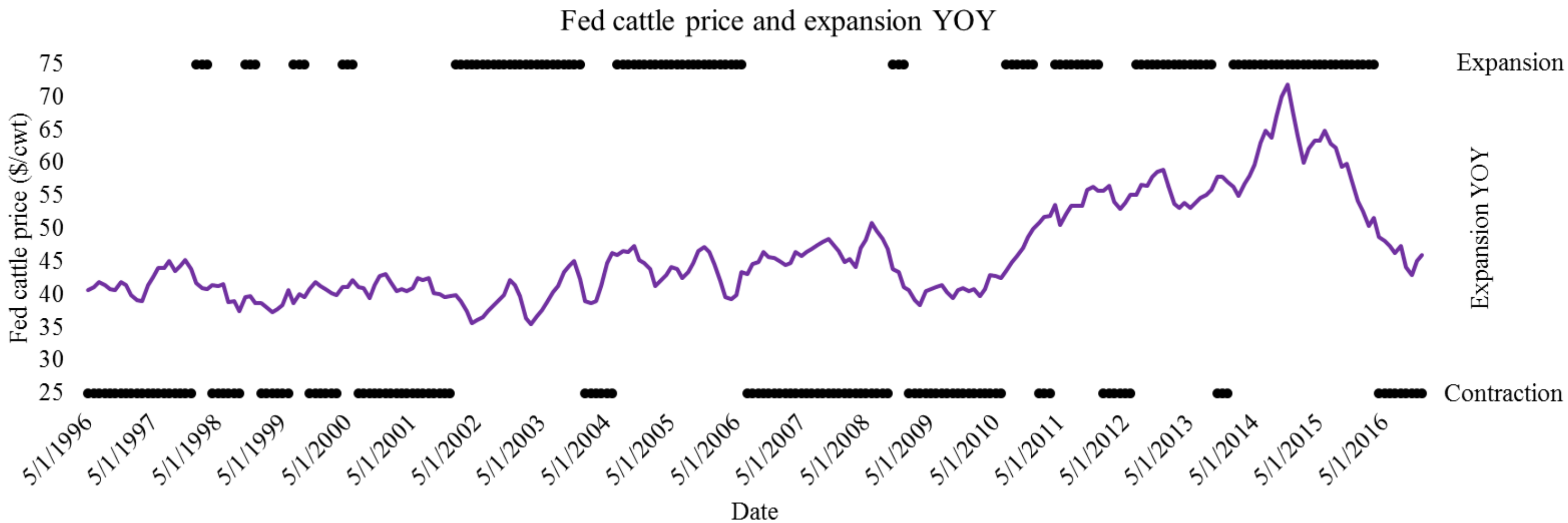


Figure 3.6 Plots of fed cattle and corn prices during expansion and contraction average over last 12 months (A12)



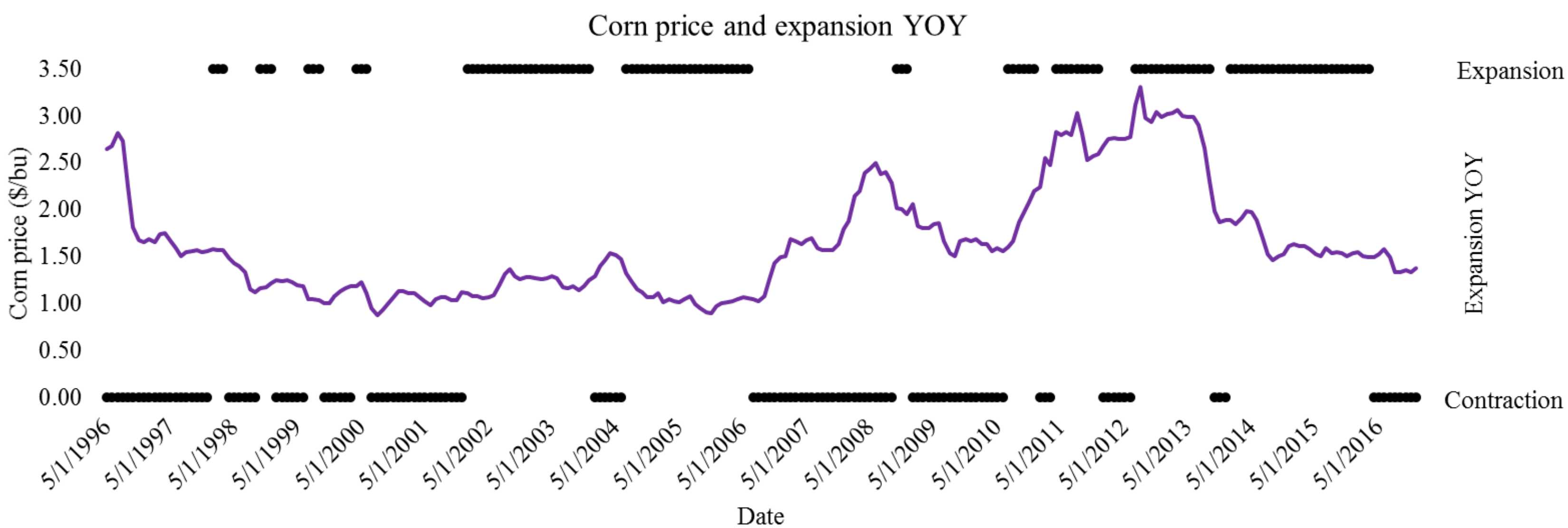


Figure 3.7 Plots of fed cattle and corn prices during year-over-year (YOY) expansion and contraction

Table 3.1 Hypothesized 100% pass-through estimates and assumptions from *Focus on Feedlots* data

Assumption	Full Time Period 12/95 to 12/16	Regime 1 12/95 to 10/06	Regime 2 11/06 to 04/11	Regime 3 05/11 to 12/16
Feeder weight (lbs.)	787.19	767.74	792.11	820.75
Finish weight (lbs.)	1308.74	1257.75	1331.87	1388.62
Pounds of gain	521.55	490.01	539.76	567.86
Feed conversion ratio	6.05	6.07	6.08	5.99
Total lbs of corn needed	3155.88	2974.56	3280.33	3402.84
Pounds of corn per bu	56.00	56.00	56.00	56.00
Corn needed (bu.)	56.35	53.12	58.58	60.76
Deathloss (%)	1.28%	1.21%	1.33%	1.38%
Discount rate	3.21%	3.86%	3.02%	2.13%
RRT ϕ_1	1.59	1.56	1.61	1.63
RRT ϕ_2	-7.16	-6.93	-7.41	-7.41

Table 3.2 Descriptive statistics from December 1995 to December 2016

Variable	Mean	St Dev	Min	Max
Real corn price ($/bu)	1.65	0.59	0.88	3.31
Real nearby feeder futures price ($/cwt)	54.63	12.77	33.54	100.88
Real fed cattle futures price ($/cwt)	46.18	7.32	36.29	71.27
Real KS cash weighted feeder price ($/cwt)	56.47	13.68	33.71	106.63
Real KS four year historical average basis ($/cwt)	-0.09	0.78	-1.37	3.07
Real KS expected fed cattle price ($/cwt)	46.09	7.50	35.54	71.91

Table 3.3 Augmented Dickey Fuller tests

Variable	Constant			Drift			Trend			Conclusion
	Optimal Lags	Test Statistic	10% Critical Value	Optimal Lags	Test Statistic	10% Critical Value	Optimal Lags	Test Statistic	10% Critical Value	
Augmented Dickey-Fuller										
Real corn price	1	-0.93	-1.61	1	-2.11	-2.57	1	-2.34	-3.13	Fail to reject unit root
Real nearby feeder futures price	1	-0.14	-1.61	1	-2.13	-2.57	11	-4.28	-3.13	Reject unit root
Real fed cattle futures price	0	-0.17	-1.61	1	-1.84	-2.57	2	-2.58	-3.13	Fail to reject unit root
Real KS cash weighted feeder price	1	-0.11	-1.61	1	-2.21	-2.57	1	-2.53	-3.13	Fail to reject unit root
Real KS expected fed cattle price	3	-0.08	-1.61	1	-2.11	-2.57	1	-2.80	-3.13	Fail to reject unit root
Augmented Dickey-Fuller with seasonal dummy variables										
Real corn price	1	-0.46	-1.61	1	-1.88	-2.57	1	-2.11	-3.13	Fail to reject unit root
Real nearby feeder futures price	1	-1.90	-1.61	1	-1.97	-2.57	11	-4.44	-3.13	Reject unit root
Real fed cattle futures price	1	-8.06	-1.61	1	-1.68	-2.57	1	-1.90	-3.13	Reject unit root
Real KS cash weighted feeder price	1	-1.72	-1.61	1	-2.06	-2.57	1	-2.34	-3.13	Reject unit root
Real KS expected fed cattle price	1	-3.74	-1.61	1	-1.70	-2.57	1	-2.11	-3.13	Reject unit root

Table 3.4 Zivot and Andrews (2002) unit root test for real cash corn price (December 1995 to December 2016)

Lag length	Model	Test statistic	0.10 critical value	Potential break	Conclusion
0	intercept	-2.96	-4.58	9	Fail to reject unit root
	trend	-2.61	-4.11	11	Fail to reject unit root
	both	-3.43	-4.82	177	Fail to reject unit root
1	intercept	-3.45	-4.58	8	Fail to reject unit root
	trend	-3.27	-4.11	10	Fail to reject unit root
	both	-3.87	-4.82	177	Fail to reject unit root
2	intercept	-3.59	-4.58	129	Fail to reject unit root
	trend	-3.28	-4.11	10	Fail to reject unit root
	both	-4.14	-4.82	177	Fail to reject unit root
3	intercept	-3.52	-4.58	129	Fail to reject unit root
	trend	-3.30	-4.11	10	Fail to reject unit root
	both	-4.11	-4.82	177	Fail to reject unit root
4	intercept	-3.89	-4.58	212	Fail to reject unit root
	trend	-3.68	-4.11	204	Fail to reject unit root
	both	-4.52	-4.82	177	Fail to reject unit root
5	intercept	-4.06	-4.58	212	Fail to reject unit root
	trend	-3.80	-4.11	204	Fail to reject unit root
	both	-4.64	-4.82	177	Fail to reject unit root
6	intercept	-4.08	-4.58	212	Fail to reject unit root
	trend	-3.77	-4.11	204	Fail to reject unit root
	both	-4.65	-4.82	177	Fail to reject unit root
7	intercept	-4.67	-4.58	212	Reject unit root
	trend	-4.32	-4.11	204	Reject unit root
	both	-5.25	-4.82	177	Reject unit root
8	intercept	-4.53	-4.58	212	Fail to reject unit root
	trend	-4.07	-4.11	203	Fail to reject unit root
	both	-5.06	-4.82	177	Reject unit root
9	intercept	-3.79	-4.58	212	Fail to reject unit root
	trend	-3.36	-4.11	200	Fail to reject unit root
	both	-4.40	-4.82	177	Fail to reject unit root
10	intercept	-3.37	-4.58	212	Fail to reject unit root
	trend	-2.91	-4.11	200	Fail to reject unit root
	both	-3.99	-4.82	177	Fail to reject unit root
11	intercept	-3.49	-4.58	211	Fail to reject unit root
	trend	-3.18	-4.11	200	Fail to reject unit root
	both	4.30	-4.82	176	Fail to reject unit root
12	intercept	-3.54	-4.58	211	Fail to reject unit root
	trend	-3.27	-4.11	200	Fail to reject unit root
	both	-4.33	-4.82	176	Fail to reject unit root
13	intercept	-3.35	-4.58	211	Fail to reject unit root
	trend	3.12	-4.11	201	Fail to reject unit root
	both	-4.01	-4.82	176	Fail to reject unit root

Table 3.5 Estimation results when using feeder and fed cattle futures and cash corn prices (analysis A)

Variable	Full Period Static 5/96 to 12/16	Full Period Dynamic 5/96 to 12/16
Fed futures price	1.86***	1.44***
	(0.04)	(0.09)
Fed futures price lag 1		0.43***
		(0.09)
Cash corn price	-8.49***	-8.45***
	(0.52)	(0.49)
January	0.003	0.95***
	(0.31)	(0.32)
February	-0.12	0.62*
	(0.30)	(0.33)
March	0.69*	1.51***
	(0.39)	(0.44)
April	-0.64	0.71
	(0.45)	(0.51)
May	-0.16	0.78
	(0.45)	(0.49)
June	-0.12	1.07*
	(0.52)	(0.64)
July	-0.47	0.55
	(0.49)	(0.60)
August	-1.29***	-0.21
	(0.47)	(0.56)
September	-1.65***	-0.86**
	(0.38)	(0.40)
October	-2.91***	-1.89***
	(0.40)	(0.39)
November	-3.75***	-2.76***
	(0.26)	(0.25)
Trend	0.02***	0.01***
	(0.003)	(0.004)
Intercept	-18.26***	-19.76***
	(1.59)	(1.60)
SBC	365.66	349.18
Joint Chi- square test p-values		
Seasonality	<.0001	0.0003
Misspecification test p-values		
Normality:		
Skewness	0.44	0.28
Kurtosis	0.01	0.01
Omnibus	0.02	0.02
Homoscedasticity:		
Static	0.72	0.85
Dynamic	<.0001	<.0001
Independence:	<.0001	<.0001
Errors stationary:	YES	YES

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.6 Testing ϕ_1 pass-through

Model	RRT pass-through	Regression pass-through	Percent pass-through	Presuming fixed RRT ϕ_1: P-value	Presuming fixed RRT ϕ_1: Conclusion	RRT ϕ_1 as a distribution: Regression pass-through < 100% p-value	Regression pass-through > 100% p-value	Conclusion
Analysis A								
Static	1.59	1.86	117%	<.0001	Reject 100% pass-through	0.0002	0.9998	Regression pass-through greater than RRT pass-through
Dynamic	1.59	1.88	118%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Dynamic- Regime 1	1.56	1.79	115%	0.0002	Reject 100% pass-through	0.0025	0.9975	Regression pass-through greater than RRT pass-through
Dynamic- Regime 2	1.61	1.45	90%	0.1341	Fail to reject 100% pass-through	0.9237	0.0763	Regression pass-through not different from RRT pass-through
Dynamic- Regime 3	1.63	1.91	117%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Analysis B								
Static	1.59	1.97	124%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Dynamic	1.59	1.99	125%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Analysis C								
Month-to-month								
Static	1.59	2.04	128%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Increase	1.59	1.96	123%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Year-over-year								
Static	1.59	1.88	118%	<.0001	Reject 100% pass-through	0.0006	0.9994	Regression pass-through greater than RRT pass-through
Increase	1.59	1.77	112%	0.1066	Fail to reject 100% pass-through	0.0772	0.9228	Regression pass-through not different from RRT pass-through
Dynamic	1.59	1.87	118%	<.0001	Reject 100% pass-through	0.0005	0.9995	Regression pass-through greater than RRT pass-through
Increase	1.59	1.78	112%	0.1121	Fail to reject 100% pass-through	0.0705	0.9295	Regression pass-through not different from RRT pass-through
Analysis D								
Average 12 months								
Static	1.59	1.89	119%	<.0001	Reject 100% pass-through	0.0003	0.9997	Regression pass-through greater than RRT pass-through
Expansion	1.59	2.02	127%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Dynamic	1.59	1.92	121%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Expansion	1.59	1.94	122%	0.0025	Reject 100% pass-through	0.0024	0.9976	Regression pass-through greater than RRT pass-through
Year-over-year								
Static	1.59	1.72	108%	0.7844	Fail to reject 100% pass-through	0.1609	0.8391	Regression pass-through not different from RRT pass-through
Expansion	1.59	2.05	129%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Dynamic	1.59	1.73	109%	0.6991	Fail to reject 100% pass-through	0.1317	0.8683	Regression pass-through not different from RRT pass-through
Expansion	1.59	2.17	137%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through

Table 3.7 Testing $\boldsymbol{\phi_2}$ pass-through

Model	RRT pass-through	Regression pass-through	Percent pass-through	Presuming fixed RRT ϕ_2: P-value	Presuming fixed RRT ϕ_2: Conclusion	RRT ϕ_2 as a distribution: Regression pass-through < 100% p-value	RRT ϕ_2 as a distribution: Regression pass-through > 100% p-value	RRT ϕ_2 as a distribution: Conclusion
Analysis A								
Static	-7.16	-8.49	119%	0.0104	Reject 100% pass-through	0.0412	0.9588	Regression pass-through greater than RRT pass-through
Dynamic	-7.16	-8.45	118%	0.0091	Reject 100% pass-through	0.0539	0.9461	Regression pass-through not different from RRT pass-through
Dynamic- Regime 1	-6.93	-5.35	77%	0.0008	Reject 100% pass-through	0.9830	0.0170	Regression pass-through less than RRT pass-through
Dynamic- Regime 2	-7.41	-7.80	105%	0.7378	Fail to reject 100% pass-through	0.3802	0.6198	Regression pass-through not different from RRT pass-through
Dynamic- Regime 3	-7.41	-8.47	114%	0.3288	Fail to reject 100% pass-through	0.1957	0.8043	Regression pass-through not different from RRT pass-through
Analysis B								
Static	-7.16	-9.59	134%	<.0001	Reject 100% pass-through	0.0008	0.9992	Regression pass-through greater than RRT pass-through
Dynamic	-7.16	-9.56	134%	<.0001	Reject 100% pass-through	0.0017	0.9983	Regression pass-through greater than RRT pass-through
Analysis C								
Month-to-month								
Static	-7.16	-9.65	135%	<.0001	Reject 100% pass-through	0.0005	0.9995	Regression pass-through greater than RRT pass-through
Year-over-year								
Static	-7.16	-8.62	120%	0.0231	Reject 100% pass-through	0.0772	0.9228	Regression pass-through not different from RRT pass-through
Dynamic	-7.16	-8.68	121%	0.0175	Reject 100% pass-through	0.0366	0.9634	Regression pass-through greater than RRT pass-through
Analysis D								
Average 12 months								
Static	-7.16	-7.20	101%	0.9662	Fail to reject 100% pass-through	0.4977	0.5023	Regression pass-through not different from RRT pass-through
Expansion	-7.16	-10.11	141%	<.0001	Reject 100% pass-through	0.0004	0.9996	Regression pass-through greater than RRT pass-through
Dynamic	-7.16	-7.43	104%	0.8266	Fail to reject 100% pass-through	0.4095	0.5905	Regression pass-through not different from RRT pass-through
Expansion	-7.16	-12.55	175%	0.0007	Reject 100% pass-through	0.0007	0.9993	Regression pass-through greater than RRT pass-through
Year-over-year								
Static	-7.16	-7.87	110%	0.454	Fail to reject 100% pass-through	0.247	0.753	Regression pass-through not different from RRT pass-through
Expansion	-7.16	-10.03	140%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through
Dynamic	-7.16	-7.93	111%	0.4151	Fail to reject 100% pass-through	0.2413	0.7587	Regression pass-through not different from RRT pass-through
Expansion	-7.16	-10.05	140%	<.0001	Reject 100% pass-through	<.0001	>.9999	Regression pass-through greater than RRT pass-through

Table 3.8 Bai Perron test for the dynamic model in analysis A

l	SupF(l+1|l) statistic	P-value	Breakpoint observation	Regimes identified
0	43.49	0.03	126	R1: May 1996 to October 2006
1	49.55	0.01	181	R2: November 2006 to April 2011
2	21.20	1.00		R3: May 2011 to December 2016

Table note: The supF, UDmaxF and WDmaxF tests indicate at least one structural break at the <0.001 level.

Table 3.9 Analysis A estimation results with regime interactions

Variable	Regime 1 Dynamic 5/96 to 10/06		Regime 2 Dynamic 11/06 to 04/11		Regime 3 Dynamic 05/11 to 12/16
Fed futures price	1.38***	Fed futures price * R2	-0.39***	Fed futures price * R3	0.08
	(0.07)		(0.12)		(0.16)
Fed futures price lag 1	0.40***	Fed futures price lag 1 *R2	0.05	Fed futures price lag 1 *R3	0.05
	(0.08)		(0.16)		(0.15)
Cash corn price	-5.35***	Cash corn price * R2	-2.45*	Cash corn price *R3	-3.12***
	(0.47)		(1.27)		(1.18)
January	0.52*	January * R2	0.06	January * R3	1.35*
	(0.29)		(0.87)		(0.74)
February	-0.25	February * R2	1.54***	February * R3	1.67**
	(0.37)		(0.59)		(0.80)
March	0.61	March * R2	0.67	March * R3	2.35**
	(0.45)		(0.52)		(1.16)
April	-0.27	April * R2	1.81**	April * R3	2.49**
	(0.50)		(0.74)		(1.20)
May	-0.52	May * R2	1.88***	May * R3	2.94**
	(0.46)		(0.56)		(1.42)
June	-0.11	June * R2	0.91	June * R3	2.97**
	(0.37)		(0.68)		(1.29)
July	-0.35	July * R2	1.40	July * R3	1.98**
	(0.38)		(1.03)		(0.93)
August	-1.19**	August * R2	1.52**	August * R3	2.44***
	(0.50)		(0.62)		(0.85)
September	-1.23***	September * R2	0.60	September * R3	1.05
	(0.28)		(0.51)		(0.72)
October	-2.05***	October * R2	-0.04	October * R3	0.62
	(0.59)		(0.84)		(1.09)
November	-2.61***	November * R2	1.05**	November * R3	-0.36
	(0.27)		(0.41)		(0.57)
Trend	0.05***	Trend * R2	0.02*	Trend * R3	-0.05
	(0.01)		(0.01)		(0.04)
Intercept	-21.20***	R2	9.13*	R3	2.45
	(2.51)		(4.71)		(13.17)
SBC	299.04				
Joint Chi- square test p-values					
Regime intercept shifters	0.15	All regime 2 interaction variables	<.0001	All regime 3 interaction variables	<.0001
Regime time interactions	0.06	Regime 2 pass-through variables	<.0001	Regime 3 pass-through variables	0.01
Base seasonality	<.0001	Regime 2 seasonality	<.0001	Regime 3 seasonality	0.01
Misspecification test p-values					
Normality:					
Skewness	0.04				
Kurtosis	0.10				
Omnibus	0.03				
Homoscedasticity:					
Static	0.01				
Dynamic	0.01				
Independence:	<.0001				
Errors stationary:	YES				

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ). R2=1 if date is from Nov 2006 to May 2011 and R2=0 otherwise. R3=1 if date is from May 2011 to Dec 2016 and R3=0 otherwise.

Table 3.10 Estimation results when using weighted feeder cattle price and expected fed cattle price with basis (analysis B)

Variable	Full Period Static 5/96 to 12/16	Full Period Dynamic 5/96 to 12/16
Expected fed price	1.97***	1.58***
	(0.07)	(0.11)
Expected fed price lag1		0.41***
		(0.12)
Cash corn price	-9.59***	-9.56***
	(0.56)	(0.54)
January	2.19***	2.07***
	(0.44)	(0.44)
February	4.38***	4.22***
	(0.54)	(0.51)
March	4.63***	4.95***
	(0.57)	(0.58)
April	3.95***	4.63***
	(0.63)	(0.67)
May	3.55***	4.06***
	(0.65)	(0.67)
June	2.64***	3.45***
	(0.73)	(0.76)
July	3.12***	3.39***
	(0.68)	(0.70)
August	2.09***	2.58***
	(0.69)	(0.72)
September	1.73***	1.93***
	(0.55)	(0.50)
October	-1.04**	-0.33
	(0.44)	(0.41)
November	-1.73***	-1.25***
	(0.42)	(0.33)
Trend	0.01**	0.01*
	(0.005)	(0.01)
Intercept	-22.25***	-23.15***
	(2.44)	(2.53)
SBC	475.40	467.74
Joint Chi- square test p-values		
Seasonality	<.0001	<.0001
Misspecification test p-values		
Normality:		
Skewness	0.90	0.52
Kurtosis	0.34	0.67
Omnibus	0.63	0.75
Homoscedasticity:		
Static	0.55	0.93
Dynamic	<.0001	<.0001
Independence:	<.0001	<.0001
Errors stationary:	YES	YES

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.11 Static model estimation results for asymmetric pass-through for month-to-month fed cattle price changes (analysis C)

Variable	Full Period Static- Base 5/96 to 12/16		Full Period Static- Increase 5/96 to 12/16
Expected fed price	2.04***	Expected fed price*Increase	-0.08
	(0.09)		(0.05)
Cash corn price	-9.65***		
	(0.51)		
January	2.35***	January*Increase	-0.73
	(0.49)		(1.06)
February	4.69***	February*Increase	-1.15
	(0.70)		(1.17)
March	5.60***	March*Increase	-1.74
	(0.92)		(1.54)
April	5.52***	April*Increase	-1.74
	(1.48)		(1.85)
May	2.74***	May*Increase	1.61
	(0.90)		(1.41)
June	4.63***	June*Increase	-1.94
	(1.04)		(1.43)
July	2.74***	July*Increase	1.10
	(1.05)		(1.34)
August	3.22***	August*Increase	-1.50
	(1.20)		(1.53)
September	2.01***	September*Increase	-0.47
	(0.76)		(1.26)
October	0.28	October*Increase	-1.27
	(1.09)		(1.62)
November	-1.05	November*Increase	-0.64
	(0.99)		(1.50)
Trend	0.01	Trend*Increase	0.01
	(0.01)		(0.01)
Intercept	-24.43***	Increase	2.35
	(3.37)		(2.41)
SBC	531.25		
Joint Chi- Square test p-values			
Base seasonality	<.0001	All increase interaction variables	<.0001
		Increase*seasonality interactions	0.02
Misspecification test p-values			
Normality:			
Skewness	0.97		
Kurtosis	0.50		
Omnibus	0.79		
Homoscedasticity:			
Static	0.93		
Dynamic	<.0001		
Autocorrelation:	<.0001		
Errors stationary:	YES		

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.12 Static model estimation results for asymmetric pass-through for year-over-year fed cattle price changes (analysis C)

Variable	Full Period Static- Base 5/96 to 12/16		Full Period Static- Increase YOY 5/96 to 12/16
Expected fed price	1.88***	Expected fed price*Increase YOY	-0.11
	(0.07)		(0.12)
Cash corn price	-8.62***		
	(0.64)		
January	2.68**	January*Increase YOY	-1.15
	(1.08)		(1.63)
February	5.02***	February*Increase YOY	-1.83
	(0.93)		(1.21)
March	4.76***	March*Increase YOY	-1.30
	(0.93)		(1.47)
April	5.37***	April*Increase YOY	-3.01**
	(1.12)		(1.37)
May	3.52***	May*Increase YOY	-0.38
	(0.92)		(1.44)
June	3.31***	June*Increase YOY	-1.64
	(1.03)		(1.34)
July	4.33***	July*Increase YOY	-2.06*
	(1.00)		(1.11)
August	3.62***	August*Increase YOY	-2.49*
	(1.27)		(1.47)
September	2.51***	September*Increase YOY	-1.32
	(0.95)		(1.12)
October	-0.09	October*Increase YOY	-1.53*
	(0.72)		(0.92)
November	-0.92*	November*Increase YOY	-1.09
	(0.55)		(0.75)
Trend	0.003	Trend*Increase YOY	0.20***
	(0.04)		(0.06)
Trend^2	0.0002	Trend^2*Increase YOY	-0.002***
	(0.0004)		(0.001)
Trend^3	-0.0000007	Trend^3*Increase YOY	0.00001***
	(0.0000009)		(0.000002)
Intercept	-20.56***	Increase YOY	1.74
	(3.43)		(5.56)
SBC	510.62		
Joint Chi- Square test p-values			
Base seasonality	<.0001	All Increase YOY interaction variables	<.0001
		Increase YOY*seasonality interactions	0.49
		Increase YOY*trend interactions	0.0001
Misspecification test p-values			
Normality:			
Skewness	0.35		
Kurtosis	0.64		
Omnibus	0.58		
Homoscedasticity:			
Static	0.63		
Dynamic	<.0001		
Autocorrelation:	<.0001		
Errors stationary:	YES		

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.13 Dynamic model estimation results for asymmetric pass-through for year-over-year fed cattle price changes (analysis C)

Variable	Full Period Dynamic- Base 5/96 to 12/16		Full Period Dynamic- Increase YOY 5/96 to 12/16
Expected fed price	1.53***	Expected fed price*Increase YOY	-0.10
	(0.09)		(0.12)
Expected fed price lag 1	0.34***	Expected fed price lag 1*Increase YOY	0.01
	(0.10)		(0.01)
Cash corn price	-8.68***		
	(0.64)		
January	2.44**	January*Increase YOY	-0.95
	(1.05)		(1.52)
February	4.62***	February*Increase YOY	-1.42
	(0.94)		(1.23)
March	4.68***	March*Increase YOY	-0.79
	(0.95)		(1.39)
April	5.35***	April*Increase YOY	-2.05
	(1.17)		(1.43)
May	3.75***	May*Increase YOY	-0.10
	(1.02)		(1.47)
June	3.81***	June*Increase YOY	-1.31
	(1.08)		(1.30)
July	4.33***	July*Increase YOY	-1.66
	(1.01)		(1.09)
August	3.98***	August*Increase YOY	-2.37
	(1.33)		(1.44)
September	2.40**	September*Increase YOY	-0.85
	(0.93)		(1.00)
October	0.23	October*Increase YOY	-1.01
	(0.78)		(0.90)
November	-0.70	November*Increase YOY	-0.74
	(0.56)		(0.63)
Trend	-0.002	Trend*Increase YOY	0.20***
	(0.04)		(0.06)
Trend^2	0.0003	Trend^2*Increase YOY	-0.002***
	(0.0004)		(0.0006)
Trend^3	-0.0000009	Trend^3*Increase YOY	0.000007***
	(0.0000009)		(0.000002)
Intercept	-20.15***	Increase YOY	0.95
	(3.37)		(5.64)
SBC	509.36		
Joint Chi- Square test p-values			
Base seasonality	<.0001	All Increase YOY interaction variables	<.0001
		Pass-through Increase YOY interactions	0.48
		Increase YOY*seasonality interactions	0.68
		Increase YOY*trend interactions	0.0003
Misspecification test p-values			
Normality:			
Skewness	0.83		
Kurtosis	0.56		
Omnibus			
Homoscedasticity:	0.83		
Static	0.93		
Dynamic	<.0001		
Autocorrelation:	<.0001		
Errors stationary:	YES		

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.14 Static model estimation results for asymmetric pass-through for herd expansion over last year (analysis D)

Variable	Full Period Static- Base 5/96 to 12/16		Full Period Static- Expansion A12 5/96 to 12/16
Expected fed price	1.89***	Expected fed price*Expansion A12	0.12
	(0.07)		(0.11)
Cash corn price	-7.20***	Cash corn price*Expansion A12	-2.91**
	(0.98)		(1.26)
January	1.80***	January*Expansion A12	0.92
	(0.57)		(0.91)
February	3.42***	February*Expansion A12	2.09*
	(0.73)		(1.10)
March	4.12***	March*Expansion A12	1.04
	(0.96)		(1.35)
April	3.80***	April*Expansion A12	0.42
	(1.05)		(1.45)
May	3.30***	May*Expansion A12	0.78
	(1.11)		(1.49)
June	2.01**	June*Expansion A12	1.71
	(0.89)		(1.57)
July	2.14***	July*Expansion A12	2.36
	(0.62)		(1.48)
August	0.95	August*Expansion A12	2.66*
	(0.70)		(1.4)
September	1.12**	September*Expansion A12	1.44
	(0.49)		(1.19)
October	-1.31***	October*Expansion A12	0.77
	(0.49)		(0.91)
November	-1.69***	November*Expansion A12	0.01
	(0.47)		(0.91)
Trend	0.12***	Trend*Expansion A12	-0.15***
	(0.04)		(0.04)
Trend^2	-0.0005***	Trend^2*Expansion A12	0.001***
	(0.0002)		(0.0002)
Intercept	-26.93***	Expansion A12	5.33
	(2.94)		(4.63)
SBC	518.42		
Joint Chi- square test p-values			
Base seasonality	<.0001	All Expansion A12 interaction variables	0.003
		Expansion A12*pass-through variables	0.07
		Expansion A12*seasonality interactions	0.57
		Expansion A12*trend interactions	0.0005
Misspecification test p-values			
Normality:			
Skewness	0.10		
Kurtosis	0.15		
Omnibus	0.09		
Homoscedasticity:			
Static	0.61		
Dynamic	<.0001		
Independence:	<.0001		
Errors stationary:	YES		

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.15 Dynamic model estimation results for asymmetric pass-through for herd expansion over last year (analysis D)

	Full Period Dynamic- Base 5/96 to 12/16		Full Period Dynamic- Expansion A12 5/96 to 12/16
Expected fed price	1.38***	Expected fed price*Expansion A12	0.04
	(0.16)		(0.20)
Expected fed price lag 1	0.53***	Expected fed price lag 1*Expansion A12	-0.01
	(0.15)		(0.2)
Cash corn price	-7.43***	Cash corn price*Expansion A12	-5.13**
	(1.21)		(2.02)
January	1.73***	January*Expansion A12	0.70
	(0.58)		(0.96)
February	3.28***	February*Expansion A12	1.80
	(0.74)		(1.11)
March	4.32***	March*Expansion A12	1.46
	(0.92)		(1.32)
April	4.48***	April*Expansion A12	1.08
	(1.08)		(1.49)
May	3.88***	May*Expansion A12	1.24
	(1.18)		(1.48)
June	2.93***	June*Expansion A12	2.38
	(1.00)		(1.47)
July	2.41***	July*Expansion A12	3.09**
	(0.70)		(1.31)
August	1.57**	August*Expansion A12	3.07**
	(0.75)		(1.41)
September	1.21***	September*Expansion A12	1.91*
	(0.45)		(0.97)
October	-0.39	October*Expansion A12	0.71
	(0.41)		(0.87)
November	-1.14***	November*Expansion A12	0.12
	(0.37)		(0.63)
Trend	0.16**	Trend*Expansion A12	-0.60**
	(0.07)		(0.26)
Trend^2	-0.0008	Trend^3*Expansion A12	-0.000009*
	(0.0007)		(0.000005)
Trend^3	0.000001	Trend^3*Expansion A12	-0.000009*
	(0.000002)		(0.000005)
Intercept	-29.31***	Expansion A12	23.78*
	(3.41)		(13.18)
SBC	497.35		
Joint Chi- Square test p-values			
Base seasonality	<.0001	All Expansion A12 interaction variables	<.0001
		Expansion A12*pass-through variables	0.05
		Expansion A12*seasonality interactions	0.59
		Expansion A12*trend interactions	<.0001
Misspecification test p-values			
Normality:			
Skewness	0.28		
Kurtosis	0.85		
Omnibus	0.55		
Homoscedasticity:			
Static	0.41		
Dynamic	<.0001		
Autocorrelation:	<.0001		
Errors stationary:	YES		

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.16 Static model estimation results for asymmetric pass-through for herd expansion year-over-year (analysis D)

Variable	**Full Period Static- Base 5/96 to 12/16**		**Full Period Static- Expansion YOY 5/96 to 12/16**
Expected fed price	1.72***	Expected fed price*Expansion YOY	0.33**
	(0.11)		(0.13)
Cash corn price	-7.87***	Cash corn price*Expansion YOY	-2.16**
	(0.94)		(1.00)
January	2.23***	January*Expansion YOY	-0.74
	(0.82)		(1.26)
February	3.81***	February*Expansion YOY	0.53
	(0.72)		(1.17)
March	4.67***	March*Expansion YOY	-0.93
	(0.98)		(1.35)
April	3.64***	April*Expansion YOY	0.19
	(0.99)		(1.35)
May	3.04***	May*Expansion YOY	0.68
	(0.95)		(1.33)
June	2.25**	June*Expansion YOY	0.60
	(0.99)		(1.28)
July	2.39**	July*Expansion YOY	1.11
	(0.99)		(1.16)
August	1.20	August*Expansion YOY	1.50
	(0.99)		(1.20)
September	2.08**	September*Expansion YOY	-1.14
	(0.82)		(1.08)
October	-0.44	October*Expansion YOY	-1.20
	(0.57)		(0.86)
November	-1.36***	November*Expansion YOY	-0.67
	(0.46)		(0.83)
Trend	0.02***	Trend*Expansion YOY	-0.01
	(0.003)		(0.01)
Intercept	-14.78***	Expansion YOY	-8.87
	(5.31)		(5.67)
SBC	518.65		
Joint Chi- Square test p-values			
Base seasonality	<.0001	All Expansion YOY interaction variables	<.0001
		Expansion YOY*pass-through variables	0.002
		Expansion YOY*seasonality interactions	0.0003
Misspecification test p-values			
Normality:			
Skewness	0.18		
Kurtosis	0.03		
Omnibus	0.03		
Homoscedasticity:			
Static	0.97		
Dynamic	<.0001		
Autocorrelation:	<.0001		
Errors stationary:	YES		

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

Table 3.17 Dynamic model estimation results for asymmetric pass-through for herd expansion year-over-year (analysis D)

Variable	Full Period Dynamic-Base 5/96 to 12/16		Full Period Dynamic-Expansion YOY 5/96 to 12/16
Expected fed price	1.47***	Expected fed price*Expansion YOY	0.09
	(0.21)		(0.21)
Expected fed price lag1	0.27	Expected fed price lag 1*Expansion YOY	0.35
	(0.27)		(0.26)
Cash corn price	-7.93***	Cash corn price*Expansion YOY	-2.12**
	(0.94)		(1.01)
January	2.25***	January*Expansion YOY	-0.66
	(0.78)		(1.14)
February	3.91***	February*Expansion YOY	0.43
	(0.82)		(1.18)
March	4.81***	March*Expansion YOY	0.40
	(1.00)		(1.25)
April	4.05***	April*Expansion YOY	1.19
	(1.17)		(1.39)
May	3.34***	May*Expansion YOY	1.45
	(1.08)		(1.30)
June	2.62***	June*Expansion YOY	1.99*
	(0.99)		(1.04)
July	2.37**	July*Expansion YOY	2.09*
	(1.06)		(1.11)
August	1.36	August*Expansion YOY	2.51**
	(1.02)		(1.11)
September	1.88**	September*Expansion YOY	0.13
	(0.90)		(1.02)
October	-0.15	October*Expansion YOY	-0.19
	(0.59)		(0.89)
November	-1.16**	November*Expansion YOY	-0.07
	(0.47)		(0.63)
Trend	0.01	Trend*Expansion YOY	0.05
	(0.02)		(0.03)
Intercept	-14.91**	Expansion YOY	-17.71***
	(5.93)		(6.50)
SBC	511.11		
Joint Chi- Square test p-values			
Base seasonality	<.0001	All Expansion YOY interaction variables	<.0001
		Expansion YOY*pass-through variables	0.0002
		Expansion YOY*seasonality interactions	0.007
		Expansion YOY*trend interactions	0.004
Misspecification test p-values			
Normality:			
Skewness	0.09		
Kurtosis	0.01		
Omnibus	0.01		
Homoscedasticity:			
Static	0.42		
Dynamic	<.0001		
Autocorrelation:	<.0001		
Errors stationary:	YES		

Table note: * p<0.10, ** p<0.05, *** p<0.01. Newey-West adjusted standard errors are shown in ( ).

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Chapter 4 - Impacts of retail and export demand on U.S. cattle producers

Over the past 40 years, consumer food preferences and perceptions of agriculture and meat production have been changing. U.S. consumers are increasingly interested in knowing both the physical attributes (e.g., nutrition, health, and safety) of their food as well as how it is produced (e.g., sustainable, animal welfare, and natural). Similarly, production segments of the U.S. food supply chain are keenly interested in economic impacts of these changes. The beef industry is no exception, experiencing dramatic changes in consumer demand over the past several decades (Tonsor, 2017). The beef industry has invested considerable resources to provide consumers with beef products possessing attributes they prefer as well as in product development and promotion (Kaiser, 2015; Tonsor, Schroeder, & Mintert, 2014). While existing research provides extensive insights into meat demand (see Bryant & Davis, 2008 and Gallett, 2010 for reviews), the literature on how changes in consumer demand impact producers is comparably limited. As such, the beef industry is interested in knowing how changing primary beef demand is shared among consumers, retailers, packers/processors, feedlots, cow-calf producers, and other production and marketing channel members.

Increased interest in food production, together with food industry positioning and product promotion, influence consumer demand. Conceptually as consumer demand varies, the impacts are passed down through the marketing chain to producers through derived demand. Despite this well-known concept, empirical efforts to quantify these effects are limited and dated. The objective of this paper is to estimate transmission of retail level and export demand signals through the U.S. beef industry to cattle producers.

How demand changes are transmitted to other levels of vertical supply chains is important to quantify. These estimates are utilized in policy analysis and estimating impacts of new technologies (e.g., Balagtas & Kim, 2007; Pendell, Brester, Schroeder, Dhuyvetter, & Tonsor., 2010; Weaber & Lusk, 2010; Okrent & Alston, 2012). Similarly, price-transmission estimates are essential when quantifying distributional impacts of events in industries comprised of multiple segments (Kinnucan, Hsia, & Jackson, 1997; Wohlgenant, 1993) such as the U.S. beef industry. A recent example was the effort to initiate a second checkoff program in the U.S. beef-cattle industry (U.S. Department of Agriculture [USDA], 2014). This in large part has arisen following a long-standing discussion about who benefits from investments in enhancing consumer beef demand. The need for this study was highlighted by Wohlgenant (2006): "For the most part, research has not focused on one very important aspect of estimating the rates of return to advertising – the retail-to-farm price transmission." (p. 2).

During the 1980s and 1990s, U.S. consumer preferences rapidly changed and consumer demand for beef declined (Genho, 1998; Purcell, 1989; Schroeder, 2000; Marsh, 2003; Schroeder, Marsh, & Mintert, 2000). To better understand how to respond to this precipitous decline, the beef industry needed more information about how beef packers, cattle feedlots, and cow-calf producers were impacted. Marsh (2003) is the most definitive quantification of how retail beef demand impacted farm level derived demand from 1970 to 1999. Up until his study, the econometric linking of shifts in retail beef and farm level demands, supplies, and revenues was overlooked (Marsh, 2003). The implications of retail demand shifts for beef marketing channel members are perhaps even more important today. However, no study has continued Marsh's work which is now more than a decade old in an industry that has experienced massive changes in demand as well as supply.

One notable change in the U.S. beef industry is the increased role of exports. From the early 1980s to 2013 beef export volume grew ten-fold from around 1% to about 10% of production (Livestock Marketing Information Center [LMIC], 2017). The heightened importance of exports in the beef market were especially evident in late 2003 and 2004 when foreign markets halted imports of U.S. beef due to discovery of bovine spongiform encephalopathy (BSE) in the U.S. beef herd. Marsh, Brester, and Smith (2008) concluded "the demand for U.S. beef was affected to a much greater degree by the reactions of foreign governments to the BSE announcements than by the reactions of U.S. households" (p. 136). The future role of beef exports is expected to increase reflecting global economic growth and expanding meat protein demand. The Economic Research Service projects that U.S. beef exports will grow by over 10% by 2026 with a large increase in beef demand coming from China and Hong Kong (USDA, 2017b). Furthermore, in June 2017 the U.S. and China reached an agreement to allow U.S. beef exports back into China following the ban in 2003 (USDA, 2017a). In 2016, China imported nearly $2.5 billion in beef (USDA, 2017a).

Model development and data

Our conceptual model uses the Marsh (2003) model as a foundation, however it is changed and expanded in multiple ways reflecting the evolving structure of the beef industry.

Demand indices

A key component in Marsh (2003) is the integration of a price based beef demand index (1970=100) into the econometric system to represent annual shifts in U.S. retail domestic beef demand. Demand indices are preferred to using beef prices only to measure changes in primary demand, because prices reflect both shifts in supply and demand (Marsh, 2003; Brester & Marsh, 1983; Wohlgenant, 1989). Indices allow the isolation of demand shifts. Brester, Bekkerman and

Tonsor (2017) used simulations to compare quantity and price based meat and energy demand indices. They found quantity based indices produce more accurate changes in demand than price based indices.[22] Following Brester, Bekkerman and Tonsor (2017) we construct a quantity based index as:

$$I_{quanitity} = \left(\frac{Q_t}{Q_t^e}\right) * 100 = \frac{Q_t}{Q_0 + \left\{Q_0 * \left[\left(\frac{P_t - P_0}{P_0}\right) * \left(\frac{\%\Delta Q}{\%\Delta \mathrm{P}}\right)\right]\right\}} * 100 \qquad (43)$$

where Q_t is the actual per capita quantity of beef consumed in quarter t. Q_t^e, the denominator, is the expected per capita consumption that would occur if there is no change in demand in quarter t. Q_0 is the base quarter quantity. P_t is the price in quarter t, while P_0 is the base quarter price. $\frac{\%\Delta Q}{\%\Delta P}$ is the own-price demand elasticity. Thus, the quantity based index is a ratio of the actual quantity demanded to the expected quantity demanded. The expected quantity reflects price changes and an assumed elasticity, thus isolating changes in demand from changes in supply. If the actual quantity demanded is larger (smaller) than expected, then the index increases (decreases).

For the U.S. retail beef demand index, P_t is the choice retail beef price in $/lb, deflated by the consumer price index. Q_t is the retail per capita disappearance (assumed consumption) consumption in lbs. The base year is 1996 to reflect availability of other data used in the models. The demand elasticity is assumed to be -0.542 (Tonsor, 2010). The quarterly U.S. retail beef demand index for 1996 QT1 to 2016 QT3 is shown in Figure 4.1 (1996 QT1=100). From 1996 to 2003, U.S. retail beef demand generally declined. From 2004 to 2007, beef demand strengthened, potentially due to popularity of the Atkins diet. However, beginning around the

[22] Both price based and quantity based indices were calculated, but quantity based indices were more well behaved.

recession in 2008, beef demand declined through 2012. In more recent years, beef demand has notably improved as the U.S. economy has recovered from the recession.

Additionally, we create an index for U.S. beef export demand by the rest of the world. Q_t is the rest of world per capita consumption of U.S. total beef and veal, and variety meat exports, in lbs. P_t is the nominal beef export price in \$/lb. The assumed elasticity of demand is -0.42 (Zhao, Wahl, & Marsh, 2006). The quarterly U.S. export beef demand index for 1996 QT1 to 2016 QT3 is shown in Figure 4.2 (1996 QT1=100). From 1996 to mid-2003 export demand for U.S. beef increased. However, the dramatic crash of export demand following the BSE discovery is evident in late 2003. After 2004, export demand steadily increased, reaching pre-BSE level around 2010. In 2014 and 2015, export demand slightly declined. The retail and export demand indices are central to answering how changes in U.S. retail and export beef demand have impacted farm level cattle prices and quantities in the last 20 years.

Conceptual model

The U.S. beef industry is comprised of multiple segments. In a simplistic version, feeder cattle suppliers (cow-calf, stocker, and backgrounder operations) supply feeder calves to feedlots. At the feedlot, animals are fed to harvest weight and then sold to the packer. After harvest, the packer distributes the wholesale beef through multiple outlets including traditional domestic retail outlets and beef for exports. Given the vertical nature of the beef supply chain, derived supply and demand theory can be applied to the U.S. beef industry. Whenever exogenous factors increase (decrease) primary demand, derived demands are also expected to increase (decrease) (Tomek & Robinson, 2003). Figure 4.3 illustrates changes to derived demand and supply curves due to an exogenous, autonomous increase in U.S. retail level demand. An exogenous increase in retail beef demand induces retailers to increase demand for wholesale beef from packers, resulting in an upward shift from D_{Live} to D_{Live}'. This increased demand for beef at the live cattle level, causes feedlot operators to demand more feeder cattle from suppliers (shifting D_{Feeder} upward to D_{Feeder}'). Upward shifts in demand will result in higher prices and quantities at the live and feeder levels. The numerical increase in prices and quantities is an empirical question of central interest in this study.

We use a simultaneous equations system of inverse demand and supply equations for the U.S. live and feeder cattle sectors as the conceptual model of the U.S. beef industry. The conceptual model of quarterly live and feeder cattle demand and supply is:

Live cattle inverse demand:

$$P_t^{L,D} = \Psi_1\left(Q_t^{L,D}, RDI_t, EI_t, M_t, time_t, BSE_t, QT2_t, QT3_t, QT4_t\right) \quad (44)$$

Live cattle supply:

$$Q_t^{L,S} = \Psi_2\left(E_{t-2}[P_t^{L,S}], P_{t-2}^F, P_{t-2}^C, Q_{t-1}^L, time_t, BSE_t, QT2_t, QT3_t, QT4_t\right) \quad (45)$$

Live cattle market clearing:

$$P_t^{L,D} = P_t^{L,S} = P_t^L;\ Q_t^{L,D} = Q_t^{L,S} = Q_t^L \quad (46)$$

Feeder cattle inverse demand:

$$P_t^{F,D} = \Psi_3\left(Q_t^{F,D}, E_t\left[P_{t+2}^{L,D}\right], P_t^C, time_t, BSE_t, QT2_t, QT3_t, QT4_t\right) \quad (47)$$

Feeder cattle supply:

$$Q_t^{F,S} = \Psi_4\begin{pmatrix} P_t^{F,S}, E_{t-8}\left[P_t^{F,S}\right], P_{t-4}^W, drought_t, drought_{t-8}, Q_{t-4}^{F,S}, time_t, QT2_t, \\ QT3_t, QT4_t \end{pmatrix} \quad (48)$$

Feeder cattle market clearing:

$$P_t^{F,D} = P_t^{F,S} = P_t^F;\ Q_t^{F,D} = Q_t^{F,S} = Q_t^F \quad (49)$$

Retail demand index:

$$RDI_t = \Psi_5(CSS_t, BSE_t, QT2_t, QT3_t, QT4_t) \quad (50)$$

Export demand index:

$$EI_t = \Psi_6(EX_t, AustCube_t, BSE_t, QT2_t, QT3_t, QT4_t) \quad (51)$$

A variable list and descriptions can be found in Table 4.1. The quarterly lag structure was based on biological considerations of the time required for a steer to be born, fed, and harvested.

Equation (44) is derived inverse live cattle demand where live cattle price at time t ($P_t^{L,D}$) is a function of live cattle quantity ($Q_t^{L,D}$), retail beef demand quantified by the beef demand index (RDI_t), export beef demand quantified by the export index (EI_t), food marketing costs (M_t) to capture wholesale and retail input costs, the BSE shock (BSE_t), and seasonality ($QT2_t, QT3_t, QT4_t$). Including the beef and export demand indices allows for shifts in primary demand to impact beef packer derived demand. A linear time trend ($time_t$) is included to account for technological changes.

Live cattle supply, equation (45), is a function of the expected output price ($E_{t-2}[P_t^{L,S}]$) at time of placement, assuming a two quarter feeding window. The input prices are feeder cattle (P_{t-2}^F) and corn price (P_{t-2}^C) at placement. All corn is assumed to be purchased at placement. A lagged dependent variable (Q_{t-1}^L) is included to account for asset fixity. The BSE shock (BSE_t) and seasonality ($QT2_t, QT3_t, QT4_t$) are also included. $Time_t$ is included to account for technological changes in cattle feeding over time in the absence of a better technology variable. Equation (46) is the live cattle market clearing condition.

Equations (47) through (49) are feeder cattle inverse demand, supply, and market clearing equations. In equation (47), feeder cattle price ($P_t^{F,D}$) is a function of feeder cattle quantity demanded by feedlots ($Q_t^{F,D}$), the expected live cattle price ($E_t\left[P_{t+2}^{L,D}\right]$) at time t (expected price the animal will sell for at the end of the two quarter feeding period), and corn price at time t

(P_t^C). $Time_t$, used as a proxy for technology in cattle finishing, the BSE shock (BSE_t), and seasonality ($QT2_t, QT3_t, QT4_t$) are also accounted for. Retail and export demand implicitly enter this equation through $E_t\left[P_{t+2}^{L,D}\right]$.

Equation (48) is feeder cattle supply. The contemporaneous feeder cattle price at time t ($P_t^{F,S}$) represents the decision to sell the animal now or to retain the calf for backgrounding. $E_{t-8}\left[P_t^{F,S}\right]$, the expected feeder cattle price at time $t-8$, represents the opportunity cost of heifer retention for a breeding animal to replace an aging breeding animal or expand the herd. P_{t-4}^W represents the opportunity cost of retaining a cow versus culling. $Drought_t$ is used to proxy pasture conditions and the decision to sell the yearling now, or wait and sell next period. $Drought_{t-8}$ can be used to judge pasture conditions and a potential indication of herd size (poor pasture conditions generally decrease the herd size). $Time_t$ is a proxy for technology. Asset fixity ($Q_{t-4}^{F,S}$), and seasonality ($QT2_t, QT3_t, QT4_t$) are also important determinants of feeder cattle supply.

Equations (50) and (51) are used to account for the endogeneity of retail and export beef demand. Retail beef demand is a function of U.S. consumer sentiment (CSS_t), the BSE shock (BSE_t), and seasonality ($QT2_t, QT3_t, QT4_t$). Export beef demand is a function of the exchange rate (EX_t), export competitors beef price ($AustCube_t$), the BSE shock (BSE_t), and seasonality ($QT2_t, QT3_t, QT4_t$). These variables will be used as exogenous variables and instruments in the econometric model. Here the consumer sentiment index measures consumer confidence in the U.S. economy (University of Michigan, 2017). Generally, when consumers feel the U.S. economy is doing well, beef demand is stronger. Seasonality is important in U.S. beef demand because of holiday seasons associated with higher beef demand and summer grilling season. The BSE shock is included in both the retail demand and export demand equations because of the high risk of consuming beef if it is contaminated with BSE. Controlling for the BSE event in export markets is especially critical because many counties banned U.S. beef following the BSE discovery. The exchange rate index accounts for how expensive U.S. goods are relative to goods from other countries on foreign markets (The Federal Reserve, 2016). The higher the index value, the stronger the U.S. dollar and thus the more expensive U.S. goods are to other countries. The price of Australian beef to Japan is used to gauge competition from other beef exporters (Meat and Livestock Australia, 2017).

Data

Quarterly data for 1996 quarter 1 to 2016 quarter 3 were collected from multiple sources (Appendix C). Descriptive statistics of variables for this analysis can be found in Table 4.2. Note, all prices (unless otherwise noted) and the marketing cost index were deflated by the Consumer Price Index (CPI where 1982-84=100) (U.S. Bureau of Labor Statistics, 2017). Specific details regarding data sources and data manipulations are provided in Appendix C. As is common when working with time series data, the natural log transformation of all variables were checked for stationarity using the Augmented Dickey Fuller (ADF) tests (Dickey & Fuller, 1979). In addition to the traditional ADF tests, ADF tests accounting for seasonality were also conducted (Appendix C). For some of the variables, stationarity is rejected. Including variables with unit root does not bias coefficient estimates, but may impact standard errors (Pouliot & Sumer, 2014). However, following Pouliot and Sumer (2014), all models are conducted with level variables but model residuals are checked for stationarity using ADF tests. Residuals for all models are stationary and thus all variables are in level form and not differenced.

Econometric model

The literature is mixed regarding whether naïve or forward looking expectations most closely mimic producer behavior (Antonovitz & Green, 1990). For example, Kastens and Schroder (1994) found evidence for naïve expectations, determining that cattle feeders view past actual profit as more important in placement decisions than live cattle futures. Conversely, Kastens, Jones and Schroeder (1998) found that using deferred futures plus historical basis yields the greatest forecast accuracy for major grains, slaughter steers, slaughter hogs, feeder cattle, cull cows, and sows. Furthermore, Antonovitz and Green (1990) found that no one price expectation model outperforms other specifications and found evidence of heterogeneous price expectations in live cattle supply. Therefore, two econometric models are presented below to account for different types of price expectations. The first is based on naïve expectations and the second incorporates forward looking expectations whenever data are available.

If naïve expectations are assumed, the four-equation model (Equations (52) through (55)) below can be estimated using three-stage least squares in log-log form:

Live cattle inverse demand:

$$\begin{aligned} lnP_t^L = {} & \alpha_1 + \alpha_2 lnQ_t^{L,*} + \alpha_3\, lnRDI_t^* + \alpha_4 lnEI_t^* + \alpha_5\, lnM_t + \alpha_6\, time_t \\ & + \alpha_7\, BSE03Q4_t + \alpha_8 BSE04Q1_t + \alpha_9 SB2005 + \alpha_{10} QT2_t \\ & + \alpha_{11} QT3_t + \alpha_{12} QT4_t + \mu_t^1 \end{aligned} \tag{52}$$

Live cattle supply:

$$\begin{aligned} lnQ_t^L = {} & \beta_1 + \beta_2 lnP_{t-2}^L + \beta_3 ln\, P_{t-2}^F + \beta_4 lnP_{t-2}^C + \beta_5 lnQ_{t-1}^L + \beta_6 time_t \\ & + \beta_7 BSE03Q4_t + \beta_7 BSE04Q1_t + \beta_8 QT2_t + \beta_9 QT3_t \\ & + \beta_{10} QT4_t + \mu_t^2 \end{aligned} \tag{53}$$

Feeder cattle inverse demand:

$$lnP_t^F = \gamma_1 + \gamma_2 lnQ_t^{F,*} + \gamma_3\, lnP_t^{L,*} + \gamma_3\, ln\, P_t^C + \gamma_4 time_t + \gamma_5\, BSE03Q4_t + \gamma_6 BSE04Q1_t + \gamma_7 SB2005 + \gamma_8\, QT2_t + \gamma_9 QT3_t + \gamma_{10} QT4_t + \mu_t^3 \quad (54)$$

Feeder cattle supply:

$$lnQ_t^F = \delta_1 + \delta_2 lnP_t^{F,*} + \delta_3 lnP_{t-8}^F + \delta_4 lnP_{t-4}^W + \delta_5 drought_t + \delta_6\, drought_{t-8} + \delta_7 lnQ_{t-4}^F + \delta_8 time_t + \delta_9 SB2005_t + \delta_{10} QT2_t + \delta_{11} QT3_t + \delta_{12} QT4_t + \mu_t^4 \quad (55)$$

The * superscript indicates an endogenous variable. Most variable descriptions are as before. Specific to the naïve model are P_{t-2}^L, the live cattle price lagged two quarters, in equation (53), P_t^L, the current live cattle price in equation (54), and P_{t-8}^F, the feeder cattle price lagged 8 quarters, in equation (55). Two dummy variables are used to account for the BSE shock. $BSE03Q4_t$ equals one for the 2003 QT1 and zero otherwise, and $BSE04Q1_t$ equals one for 2004 QT1 and zero otherwise. These two individual dummy variables are included to help with normality of the residual terms.[23] Additionally, Chow tests (Chow, 1960) in the reduced form equations indicated a potential structural break. To help account for this shift, $SB2005_t$ is added to specific equations. $SB2005_t$ is equal to zero before 2005 QT1 and equal to one beginning in 2005 QT1 through the end of the sample. Misspecification testing is detailed more below.

Due to the large number of variables and potential degrees of freedom concerns, an equation by equation instrumentation strategy is used. Specifically, $lnM_t, lnP_{t-2}^L, lnP_t^C, time_t, BSE03Q4_t, BSE04Q1_t, SB2005,\ QT2_t, QT3_t, QT4_t\ CSS_t, EX_t$, and

[23] Other, less effective, ways of accounting for the BSE shock were explored.

$AustCube_t$ are the exogenous variables and instruments in the live cattle demand equation (52). All variables in equation (53) are exogenous. For equations (54) and (55), $lnP_t^C, lnP_{t-8}^F, lnP_{t-4}^W, drought_t, drought_{t-8}, lnQ_{t-4}^F\ time_t, BSE03Q4_t, BSE04Q1_t, SB2005,$ $QT2_t, QT3_t$, and $QT4_t$ are the exogenous variables and instruments.

If forward looking expectations are assumed, the four-equation model (Equations (56) through (59)) is estimated using three-stage least squares in log-log form:

Live cattle inverse demand:

$$\begin{aligned} lnP_t^L = \alpha_1 + \alpha_2 lnQ_t^{L,*} + \alpha_3\ lnRDI_t^* + \alpha_4 lnEI_t^* + \alpha_5\ lnM_t + \alpha_6\ time_t \\ + \alpha_7\ BSE03Q4_t + \alpha_8 BSE04Q1_t + \alpha_9 SB2005 + \alpha_{10} QT2_t \\ + \alpha_{11} QT3_t + \alpha_{12} QT4_t + \mu_t^1 \end{aligned} \tag{56}$$

Live cattle supply:

$$\begin{aligned} lnQ_t^L = \beta_1 + \beta_2 lnE_{t-2}[P_t^L] + \beta_3 ln\ P_{t-2}^F + \beta_4 lnP_{t-2}^C + \beta_5 lnQ_{t-1}^L + \beta_6 time_t \\ + \beta_7 BSE03Q4_t + \beta_7 BSE04Q1_t + \beta_8 QT2_t + \beta_9 QT3_t \\ + \beta_{10} QT4_t + \mu_t^2 \end{aligned} \tag{57}$$

Feeder cattle inverse demand:

$$\begin{aligned} lnP_t^F = \gamma_1 + \gamma_2 lnQ_t^{F,*} + \gamma_3\ lnE_t[P_{t+2}^L] + \gamma_3\ ln\ P_t^C + \gamma_4 time_t + \gamma_5\ BSE03Q4_t \\ + \gamma_6 BSE04Q1_t + \gamma_7 SB2005 + \gamma_8 QT2_t + \gamma_9 QT3_t + \gamma_{10} QT4_t \\ + \mu_t^3 \end{aligned} \tag{58}$$

Feeder cattle supply:

$$\begin{aligned} lnQ_t^F = \delta_1 + \delta_2 lnP_t^{F,*} + \delta_3 lnE_{t-4}[P_t^F] + \delta_4 lnP_{t-4}^W + \delta_5 drought_t \\ + \delta_6\ drought_{t-8} + \delta_7 lnQ_{t-4}^F + \delta_8 time_t + \delta_9 QT2_t + \delta_{10} QT3_t \\ + \delta_{11} QT4_t + \mu_t^4 \end{aligned} \tag{59}$$

In the forward looking model, P_{t-2}^{L} is replaced by $E_{t-2}[P_t^L]$, which is the expectation in period $t-2$ (placement) of the live cattle price in period t (finish). This price is created using the expected price formula, $expected\ price = deferred\ futures + historical\ basis$. The deferred CME live cattle contract for six months in the future is used for deferred futures.[24] A four-year historical average basis is used for the five market area (Tonsor, Dhuyvetter, & Mintert, 2004).[25] In equation (58), $E_t[P_{t+2}^L]$ is the expected live cattle price at placement time t for finish time $t+2$. In equation (59), $E_{t-4}[P_t^F]$, is the expected price of today's feeder cattle from one year ago. This is created using the expected price formula. The CME feeder cattle futures contract for one year out and a four year historical Kanas basis are used.[26] The exogenous variables and instruments for equation (56) are lnM_t, $lnE_{t-2}[P_t^L], lnP_t^C, CSS_t, EX_t, AustCube_t, time_t, BSE03Q4_t, BSE04Q1_t, SB2005, QT2_t, QT3_t$, and $QT4_t$. The exogenous variables and instruments for equations (58) and (59) are $lnE_t[P_{t+2}^L], lnP_t^C, lnP_{t-8}^F, lnP_{t-4}^W, drought_t, drought_{t-8}, lnQ_{t-4}^F\ time_t, BSE03Q4_t, BSE04Q1_t, SB2005,$ $QT2_t, QT3_t$, and $QT4_t$.

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[24] Live cattle future contracts are traded for February, April, May, June, August, September, October, and December. Accordingly, $E_t\ [P_{t+2}^L]$ uses the nearby fed cattle contract price for the contract corresponding to six months in the future. For example, if the steer is placed in December, it is assumed to finish feeding in June, so the June futures price in December is used. However, if the steer is placed in January, it will finish feeding in July. There is no July futures contract and hence the August futures contract price in February is used. These monthly expected prices are then aggregated to the quarterly level. This value is then lagged two quarters to arrive at $E_{t-2}[P_t^L]$

[25] $Basis = cash - futures$

[26] Feeder futures contracts are not available or are thin for more than one year out.

Misspecification testing

Following McGuirk, Driscoll, and Alwang (1993) and McGuirk, Driscoll, Alwang, and Huang (1995) equation by equation individual and joint misspecifications tests are conducted using the reduced form equations. However, due to limited degrees of freedom, system wide misspecification tests can not be conducted. The D'Agostino third sample moment tests, the Anscombe and Glynn fourth sample moment test, and D'Agostino-Pearson K^2 omnibus tests are used to test for normality (Anscombe & Glynn, 1983; D'Agostino, Belanger, & D'Agostino 1990). Functional form is tested using the Ramsey RESET 2, 3, and 4 tests. Static and dynamic homoscedasticity are examined using a RESET2 test and autoregressive conditional heteroscedasticity (ARCH) test, respectively. Independence is checked using the following auxiliary regression:

$$\widehat{\varepsilon_t} = \beta_0'\boldsymbol{X}_t + \Lambda'\widehat{\varepsilon_{t-1}} + \upsilon_t \tag{60}$$

where $\boldsymbol{X}_t$ is a $k \times 1$ vector of independent variables, ε_t is the residual from the original model and υ_t is the estimated residuals from the auxiliary regression (McGuirk, Driscoll, & Alwang, 1993). If Λ is significant then independence is rejected. Structural change is tested using the chow test (Chow, 1960). P-values for the misspecification tests are show in Table 4.3. These results are much improved from initial models. However, we were not able to correct for or fix all misspecification issues. We attempted to correct for autocorrelation following Berndt and Savin (1975), but were unsuccessful. Alas, we do not live in a perfect econometric utopia! The models presented below represent the final specification which best aligned with economic theory and the fewest misspecification issues.

Results and discussion

Naïve model specification

Coefficient estimates from the naïve model are in Table 4.4. Generally, signs are consistent with what economic theory and cattle market structure would suggest. In the inverse live cattle demand equation, the quantity of live cattle has a negative and statistically significant impact. Due to the log-log specification, -3.38 is also the own-quantity flexibility (or a -0.30 [1/(-3.38)] demand elasticity). This is much larger than own-quantity flexibility estimates of Marsh (2003), -0.69, and Buhr and Kim (1997), -0.61. The retail demand impact on live cattle price is 3.18, indicating that a 1% change in retail demand increases the live cattle price by 3.18%. This is much larger than the export demand index impact of 0.20. However, given that the U.S. exports approximately 10% of its production, the relative impact of domestic versus export demand is not surprising (USDA, 2017b). In Marsh (2003), the retail demand index coefficient was 0.60. However, there are many differences between our model and Marsh's model, including the time period under investigation, data frequency (annual versus quarterly data), and control variables included.

The naïve expected live cattle price is not statistically significant and small in the live cattle supply equation. However, both input prices, feeder cattle and corn, have statistically significant and negative impacts on the live cattle supply. Given that the feeder cattle price coefficient is nearly four times as large as the corn coefficient, feedlot operators are more sensitive to a 1% change in the feeder cattle price than the corn price. This could potentially be related to the relative costs of these two main inputs in live cattle production and impacts on profitability.

The lagged dependent variable measures asset fixity. The coefficient, 0.47, indicates some rigidity in live cattle supply. This is similar to Marsh's (2003) estimate of 0.56. Using the live cattle price coefficient and the lagged dependent variable, the long run live cattle supply elasticity is 0.09 [0.05/(1-0.47)], which is inelastic.

The coefficient estimates in the feeder cattle demand equation are consistent with expectations. As the feeder cattle quantity increases by 1%, feeder cattle demanded decreases by 0.43%. This is smaller than the feeder flexibilities of Marsh (2003), Brester and Marsh (1983), and Shonkwilier and Hinckley (1985) of -1.35, -1.61, and -1.10. Potentially, this is due to the use of quarterly versus annual data and different time periods analyzed. Feeder cattle demand is more responsive to an increase in the live cattle price. The 1.61 estimate is slightly larger than Marsh (2003), 1.20, Shonkwiler and Hincklet (1985), 1.48, and Buccola (1980), 1.36. The corn price flexibility is also negative and significant.

Treating the live cattle price coefficient as a transmission flexibility, the impact of autonomous changes in retail and export demand on feeder cattle demand can be calculated. If the retail demand index increases by 1% the feeder cattle price changes by 5.12% [1.61*3.18]. If the export demand index increases by 1% the feeder cattle price increases by 0.32% [1.61*0.20]. These transmissions suggest that changes in retail and export demand have a larger impact on feeder cattle price than on live cattle price. The larger transmissions to feeder cattle producers are consistent with Ricardian rent theory (see chapter 3; Zhao, Du, & Hennessey, 2011). Since feeder calves are the most scarce and widely traded resource in the beef industry, the benefits and losses are largely passed back to the holder of the scarce resource, the feeder cattle producers.

In the feeder cattle supply equation, the own price supply elasticity is significant and positive. This represents the decision to sell the calf now, or wait. Thus, the positive estimate indicates that if the current price increases by 1% then producers will sell their calves now, increasing calves supplied by 0.33%. Additionally, the feeder cattle price lagged 8 quarters, which represents the naïve price expectation at the time of cow breeding and heifer retention decisions are made, is significant and positive as expected. Thus, a higher price two years ago results in more calves supplied today. The negative and significant cull cow price shows the opportunity cost of culling the cow instead of breeding. If the cull cow price one year ago was higher, then more cows are likely culled, resulting in fewer calves (-0.23%) today. The two drought variables are used to proxy pasture conditions. The contemporaneous drought variable is positive, indicating that severe drought results in more calves coming to market since the opportunity cost (or even inability) of keeping them on pasture is high. Additionally, the drought conditions two years ago impact current feeder calves supplied. If there was severe drought two years ago there are fewer feeder cattle supplied today. Poor pasture conditions likely caused heifers and cows to be sold instead of being retained for breeding. The lagged dependent variable indicates some fixity in feeder supply. Note, however, that this is lagged four quarters whereas the live cattle quantity was only lagged one quarter in the live cattle supply equation because of differences in asset fixity in feeder cattle versus live cattle production. The long run feeder cattle supply elasticity is 0.52 [0.33/(1.00-0.36)]. Buhr and Kim (1997) estimated short and long run calf crop (feeder cattle) supply elasticities of 0.05 and 0.46, respectively.

Forward looking expectations

Forward looking model coefficient estimates are in Table 4.5. With a few exceptions, the signs and statistical significance of the variables in the forward looking model are similar to the naïve model. Additionally, the Swartz Bayesian Criterion (SBC) value indicate the forward looking model provides a better model fit for each equation.

In the live cattle supply equation, coefficients are generally smaller in magnitude compared to the naïve estimates indicating that producers are less responsive to changes in the forward looking model than the naïve model. Notably, the live cattle quantity coefficient decreased from -3.38 to -2.63 and the retail demand index coefficient decreased by over half to 1.41. However, both of these point estimates are larger than calculated by Marsh (2003).

The live cattle supply equation includes a forward looking expected live cattle price. As expected, the estimate is positive and statistically significant. This estimate is larger than the equivalent coefficient in the naïve expectations model (0.05 and insignificant). The feeder cattle and corn prices at placement have negative and significant impacts, with coefficients being slightly larger in magnitude than in the naïve model. Conversely, the lagged dependent variable is smaller, 0.38. The long run live cattle supply elasticity is 0.62 [0.20/(1.00-0.38)]. This long run supply elasticity is in line with Marsh's (2003) estimate of 0.59.

The key coefficient estimates in the forward looking feeder demand equation are smaller in magnitude than the naïve estimates. Using the live cattle price transmission flexibility, 1.45, and the retail and export demand coefficients from the live cattle equation, primary demand impacts on feeder cattle price can be calculated. A 1% increase in the retail demand index increases the feeder cattle price by 2.04% [1.45*1.41]. If the export demand index increases by 1% the feeder cattle price increases by 0.23% [1.45*0.16]. As in the naïve model, the retail and export demand changes impact the feeder cattle prices more than the live cattle price. However, these transmissions are smaller than the naïve model.

Differences in the feeder cattle supply estimates across the naïve and forward looking models are evident. The contemporaneous feeder cattle price impact is insignificant. Additionally, the expected feeder cattle price is negative and significant. Thus if today's expected feeder cattle price from one year ago increased, then there are fewer feeder cattle supplied today. This is different than the naïve model, but given the lag structure (t-4 vs t-8) the prices used in each model potentially represent different decisions. Given the one year horizon in the forward looking model, the negative coefficient could indicate that cow-calf producers are retaining heifers and expanding their herds because of more favorable market conditions. However, calves from the retained heifers have not come to market yet, resulting in less feeder calves supplied today. The lagged dependent variable coefficient estimate, 0.34, indicates some asset fixity. The long run feeder cattle supply elasticity is very inelastic, 0.02 [0.01/(1.00-0.34)].

Implications

The implications of model results are demonstrated in two ways below. First a "what-if" analysis is completed for changes in future demand using data from 2016 QT3 by increasing values of the retail and export demand indices (Table 4.6). Second, a decomposition of predicted values for key historical time periods of interest is presented (Table 4.7).

Given that understanding how changes in retail and export demand impact the live cattle and feeder cattle prices is core to our analysis, demonstrating how shocks to these indices change predicted values is key. Results are presented for a one index point and one standard deviation increase in each index individually.[27] Overall, the retail demand index is less variable than the export demand index and thus a one index point difference alone does not reflect this. A four

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[27] Assuming a normal distribution, a one standard deviation change represents 34.1% of the data above the mean and 34.1% of the data below the mean. Hence these changes would be expected to occur over one-third of the time.

and 11 point increase in the retail and export demand indices, respectively, are equivalent to a one standard deviation increase.[28]

Industry wide efforts are made to increase domestic beef demand, such as those funded through the beef checkoff program. While this study cannot speak for what increases retail beef demand, it can detail the implications of an increase in retail beef demand on live and feeder cattle prices (Table 4.6). Increasing the retail demand index by one point in 2016 QT3 would increase the live cattle price by 3.42% and the feeder cattle price by 5.55% in the naïve model and by 1.50% and 2.18% in the forward looking model. A one standard deviation increase in the retail demand index, a four point change, would increase the live cattle price by 14.14% in the naïve model and 6.03% in the forward looking model. The feeder cattle price increases by 23.69% in the naïve model and 8.85% in the forward looking model.

A one index point increase in the export demand index has a small impact on the live and feeder cattle predicted prices in both the naïve and forward looking model (Table 4.6). Conversely, a one standard deviation increase boosts the live cattle price prediction by nearly 2%, and the feeder steer price by nearly 3% in the naïve model. In the forward looking model, the one standard deviation shock to the export index increases the live and feeder cattle prices by just over 1% and nearly 2%, respectively. Although these might seem like small percentages, given the real live and feeder cattle prices were $47.72/cwt ($113.30, nominal) and $59.56/cwt ($142.67, nominal) in 2016 QT3, increasing live and feeder prices by 1.50% and 2.30% (average of naïve and forward looking model estimates) increases prices by $0.71/cwt ($1.70, nominal)

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[28] The quarter to quarter difference in each index was taken. Then the mean and standard deviation of these differences were calculated. The mean difference in the retail demand and export demand indices were -0.09 and 1.52, respectively.

and \$1.37/cwt (\$3.30, nominal). Holding live and feeder cattle quantities constant (8,526,746,200 live pounds and 3,938,100,000 feeder pounds), the increase in prices would result in increased real revenue of approximately \$60.14 million (\$144.91 million, nominal) and \$53.95 million (\$129.99 million, nominal) for the live cattle and feeder cattle sectors, respectively.

Three important time periods in the beef industry were the identification of BSE (2001 QT3 vs 2006 QT1) in the U.S., the U.S. recession (2007 QT1 vs 2010 QT1), and the period of higher cattle prices (2010 QT1 vs 2015 QT1). The decomposition of predicted live cattle price changes from both the naïve and forward looking models over these event periods are detailed in Table 4.7 to further illustrate the core drivers of price changes. The first event, identification of BSE, looks at changes to the live cattle price before BSE, 2001 QT3, to two years after BSE, 2006 QT1. Over this period the actual live cattle price increased by 2.70%. The naïve model predicts a change of 7.85% and the forward looking model predicts an increase of 11.36%. We can decompose the predicted value to understand how changes in the live cattle quantity, retail demand index, and export demand index impacted the predicted live cattle price. Given this adverse BSE shock, one would expect the live cattle price to decease, ceteris paribus. However, ceteris paribus doesn't apply as over this time period. The live cattle price actually increased. Investigating the decomposition, there was a decrease in live cattle quantity by nearly 15%, a decrease in the retail demand index by 4.15%, and a decrease in the export demand index by 62.94%. Multiplying these decreases by the model coefficients, we can understand their impact on live cattle price. Given the magnitudes and signs of the coefficients, the predicted positive impact from the decline in live cattle quantity is larger than the combined negative demand impact. This can be seen in both the naïve and forward looking models.

The U.S. recession occurred from December 2007 to June 2009 during which unemployment peaked at 10% and consumer spending decreased (U.S. Bureau of Labor Statistics, 2012). From 2007 QT1 to 2010 QT1, the live cattle price decreased by 8.00%. During this time, the quantity of live cattle and the retail demand index decreased, however, export demand improved. The live cattle predicted value in the naïve model decreased by 8.96%, but increased by 0.66% in the forward looking model. In the naïve model, the retail demand decrease alone would have caused the live cattle price to decrease by 35.67 percentage points. However, the positive impacts of decreased live cattle quantity and increased export demand partially offset the negative retail demand impact.

From 2010 to 2015 both live and feeder cattle prices increased. The live cattle price increased by 70.11% from 2010 to 2015. In 2014 and 2015, historically high average net returns for feedlots occurred (Tonsor, 2016). Additionally, cow-calf returns were positive from 2010 to 2015, especially in 2014 and 2015 (LMIC, 2017). Both the naïve and forward looking models predicted an increase in live cattle price over this time, however, not as much of an increase as actually occurred. A decrease in live cattle quantity explained about 15 percentage points of the increase in live cattle prices in the naïve model and about 11 percentage points in the forward looking model. The change in retail demand quantity based index was small. Export demand nearly doubled over this time period. The increased export demand accounted for about 21 percentage points of the live cattle price increase in the naïve model and 16 percentage points in the forward looking model.

Conclusion

Limited empirical work has quantified how changes in primary demand, retail and export beef demand, impact farm level demands. The goal of this study is to provide current estimates of these price transmissions. Two systems of equations were estimated to quantify the impacts of U.S. retail beef and export beef demand on live cattle and feeder cattle demand and supply. One system utilizes naïve price expectations and the other forward looking price expectations.

In the naïve model, when retail level beef demand increases (decreases) by 1%, inverse live cattle demand increases (decreases) by 3.18% and feeder cattle inverse demand increases (decreases) by 5.12%. Additionally, if the export demand index increases (decreases) by 1% the inverse live cattle demand increases (decreases) by 0.20% and feeder cattle demand increases (decreases) by 0.32%. In the forward looking model, when retail level beef demand increases (decreases) by 1%, inverse live cattle demand increases (decreases) by 1.41% and feeder cattle inverse demand increases (decreases) by 2.04%. Furthermore, if the export demand index increases (decreases) by 1% the inverse live cattle demand increases (decreases) by 0.16% and feeder cattle demand increases (decreases) by 0.23%. The larger price transmission at the feeder cattle level is consistent with Ricardian rent theory and rents in the beef system being passed to cow-calf producers, the holder of the scarce resource (see chapter 3; Zhao, Du, & Hennessey, 2011). Therefore, even though cow-calf and stocker/backgrounder producers (primary suppliers) are not directly involved in primary domestic and export demand, it is important to understand how primary demand changes are transmitted through the supply chain and impact demand for their farm level products.

Promotional efforts like the Beef Checkoff Program aim to increase primary retail demand for beef. The results confirmed that both feedlot operations and feeder cattle producers (cow-calf, stocker, and backgrounding) benefit from programs that increase domestic and export demand. Additionally, the price transmission from the live cattle price to the feeder cattle price is greater than one. These implications are timely and should be noted in ongoing discussions around beef checkoff programs (USDA, 2014). On the other hand, negative shifts at the retail level or in export demand also impact farm level demand. For example, a food safety or alternative adverse event, such as BSE, that decreases beef demand will negatively impact farm level revenues more than feedlot revenues.

A "what-if" analysis and decomposition of predicted values was conducted. The "what-if" analysis was conducted using data from 2016 QT3 and shocking retail and export beef demand. Overall, a one standard deviation shock in the retail beef demand index had a larger impact than a one standard deviation shock in the export beef demand index. The live and feeder cattle price predictions were decomposed over three key time periods; BSE identification in the U.S., the U.S. recession in the late 2000s, and the period of cattle price increases from 2010 to 2015. Interestingly, the live cattle price increased from 2001 QT3 (before BSE) to 2006 QT1 (after BSE). The positive impact on the live cattle price from the decrease in live cattle quantity offset the negative impacts from decreased retail and export demand.

Results are useful in evaluating investment opportunities and impacts of new technologies or policies. If investment is anticipated to increase retail beef demand, an analysis can be conducted using our results to determine whether the increase in demand will offset the costs of implementing the proposed investment. Similarly, when new policies are evaluated that impact domestic or export demand for U.S. beef our results can be used to assess impacts on live and feeder cattle producers.

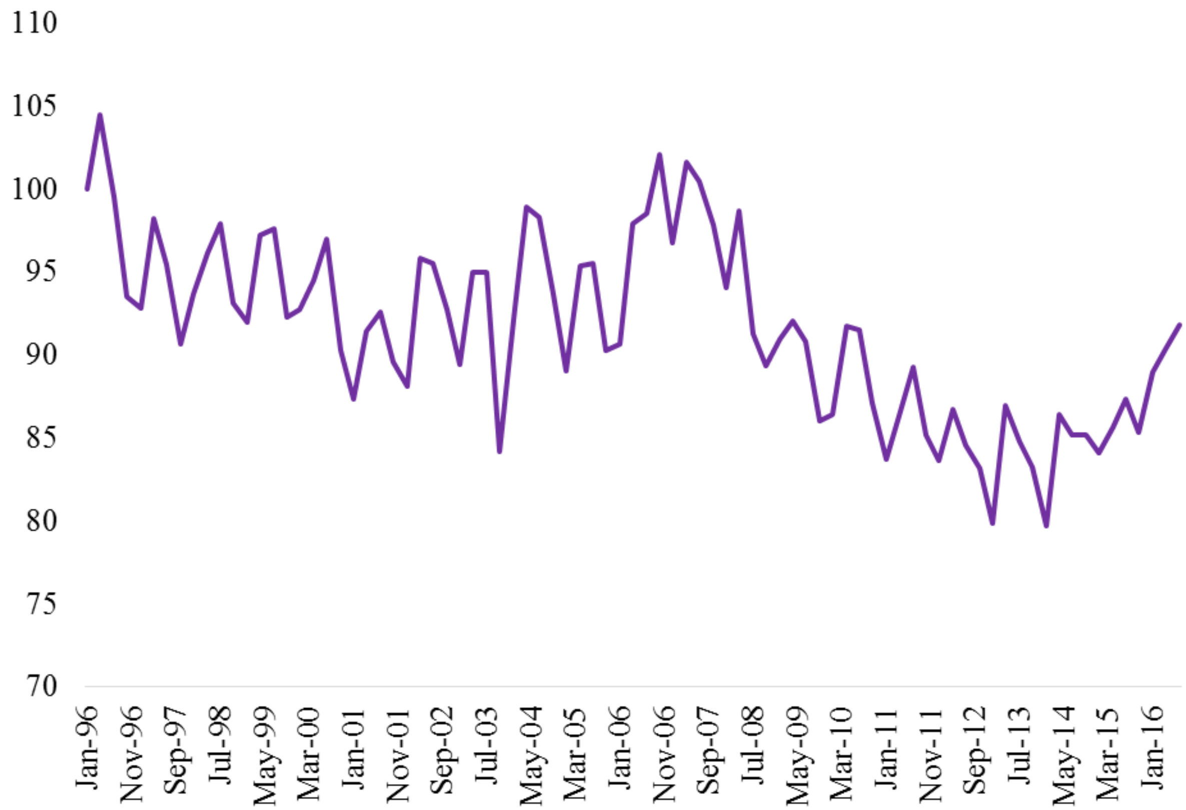

Figure 4.1 Retail beef demand index (QT1 1996=100)

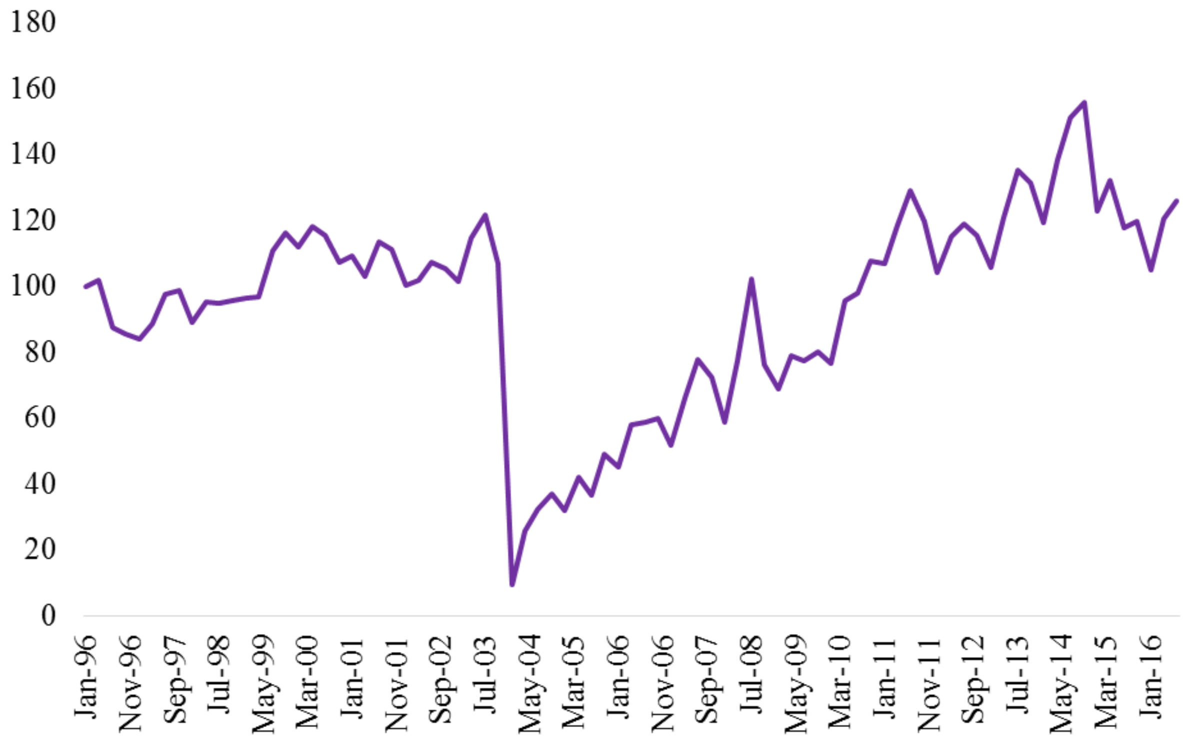

Figure 4.2 Export beef demand index (QT1 1996=100)

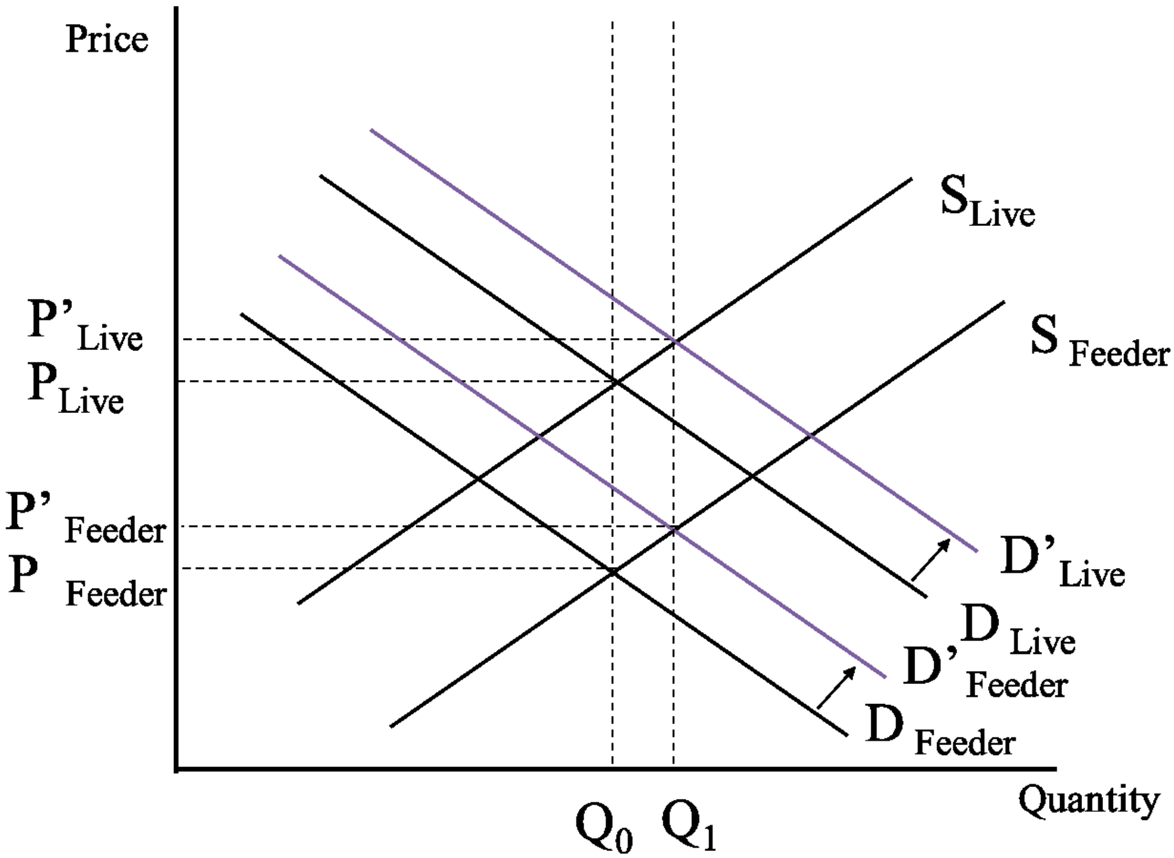

Figure 4.3 Effects of increased beef demand on live and feeder cattle prices and quantities

Table 4.1 Variable list and descriptions

Variable	Description
P_t^L	Fed steer price, live basis, 5-market average, total all grades, \$/cwt
$E_t[P_{t+2}^L]$	Expected 5-market average price in two quarters, expected price= deferred futures+ historical basis, \$/cwt
P_t^F	Feeder steer price, weighted price, Kansas, \$/cwt
$E_t[P_{t+4}^F]$	Expected Kansas feeder steer price in four quarters, expected price=deferred futures + historical basis, \$/cwt
Q_t^L	Live cattle quantity, federally inspected steers and heifer harvested, thousands of lbs
Q_t^F	Feeder cattle quantity (feeder cattle placements), thousands of lbs
RDI_t	Quantity based retail demand index (1996 QT1=100)
EI_t	Quantity based export demand index (1996 QT1=100)
P_t^C	Feed corn price, \$/bu
P_t^W	Cull cow price, boning utility, Sioux Falls, \$/cwt
M_t	Food marketing cost index (1967=100)
CSS_t	Index of consumer sentiment (QT1 1960=100)
EX_t	Real broad exchange rate index
$AustCube_t$	Australian cube roll price from Australia to Japan, cents/lb
$droughtsevere_t$	Dummy variable to indicate severe drought in KS, =1 if Modified Palmer Drought Index ≤-2
$time_t$	Linear time trend (1997 QT1=1, 1997 QT2=2, etc.)
$SB2005_t$	Structural break dummy, =1 if year≥2005
$QT2_t, QT3_t, QT4_t$	Quarter 2, 3, and 4 dummy variables

Table 4.2 Descriptive statistics for QT1 1996 to QT3 2016 (n=83)

Variable	Mean	Std Dev	Minimum	Maximum	Coeff of Variation
P_t^L	45.89	7.98	35.35	70.11	17.39
$E_t[P_{t+2}^L]$	46.16	7.53	36.18	68.91	16.31
P_t^F	56.30	13.64	36.08	105.04	24.23
$E_t[P_{t+4}^F]$	55.91	12.18	38.43	98.23	21.78
Q_t^L	8477938.88	487795.20	7322813.33	9521782.67	5.75
Q_t^F	4095384.34	413763.77	3004100.00	5185650.00	10.10
RDI_t	91.61	5.46	79.74	104.47	5.96
EI_t	94.84	29.76	9.45	155.94	31.38
P_t^C	1.66	0.59	0.92	3.14	35.83
P_t^W	27.47	6.76	16.80	48.20	24.60
M_t	285.75	3.02	278.37	291.41	1.06
CSS_t	87.15	13.16	57.70	110.10	15.10
EX_t	94.77	8.41	80.96	112.38	8.87
$AustCube_t$	404.97	131.29	201.26	700.21	32.42
$droughtsevere_t$	0.11	0.31	0.00	1.00	288.49

Table 4.3 Misspecification tests p-values for reduced form equations

	NAÏVE				FORWARD			
	Live Demand	Live Supply	Feeder Demand	Feeder Supply	Live Demand	Live Supply	Feeder Demand	Feeder Supply
					Individual Tests			
Normality								
Skewness	0.54	0.27	0.67	0.16	0.60	0.23	0.50	0.26
Kurtosis	0.59	0.59	0.71	0.53	0.61	0.56	0.42	0.65
Omnibus	0.71	0.47	0.85	0.30	0.77	0.41	0.57	0.48
Functional Form								
RESET 2	0.03	0.68	<0.01	0.11	0.05	0.52	0.04	0.11
RESET 3	0.09	0.75	<0.01	0.29	0.14	0.51	0.11	0.27
RESET 4	0.03	0.88	0.01	0.45	0.07	0.71	0.22	0.32
Homoscedasticity								
Static RESET2	0.41	0.96	0.08	0.67	0.30	0.95	0.13	0.62
Dynamic ARCH1	0.61	0.28	<0.01	0.33	0.69	0.12	0.82	0.21
Parameter Stability								
Chow- Mean	Breaks	None	Breaks	None	Breaks	None	None	None
Variance	0.63	0.76	<0.01	0.42	0.75	0.91	0.78	0.82
Autocorrelation								
AC1	<0.01	0.24	<0.01	0.66	<0.01	0.37	0.27	0.55
					Joint Tests			
Conditional Mean								
All- Joint F	<0.01	0.51	<0.01	0.44	<0.01	0.68	0.14	0.37
Parameter Stability	0.03	0.48	0.04	0.44	0.03	0.91	0.55	0.39
Functional Form	0.08	0.53	0.43	0.23	0.08	0.42	0.04	0.20
Autocorrelation	<0.01	0.23	<0.01	0.76	<0.01	0.31	0.36	0.62
Conditional Variance								
All- Joint F	0.83	0.22	<0.01	0.74	0.76	0.24	0.18	0.65
Parameter Stability	0.89	0.08	0.03	0.62	0.84	0.20	0.06	0.96
Static Homoscedasticity	0.50	0.73	0.64	0.96	0.39	0.84	0.06	0.77
Dynamic Homoscedasticity	0.70	0.18	<0.01	0.35	0.88	0.09	0.82	0.22

Table 4.4 Three-stage least squares naive coefficient estimates (n=75)

Variable	Coefficient estimate	Variable	Coefficient estimate	Variable	Coefficient estimate	Variable	Coefficient estimate
Inverse Live Cattle Demand		*Live Cattle Supply*		*Feeder Cattle Demand*		*Feeder Cattle Supply*	
lnQ_t^L	-3.38***	$ln[P_{t-2}^L]$	0.05	lnQ_t^F	-0.43*	lnP_t^F	0.33*
	(1.21)		(0.07)		(0.27)		(0.21)
$lnRDI_t$	3.18*	lnP_{t-2}^F	-0.11***	lnP_t^L	1.61***	lnP_{t-8}^F	0.20***
	(2.16)		(0.05)		(0.16)		(0.09)
$lnEI_t$	0.20*	lnP_{t-2}^C	-0.03***	lnP_t^C	-0.13***	lnP_{t-4}^W	-0.23***
	(0.13)		(0.01)		(0.03)		(0.12)
lnM_t	4.35	lnQ_{t-1}^L	0.47***			$drought_t$	0.01
	(3.70)		(0.10)				(0.02)
$time_t$	0.01***	$time_t$	-0.00003	$time_t$	-0.004***	$drought_{t-8}$	-0.08**
	(0.004)		(0.0003)		(0.001)		(0.04)
$BSE03Q4_t$	0.09	$BSE03Q4_t$	-0.15***	$BSE03Q4_t$	-0.27***	lnQ_{t-4}^F	0.36***
	(0.16)		(0.03)		(0.07)		(0.14)
$BSE04Q1_t$	0.16	$BSE04Q1_t$	-0.02	$BSE04Q1_t$	-0.06	$time_t$	-0.003***
	(0.27)		(0.03)		(0.06)		(0.002)
$SB2005_t$	-0.16			$SB2005_t$	0.06***	$SB2005_t$	0.03
	(0.12)				(0.03)		(0.03)
$QT2_t$	0.05	$QT2_t$	0.08***	$QT2_t$	0.03	$QT2_t$	0.01
	(0.07)		(0.01)		(0.02)		(0.02)
$QT3_t$	0.06	$QT3_t$	0.06***	$QT3_t$	0.16***	$QT3_t$	0.08***
	(0.08)		(0.01)		(0.04)		(0.03)
$QT4_t$	0.002	$QT4_t$	0.005	$QT4_t$	0.09***	$QT4_t$	0.03
	(0.05)		(0.01)		(0.03)		(0.03)
Intercept	17.55	*Intercept*	8.72***	*Intercept*	4.48	*Intercept*	8.51***
	(18.57)		(1.66)		(4.31)		(2.35)
SBC	-272.91		-526.90		-392.94		-376.61
Errors stationary	YES		YES		YES		YES

Table note: Standard errors in ( ). * $p<0.15$, ** $p<0.10$, *** $p<0.05$

Table 4.5 Three-stage least squares forward looking coefficient estimates (n=79)

Variable	Coefficient estimate	Variable	Coefficient estimate	Variable	Coefficient estimate	Variable	Coefficient estimate
Inverse Live Cattle Demand		*Live Cattle Supply*		*Feeder Cattle Demand*		*Feeder Cattle Supply*	
lnQ_t^L	-2.63***	$lnE_{t-2}[P_t^F]$	0.20*	lnQ_t^F	0.05	lnP_t^F	0.01
	(0.58)		(0.13)		(0.12)		(0.05)
$lnRDI_t$	1.41	lnP_{t-2}^F	-0.23***	$lnE_t[P_{t+2}^L]$	1.45***	$lnE_{t-4}[P_t^F]$	-0.25***
	(1.04)		(0.09)		(0.04)		(0.09)
$lnEI_t$	0.16***	lnP_{t-2}^C	-0.07***	lnP_t^C	-0.29***	lnP_{t-4}^W	0.14**
	(0.06)		(0.03)		(0.01)		(0.08)
lnM_t	1.32	lnQ_{t-1}^L	0.38***			$drought_t$	-0.004
	(2.25)		(0.09)				(0.02)
$time_t$	0.005***	$time_t$	0.0003	$time_t$	0.002***	$drought_{t-8}$	-0.03*
	(0.002)		(0.0002)		(0.0004)		(0.02)
$BSE03Q4_t$	0.04	$BSE03Q4_t$	-0.13***	$BSE03Q4_t$	0.08***	lnQ_{t-4}^F	0.34***
	(0.11)		(0.03)		(0.03)		(0.09)
$BSE04Q1_t$	0.19	$BSE04Q1_t$	-0.02	$BSE04Q1_t$	0.03	$time_t$	-0.0005
	(0.16)		(0.03)		(0.03)		(0.0005)
$SB2005_t$	-0.06			$SB2005_t$	-0.04***		
	(0.09)				(0.01)		
$QT2_t$	0.09**	$QT2_t$	0.07***	$QT2_t$	-0.02*	$QT2_t$	-0.02
	(0.05)		(0.01)		(0.01)		(0.02)
$QT3_t$	0.10**	$QT3_t$	0.07***	$QT3_t$	-0.05***	$QT3_t$	0.09***
	(0.05)		(0.01)		(0.02)		(0.02)
$QT4_t$	0.02	$QT4_t$	0.01	$QT4_t$	-0.06***	$QT4_t$	0.06***
	(0.03)		(0.01)		(0.01)		(0.02)
Intercept	31.05***	*Intercept*	10.05***	*Intercept*	-2.18	*Intercept*	10.55***
	(12.76)		(1.48)		(1.81)		(1.36)
SBC	-357.00		-555.26		-517.82		-434.68
Errors stationary	YES		YES		YES		YES

Table note: Standard errors in ( ). * p<0.15, ** p<0.10, *** p<0.05

Table 4.6 Simulations of how live and feeder cattle prices respond to changes in retail and export demand indices

	NAÏVE		FORWARD	
	Percent change in P_t^L prediction	Percent change in P_t^F prediction	Percent change in P_t^L prediction	Percent change in P_t^F prediction
Changing retail demand index by 1 index point	3.42%	5.55%	1.50%	2.18%
Changing retail demand index by 4 index points (1 st dev)	14.14%	23.69%	6.03%	8.85%
Changing export index by 1 index point	0.16%	0.26%	0.12%	0.18%
Changing export index by 11 index points (1 st dev)	1.73%	2.79%	1.31%	1.90%

Table 4.7 Decomposition of model prediction for time periods of interest

BSE: 2001 QT3 vs 2006 QT1						
Actual change in P_t^L	2.70%					
Predicted change in P_t^L	7.85%			Predicted change in P_t^L 11.36%		
	NAÏVE			**FORWARD**		
	Q_t^L	RDI_t	EI_t	Q_t^L	RDI_t	EI_t
Actual percentage change in data over time period	-14.72%	-4.15%	-62.94%	-14.72%	-4.15%	-62.94%
Coefficient estimate	-3.38	3.18	0.20	-2.63	1.41	0.16
Predicted incremental change in P_t^L given change in	49.70%	-13.20%	-12.90%	38.73%	-5.84%	-9.78%
Recession: 2007 QT1 vs 2010 QT1						
Actual change in P_t^L	-8.00%					
Predicted change in P_t^L	-8.96%			Predicted change in P_t^L 0.66%		
	NAÏVE			**FORWARD**		
	Q_t^L	RDI_t	EI_t	Q_t^L	RDI_t	EI_t
Actual percentage change in data over time period	-1.30%	-11.22%	47.57%	-1.30%	-11.22%	47.57%
Coefficient estimate	-3.38	3.18	0.20	-2.63	1.41	0.16
Predicted incremental change in P_t^L given change in	4.38%	-35.67%	9.75%	3.41%	-15.78%	7.39%
Price changes: 2010 QT1 vs 2015 QT1						
Actual change in P_t^L	70.11%					
Predicted change in P_t^L	51.72%			Predicted change in P_t^L 30.88%		
	NAÏVE			**FORWARD**		
	Q_t^L	RDI_t	EI_t	Q_t^L	RDI_t	EI_t
Actual percentage change in data over time period	-4.34%	0.24%	103.45%	-4.34%	0.24%	103.45%
Coefficient estimate	-3.38	3.18	0.20	-2.63	1.41	0.16
Predicted incremental change in P_t^L given change in	14.66%	0.77%	21.20%	11.43%	0.34%	16.07%

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Appendix A - Survey instrument

Following is a survey designed to obtain important information from U.S. feedlot operators. The survey is focused on assessing various aspects of risk management including incoming cattle purchases and outgoing cattle sales. We want to emphasize that your participation in this survey is entirely voluntary and highly encouraged. All your responses will be kept in strict confidence. Typical demographic questions are included to ensure our sample is representative of the U.S. feedlot industry and will remain strictly confidential. If you wish to provide comments please use the space at the end of the survey. We very much appreciate your assistance with this important project and look forward to receiving your completed survey. If you have any questions or comments regarding this survey, please feel free to contact Melissa McKendree (mgsm@ksu.edu) or Dr. Glynn Tonsor by email (gtonsor@ksu.edu) or by phone (785-532-1518).

Q1A Please describe your cattle operation by indicating the percentage of your operation devoted to each segment of the beef cattle industry (should sum to 100%)

______ Seed Stock (1)

______ Cow-calf (2)

______ Backgrounding/Stocker (3)

______ Feedlot (4)

______ Other (please describe): (5)

Q1B Do you play a role in price risk management and/or animal health risk management decisions?

- o Yes, both price risk and animal health risk decisions (3)
- o Yes, price risk management decisions (1)
- o Yes, animal health risk management decisions (2)
- o No (4)

The following questions will refer to "your operation." Please answer the questions when considering the finishing feedlot(s) in your operation. If your operation includes multiple feedlots, please answer for them collectively.

Q2 Please answer the following questions:

	Never (1)	Sometimes (2)	About half the time (3)	Most of the time (4)	Always (5)
How often does your operation use futures markets to hedge corn for feeding? (1)					
How often does your operation use futures markets to hedge feeder cattle? (2)					
How often does your operation use futures markets to hedge fed cattle? (3)					

Q3 What is the average placement weight of calves your feeding operation places in March?

- o Under 600 lbs (1)
- o 600 to 699 lbs (2)
- o 700 to 799 lbs (3)
- o 800 to 899 lbs (4)
- o 900 lbs or more (5)

Q4 On average, what percentage of feeder cattle does your operation source from (should sum to 100%):

______ Traditional auction (1)

______ Satellite/video auction (2)

______ Purchased direct from seller (ranch) (3)

______ Home raised from own cow-herd (4)

______ Custom fed, so I did not buy or own animals (5)

______ Other(please describe): (6)

Q5 Compared to calves sourced from auctions with unknown backgrounds, how do you believe calves from a single source ranch perform (i.e. average daily gain, feed conversion, morbidity) in the feedlot?

- Much worse (1)
- Somewhat worse (2)
- About the same (3)
- Somewhat better (4)
- Much better (5)

Q6 In the past 12 months, what do you believe is the average premium paid nationally in the market for feeder calves sourced from a single known ranch versus multiple unknown sources?

- Discount (1)
- No premium (2)
- Premium less than $1/cwt (3)
- $1 to $1.99/cwt premium (4)
- $2 to $2.99/cwt premium (5)
- $3 to $3.99/cwt premium (6)
- $4 to $4.99/cwt premium (7)
- $5 to $5.99/cwt premium (8)
- $6 to $6.99/cwt premium (9)
- $7 to $7.99/cwt premium (10)
- $8 to $8.99/cwt premium (11)
- $9 to $9.99/cwt premium (12)
- Premium greater than $10/cwt (13)

Q7 In the past 12 months, what percentage of finished cattle did your operation market as (should sum to 100%):

______ Live weight, negotiated price (includes auctions) (1)

______ Live weight, formula price (2)

______ Live weight, forward contract (3)

______ Dressed weight, negotiated price (4)

______ Dressed weight, formula price (5)

______ Dressed weight, forward contract (6)

______ Grid (dressed, grade and yield) (7)

______ Other (please describe): (8)

Q8 In the past 12 months, what percentage of the following pricing methods did your operation use for marketing finished cattle (should sum to 100%):

______ Spot cash market (1)

______ Forward contract or marketing agreement (2)

______ Futures hedge (3)

______ Options hedge (4)

______ Livestock Risk Protection (LRP) Insurance (5)

______ Livestock Gross Margin (LGM) Insurance (6)

______ Other (please describe): (7)

Q9 How do you think the August 2017 live cattle futures contract will settle (at expiration in August)?

- Settle price will be higher than today's trading price (1)
- Settle price will be lower than today's trading price (2)
- Settle price will be the same as today's trading price (3)

Display This Question:

If What are your price expectations for fed cattle between now and August 2017? Prices will increase Is Selected

Q9-A By how much do you expect the August 2017 live cattle price to increase by settle (at expiration in August)?

- o increase by less than $2/cwt (1)
- o increase by $2 to $4/cwt (2)
- o increase by $4 to $6/cwt (3)
- o increase by $6 to $8/cwt (4)
- o increase by $8 to $10/cwt (5)
- o increase by more than $10/cwt (6)

Display This Question:

If What are your price expectations for fed cattle between now and August 2017? Prices will decrease Is Selected

Q9-B By how much do you expect the August 2017 live cattle price to decrease by settle (at expiration in August)?

- o decrease by less than $2/cwt (1)
- o decrease by $2 to $4/cwt (2)
- o decrease by $4 to $6/cwt (3)
- o decrease by $6 to $8/cwt (4)
- o decrease by $8 to $10/cwt (5)
- o decrease by more than $10/cwt (6)

Q10 What is the historical nearby August fed cattle basis ($/cwt) in your area? (Please slide the purple circle to the appropriate basis) Note: Basis = local cash price - futures price

______ August basis ($/cwt) (1)

CV1

The following two questions look similar but importantly are different. Please complete both questions carefully. Research studies have found people to overstate their willingness to pay in hypothetical situations, such as this survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.

Q11.1 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800 lbs each at placement, are available for purchase from a single known ranch for a premium of $ 0 /cwt over cattle purchased at an auction from unknown sources. Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Q12.1 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800 lbs each at placement, are available for purchase from a single known ranch for a premium of $ 0 /cwt over cattle purchased at an auction from unknown sources. The August CME live cattle futures contract is trading at $ 0/cwt (CME contract is for 40,000lb of live cattle). The expected local August basis is $ 0 /cwt. Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Display This Question:

If Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at... Text Response Is Greater Than 0

Q12B.1 Of the ${q://QID22/ChoiceTextEntryValue} feeder steers purchased, how many would you place under a futures hedge using the CME live cattle contract given the above information? Recall: The August CME live cattle futures contract is trading at $ 0/cwt (CME contract is for 40,000lb of live cattle). The expected local August basis is $ 0 /cwt.

CV2

The following two questions look similar but importantly are different. Please complete both questions carefully. Research studies have found people to overstate their willingness to pay in hypothetical situations, such as this survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.

Q11.2 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800 lbs each at placement, are available for purchase from a single known ranch for a premium of $ 0 /cwt over cattle purchased at an auction from unknown sources. Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Q12.2 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800 lbs each at placement, are available for purchase from a single known ranch for a premium of $ 0 /cwt over cattle purchased at an auction from unknown sources. The August CME live cattle futures contract is trading at $ 0 /cwt. A forward contract (with typical specifications for your area) is currently being offered with a basis of $ 0 /cwt tied to the August futures contract. Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Display This Question:
If Single source feeder calves, originating from a single ranch of origin, are generally considered... Text Response Is Greater Than 0
Q12B.2 Of the ${q://QID24/ChoiceTextEntryValue} feeder steers purchased, how many would you place under a forward contract (with typical specification for your area) given the above information? Recall: The August CME live cattle futures contract is trading at $ 0 /cwt. A forward contract (with typical specifications for your area) is currently being offered with a basis of $ 0 /cwt tied to the August futures contract.

CV3

The following two questions look similar but importantly are different. Please complete both questions carefully. Research studies have found people to overstate their willingness to pay in hypothetical situations, such as this survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.

Q11.3 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800 lbs each at placement, are available for purchase from a single known ranch for a premium of $ 0 /cwt over cattle purchased at an auction from unknown sources. Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Q12.3 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You are looking to buy feeder steers for March placement with an expectation of August finish/sale. A sale lot of 150 feeder steers, which will weigh approximately 800lb each at placement, are available for purchase from a single known ranch for a premium of $ 0 /cwt over cattle purchased at an auction from unknown sources. The August CME live cattle futures contract is trading at $ 0 /cwt (CME contract is for 40,000lb of live cattle). The expected local August basis has a ${e://Field/Percent1} % chance of being less (weaker) than $ 0, and a 100% chance of being greater (stronger) than $ 0. Of the 150 head of feeder steers available from the single source ranch, how many would you purchase?

Display This Question:

If Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at... Text Response Is Greater Than 0

12B.3 Of the ${q://QID47/ChoiceTextEntryValue} feeder steers purchased, how many would you place under a futures hedge using the CME live cattle contract given the above information? Recall: The August CME live cattle futures contract is trading at $ 0 /cwt (CME contract is for 40,000lb of live cattle). The expected local August basis has a ${e://Field/Percent1} % chance of being less (weaker) than $ 0, and a 100% chance of being greater (stronger) than $ 0.

CV4

Research studies have found people to overstate their willingness to participate in hypothetical situations, such as this survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.

Q11.4 Suppose it is February 15th. You just purchased a lot of 150 feeder steers weighing approximately 800 lbs each for March placement with an expectation of August finish/sale. The August CME live cattle futures contract is trading at $ 0 /cwt (CME contract is for 40,000lb of live cattle). How many head would you place under each of the following output pricing strategies?

______ A futures hedge with an expected local August basis of $ 0/cwt. (1)

______ A forward contract (with typical specifications for your area) with a basis of $ 0 /cwt tied to the August futures contract. (2)

______ Other output pricing strategy (e.g., options, Livestock Risk Protection, formula pricing, etc.) (3)

______ I would accept the local cash price at time of sale in August (4)

CV5

Research studies have found people to overstate their willingness to participate in hypothetical situations, such as this survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.

Q11.5 Suppose it is February 15th. You just purchased a lot of 150 feeder steers weighing approximately 800 lbs each for March placement with an expectation of August finish/sale. The August CME live cattle futures contract is trading at $ 0 /cwt (CME contract is for 40,000lb of live cattle). How many head would you place under each of the following output pricing strategies?

______ A futures hedge where the expected local August basis has a ${e://Field/Percent1}% chance of being less (weaker) than $ 0, and a 100% chance of being greater (stronger) than $ 0. (1)

______ A forward contract (with typical specifications for your area) with a basis of $ 0 /cwt tied to the August futures contract. (2)

______ Other output pricing strategy (e.g., options, Livestock Risk Protection, formula pricing, etc.) (3)

______ I would accept the local cash price at time of sale in August (4)

CV6

Research studies have found people to overstate their willingness to participate in hypothetical situations, such as this survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.

Q11.6 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You just purchased a lot of 150 feeder steers weighing approximately 800 lbs each for March placement with an expectation of August finish/sale. The steers were sourced from a single known ranch for a premium of $ 0/cwt over cattle purchased at an auction from unknown sources. The August CME live cattle futures contract is trading at $ 0/cwt (CME contract is for 40,000lb of live cattle). How many head would you place under each of the following output pricing strategies?

______ A futures hedge with an expected local August basis of $ 0 /cwt. (1)

______ A forward contract (with typical specifications for your area) with a basis of $ 0 /cwt tied to the August futures contract. (2)

______ Other output pricing strategy (e.g., options, Livestock Risk Protection, formula pricing, etc.) (3)

______ I would accept the local cash price at time of sale in August (4)

CV7

Research studies have found people to overstate their willingness to participate in hypothetical situations, such as this survey. It is important that you make your selection as if you were actually facing these choices in operation of your feed yard.

Q11.7 Single source feeder calves, originating from a single ranch of origin, are generally considered less risky than calves with unknown histories due to their better performance and lower morbidity at the feedlot. Suppose it is February 15th. You just purchased a lot of 150 feeder steers weighing approximately 800 lbs each for March placement with an expectation of August finish/sale. The steers were sourced from a single known ranch for a premium of $ 0/cwt over cattle purchased at an auction from unknown sources. The August CME live cattle futures contract is trading at $ 0 /cwt (CME contract is for 40,000lb of live cattle). How many head would you place under each of the following output pricing strategies?

______ A futures hedge where the expected local August basis has a ${e://Field/Percent1}% chance of being less (weaker) than $ 0, and a 100% chance of being greater (stronger) than $ 0. (1)

______ A forward contract (with typical specifications for your area) with a basis of $ 0 /cwt tied to the August futures contract. (2)

______ Other output pricing strategy (e.g., options, Livestock Risk Protection, formula pricing, etc.) (3)

______ I would accept the local cash price at time of sale in August (4)

Q13 Please rate your level of agreement or disagreement with the following statements.

	Strongly Disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither agree nor disagree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
I usually like “playing it safe” (for instance, “locking in a price”) instead of taking risks for market prices for fed cattle. (1)							
When selling/marketing fed cattle, I prefer financial certainty to financial uncertainty. (2)							
When selling/marketing fed cattle, I am willing to take higher risks in order to realize higher average returns. (3)							
I like taking financial risks with my feeding operation. (4)							
I accept more risk in my feedlot than other feedlot operators. (5)							
With respect to the conduct of business, I dislike risk. (6)							

Q14 What was the average cost of gain for feeder cattle placed over the past 12 months on your operation?

- Less than $60/cwt (1)
- $60 to $64.99/cwt (2)
- $65 to $69.99/cwt (3)
- $70 to $74.99/cwt (4)
- $75 to $79.99/cwt (5)
- $80 to $84.99/cwt (6)
- $85/cwt to $89.99/cwt (7)
- Over $90.00/cwt (8)

Q15 How important are the following traits for the feeder cattle you buy?

	Extremely important (13)	Very important (14)	Moderately important (15)	Slightly important (16)	Not at all important (17)
Weaned at least 30 days (1)					
Weaned at least 45 days (2)					
Vaccination history (3)					
Third-party health verified (4)					
Animal care/handling practices (5)					
Castrated (6)					
Dehorned (7)					
Implanted (8)					
Specific sire/genetic information (9)					
Breed background information (10)					
Reputation of seller (11)					
Weight (12)					
Frame (13)					
Condition (14)					
Number of head in a lot (15)					
Uniformity of head in a lot (16)					
Sex of animal (17)					
Age and source verified (18)					
Naturally raised (19)					
Organically raised (20)					
Non-hormone treated (21)					

Q16 In what state does your operation primarily feed cattle?

- Alabama (1)
- Alaska (2)
- Arizona (3)
- Arkansas (4)
- California (5)
- Colorado (6)
- Connecticut (7)
- Delaware (8)
- Florida (9)
- Georgia (10)
- Hawaii (11)
- Idaho (12)
- Illinois (13)
- Indiana (14)
- Iowa (15)
- Kansas (16)
- Kentucky (17)
- Louisiana (18)
- Maine (19)
- Maryland (20)
- Massachusetts (21)
- Michigan (22)
- Minnesota (23)
- Mississippi (24)
- Missouri (25)
- Montana (26)
- Nebraska (27)
- Nevada (28)
- New Hampshire (29)
- New Jersey (30)
- New Mexico (31)
- New York (32)
- North Carolina (33)
- North Dakota (34)
- Ohio (35)
- Oklahoma (36)
- Oregon (37)
- Pennsylvania (38)
- Rhode Island (39)
- South Carolina (40)
- South Dakota (41)
- Tennessee (42)
- Texas (43)
- Utah (44)
- Vermont (45)
- Virginia (46)
- Washington (47)
- West Virginia (48)
- Wisconsin (49)
- Wyoming (50)

Q17 For the feeding operation I am the:

- Owner and manager (1)
- Owner (2)
- Manager (3)
- Other (please specify): (4) ____________________

Q18 I am ________ years old.

Q19 The best description of my educational background is:

- o Did not obtain high school diploma (1)
- o High school graduate (2)
- o Some college (3)
- o Technical training (Certification or Associates Degree) (4)
- o Bachelor's (B.S. or B.A.) College Degree (5)
- o Graduate or Professional Degree (M.S., Ph.D., D.V.M., Law School) (6)
- o Other (please describe): (7) ____________________

Q20 What percentage of the cattle fed on your operation in the last 12 months were (should sum to 100%):

______ Commercial beef cattle (1)

______ Dairy cattle (2)

______ Beef and dairy cross cattle (3)

______ Other (please describe): (4)

Q21 How many fed cattle were sold on your operation in the last 12 months?

- o Less than 1,000 head (1)
- o 1,000 to 1,999 head (9)
- o 2,000 to 3,999 head (2)
- o 4,000 to 7,999 head (3)
- o 8,000 to 15,999 head (4)
- o 16,000 to 23,999 head (5)
- o 24,000 to 31,999 head (6)
- o 32,000 to 49,999 head (7)
- o More than 50,000 head (8)

Q22 Of the animals placed on feed in the last 12 months, what percentage of calves placed did your operation own (as opposed to someone outside the operation retaining ownership)?

- 0% (1)
- 1 to 20% (2)
- 21 to 40% (3)
- 41 to 60% (4)
- 61 to 80% (5)
- 81 to 100% (6)

Q23 What is the one-time capacity of your feedlot?

- Less than 1,000 head (1)
- 1,000 to 1,999 head (9)
- 2,000 to 3,999 head (2)
- 4,000 to 7,999 head (3)
- 8,000 to 15,999 head (4)
- 16,000 to 23,999 head (5)
- 24,000 to 31,999 head (6)
- 32,000 to 49,999 head (7)
- More than 50,000 head (8)

Q24 How easy were the survey questions to understand?

- Extremely easy (20)
- Somewhat easy (21)
- Neither easy nor difficult (22)
- Somewhat difficult (23)
- Extremely difficult (24)

Q25 Thank you for your participation! Please leave any additional comments here:

Appendix B - ϕ_1 and ϕ_2 descriptive statistics and plots

Table B.1 Ricardian rent theory ϕ_1 and ϕ_2 descriptive statistics

	Full period 12/95 to 12/16		Regime 1 12/95 to 10/06		Regime 2 11/06 to 04/11		Regime 3 05/11 to 12/16	
	RRT ϕ_1	RRT ϕ_2	RRT ϕ_1	RRT ϕ_2	RRT ϕ_1	RRT ϕ_2	RRT ϕ_1	RRT ϕ_2
Mean	1.59	-7.16	1.56	-6.93	1.61	-7.41	1.63	-7.41
Median	1.60	-7.18	1.56	-6.94	1.62	-7.34	1.63	-7.45
Standard Deviation	0.06	0.59	0.05	0.56	0.04	0.51	0.04	0.51
Kurtosis	-0.60	-0.43	-0.91	-0.39	-0.80	-0.72	-0.43	-0.36
Skewness	-0.17	0.17	0.10	0.04	0.27	-0.28	-0.13	0.53
Range	0.27	2.96	0.23	2.76	0.15	2.16	0.19	1.99
Minimum	1.46	-8.54	1.46	-8.33	1.55	-8.54	1.54	-8.32
Maximum	1.72	-5.58	1.68	-5.58	1.70	-6.38	1.72	-6.33
Count	253	253	131	131	54	54	68	68

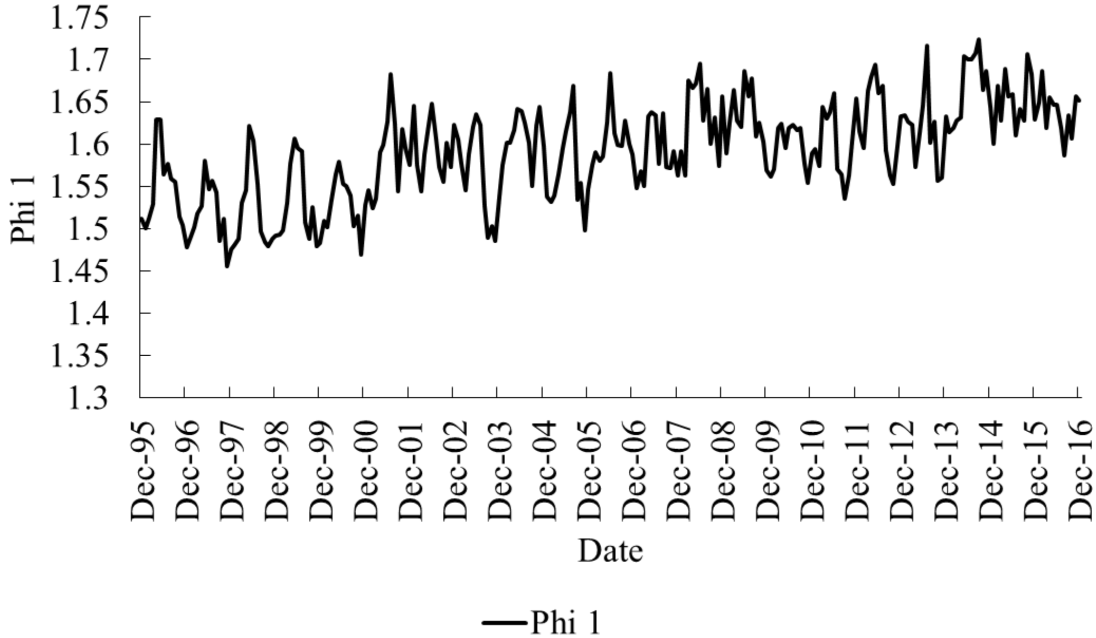

Figure B.1 Monthly $\boldsymbol{\phi_1}$ hypothesized by Ricardian rent theory using data from *Focus on Feedlots* from December 1995 to December 2016

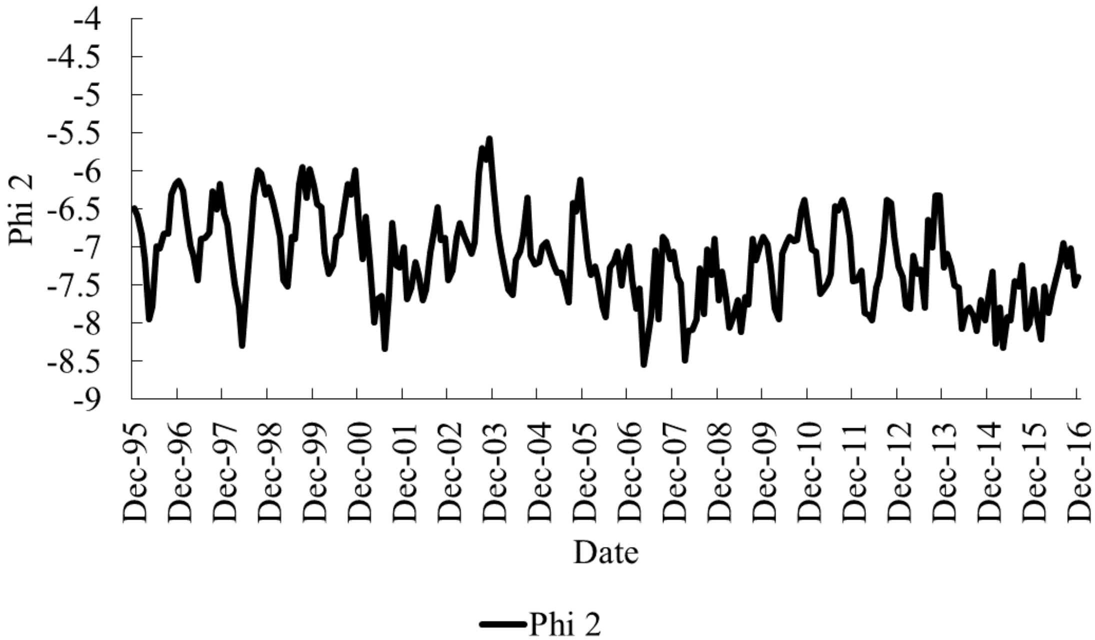

Figure B.2 Monthly $\boldsymbol{\phi_2}$ hypothesized by Ricardian rent theory using data from *Focus on Feedlots* from December 1995 to December 2016

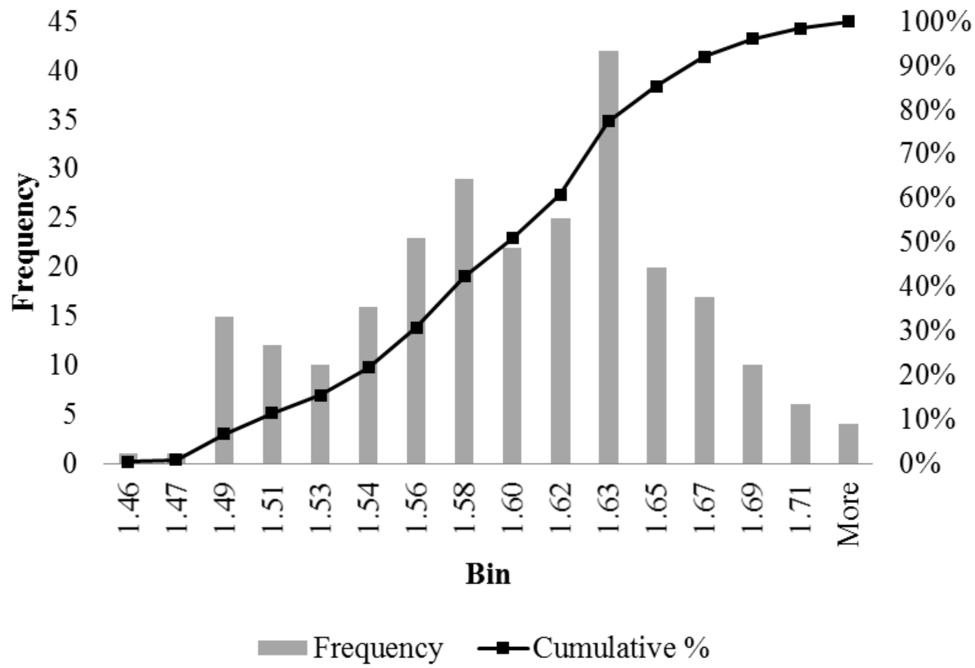

Figure B.3 ϕ_1 histogram

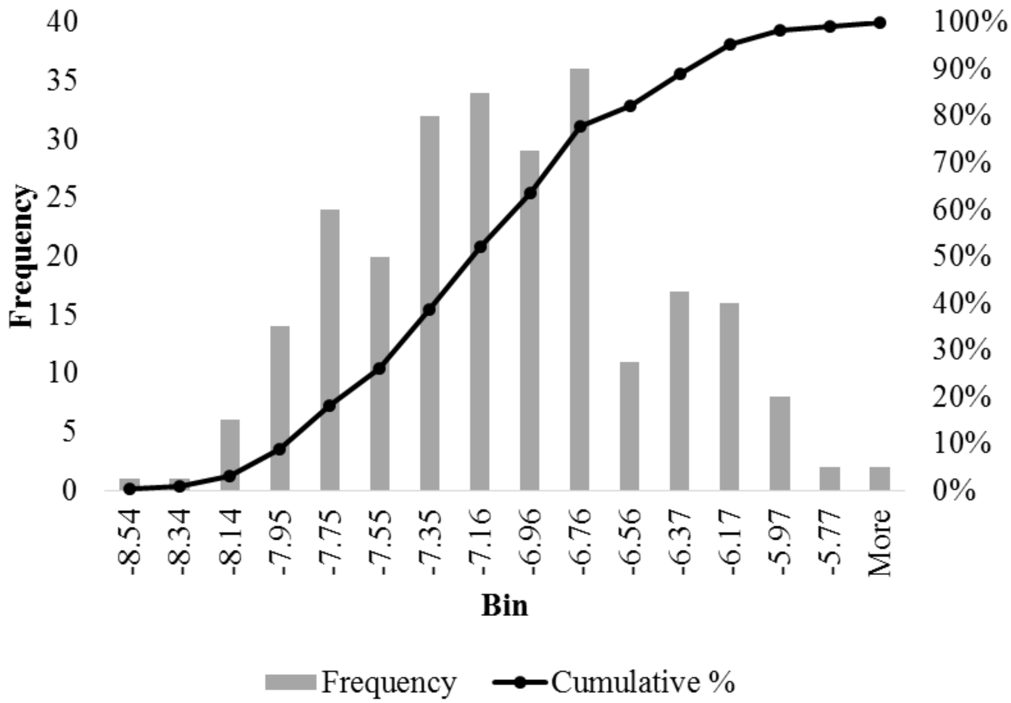

Figure B.4 ϕ_2 histogram

Appendix C - Data sources and stationarity tests

Table C.1 Data sources

Variable	Description	Source
Q_t^L	Live cattle quantity, federally inspected steers and heifer harvested, thousands of lbs	LMIC, catsltr file, sheet C, using the sum of FI Steer Slaughter and Heifer Slaughter as number of head times FI weight, updated 12-5-16
Q_t^F	Feeder cattle quantity (feeder cattle placements), thousands of lbs	LMIC, COFWTS file, sheet B, using total calves placed in US (column AU) times the midpoint of each weight category, updated 12-5-16
P_t^L	Demand and supply prices of fed steers, live basis, 5-market average, total all grades, \$/cwt	LMIC, Mo180-5MktAvgFats.xls, sheet LV steers, column V "average", updated 12-6-16
Fat futures	CME live cattle futures prices, \$/cwt, used in creating expected price	LMIC, fatfutures.xlsx, updated 12-6-16
P_t^F	Kansas feeder steers, weighted price, \$/cwt	LMIC, wkancatl.xlsx, sheet D, using feeder steer prices for 500-600, 600-700, 700-800, 800-900 weights. To create weighted price, multiple by percent of placements in that weight category from KS that month from COF report (COFWTS.xlsx) and sum up, updated 5-30-17
Feeder futures	CME feeder cattle futures, \$/cwt, used in creating expected feeder cattle price	LMIC, feederfutures.xlsx, updated 1-14-17
P_t^W	Slaughter cow price, boning utility, Sioux Falls, \$/cwt	LMIC, WklyCow-Bull.xls, sheet SF-monthly, column V (boning, 800-1200 lbs), updated 12-6-16
P_t^C	Feed corn price, \$/bu	LMIC, feedpr.xls, sheet B, column C (Corn price), updated 12-6-16
RDI_t	Quantity based retail demand index (1996 QT1=100)	
EI_t	Quantity based export demand index (1996 QT1=100)	
M_t	Food marketing cost index (1967=100)	Contact with Howard Elitzak, Agricultural Economist, Economic Research Service, U.S. Department of Agriculture, updated 1-2-17
$time_t$	Time trend	Where QT1 1997=1, QT2 1997=2, etc.

$QT2_t, QT3_t, QT4_t$	Quarter 2, 3, 4 dummy variables	
EX_t	Real broad exchange rate index	Federal Reserve Bank, https://www.federalreserve.gov/releases/h10/summary/indexbc_m.htm, Price-adjusted Broad Dollar Index
CPI	Consumer price index	Bureau of labor statistics, Go to http://www.bls.gov/cpi/#tables. Under database, Click on top picks (it is a star) under the first row. click on U.S. All items, 1982-84=100 - CUUR0000SA0 which is top box, Downloaded 12-5-16.
Per capita US beef consumption	Per capita U.S. beef consumption used in RDI	LMIC, sumq.xls, sheet A, column M, retail consumption, updated 1-8-17
Nominal choice beef price	Nominal choice beef price used in RDI, $/cwt	LMIC, Retmt.xls, sheet C, Column C (new series beef MO), updated 1-8-17
Export quantity	Total beef and veal+ variety meats beef, pounds	LMIC, file EXPVALUE.xls, sheet B, sum of columns B and C, in metric tons so multiply by 2204.62 to get pounds, updated 1-9-17
Export value	Total value of beef and veal + value of variety meats beef, thousands of $	LMIC, file EXPVALUE.xls, sheet B, sum of columns I and J, updated 1-9-17
CSS_t	Index of Consumer Sentiment (QT1 1960=100)	http://www.sca.isr.umich.edu/tables.html, quarterly excel, updated 1-18-17
PMDI- used to create drought dummies	Modified Palmer Drought Index (PMDI), Positive values of the indices indicate wet conditions and negative values dry conditions, with more extreme values indicating more extreme anomalies	https://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/indices/palmer/div#select-form, click on https://www.ncdc.noaa.gov/monitoring-content/temp-and-precip/drought/nadm/palmer/pmdi-us-div.txt, averaged all the divisions for KS each month US-DIV01401 to US-DIV01409, updated 1-18-17
$AustCube_t$	Australian cube roll price from Australia to Japan, cents/lb	MLA market information, Australian beef export prices to Japan, Quarterly, USc/lb, cube roll chilled

Table C.2 Dickey Fuller unit root tests

	No Intercept		Intercept		Trend			No Intercept		Intercept		Trend			
Variable Name	**Lag length**	**Test Statistic**	**Lag length**	**Test Statistic**	**Lag length**	**Test Statistic**	**NOSA Conclusion**	**Lag length**	**Test Statistic**	**Lag length**	**Test Statistic**	**Lag length**	**Test Statistic**	**SA Conclusion**	**Overall Conclusion**
Q_t^L	3	0.00	4	-2.28	4	-3.43	Reject Unit Root	0	-3.10	0	-3.36	0	-3.93	Reject Unit Root	Reject Unit Root
Q_t^F	3	-0.30	3	-1.31	3	-3.46	Reject Unit Root	3	-1.07	3	-1.39	1	-9.30	Reject Unit Root	Reject Unit Root
r_t	0	0.17	0	-1.87	0	-2.71	Fail to Reject Unit Root	0	0.85	0	-1.75	0	-2.55	Fail to Reject Unit Root	Fail to Reject Unit Root
$E_t[P_{t+2}^L]$	0	0.25	0	-1.71	0	-2.08	Fail to Reject Unit Root	0	-3.89	0	-1.45	0	-1.65	Reject Unit Root	Reject Unit Root
P_t^F	0	0.60	0	-2.07	0	-2.23	Fail to Reject Unit Root	0	-1.10	0	-1.96	0	-2.05	Fail to Reject Unit Root	Fail to Reject Unit Root
$E_t[P_{t+4}^F]$	0	0.67	0	-1.93	0	-1.59	Fail to Reject Unit Root	0	0.19	0	-1.90	1	-2.47	Fail to Reject Unit Root	Fail to Reject Unit Root
P_t^W	0	-0.09	4	-3.11	4	-4.00	Reject Unit Root	0	4.04	0	-1.70	0	-1.64	Fail to Reject Unit Root	Reject Unit Root
r_t	0	-1.35	0	-1.69	1	-2.94	Fail to Reject Unit Root	0	-0.27	0	-1.56	1	-2.81	Fail to Reject Unit Root	Fail to Reject Unit Root
M_t	0	-0.91	0	-1.82	0	-1.79	Fail to Reject Unit Root	0	-0.85	0	-1.32	0	-1.27	Fail to Reject Unit Root	Fail to Reject Unit Root
RDI_t	3	-0.47	0	-3.94	0	-4.35	Reject Unit Root	0	-1.54	0	-3.20	0	-3.33	Reject Unit Root	Reject Unit Root
EI_t	0	-0.23	0	-3.32	0	-3.43	Reject Unit Root	0	-3.74	0	-3.01	0	-3.13	Reject Unit Root	Reject Unit Root
EX_t	0	0.72	0	-1.09	0	-1.21	Fail to Reject Unit Root	0	0.97	0	-1.07	0	-1.20	Fail to Reject Unit Root	Fail to Reject Unit Root
CSS_t	0	-0.01	0	-1.74	0	-1.84	Fail to Reject Unit Root	0	1.61	0	-1.64	0	-1.71	Fail to Reject Unit Root	Fail to Reject Unit Root
$AustCube_t$	2	1.29	2	-0.96	0	-3.83	Reject Unit Root	0	1.31	0	-1.20	0	-3.08	Fail to Reject Unit Root	Reject Unit Root
DF Critical Values		**-1.61**		**-2.58**		**-3.15**			**-1.61**		**-2.58**		**-3.15**		

Table notes: Optimal lag length selected using minimum SBC. NOSA means no seasonal dummy variables were included. SA means seasonal dummy variables were included.