OPTIMAL CONTRACTING FOR CATTLE FEEDING: AN ASSESSMENT OF CLIMATIC CONDITIONS

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Abstract

A unique approach using a biophysical growth model from the animal science literature is used to examine optimal contract cattle feeding behavior under alternative climatic conditions. The examination of incentives and outcomes in an unusually comprehensive contract parameter and behavioral space is made possible by combining simulated feedlot and carcass performance of a large set of cattle with public price and weather data. The model uniquely fits typical risk aversion levels and rationalizes existing contract types. The results show that optimal cattle feeding contract varies with climatic condition, but there is a tendency to replace cost-of-gain contracts with yardage-feed contracts as grid pricing has emerged.

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Cattle feeding contracts currently being used in the United States differ not only in terms of their intrinsic incentive structures, but also in the way they allocate risks among the cattle owners and feeders. Typical yardage-feed and yardage-feed-markup contracts assign risks associated with fluctuating feed prices and feedlot performance of the cattle entirely to the cattle owner, while the latter magnifies the feed price risk through the markup. On the other hand, the cost-of-gain contracts assign feed price and feedlot performance risks to the feeders. Interestingly, commercial cattle feeding in the Great Plains is dominated by the yardage-feed and yardage-feed-markup contracts, while the cost-of-gain contracts are common in the Midwest (Weimar and Hallam 1990).

Highly variable seasonal cattle performance and lack of economies of size of the feedlots in the Midwestern states are cited as plausible reasons for the use of cost-of-gain contracts (Loy et al. 1986, Weimar and Hallam 1990). Animal science research shows that feedlot performance of beef cattle significantly varies with precipitation, temperature, humidity, hours of sunshine, and wind speed (NRC 2000). A recent study shows that the introduction of value-based grid pricing of fed cattle decreases (increases) the tendency towards cost-of-gain (yardage-fee-plus-feed-cost) contracts in commercial cattle feeding in typical Midwestern climatic conditions (Rahman 2007). However, it is yet to examine the role of climatic conditions in the choice of cattle feeding contract forms and parameters. A major constraint for such research is that contract data are proprietary.

This article examines optimal behavior of cattle feeders in different climatic conditions when cow-calf producers make optimal choices among contract types and pricing system alternatives using a unique approach that permits analysis without proprietary contract data. The investigation is carried out in a multiple task principal-agent framework using historical input and output price data in combination with simulated feedlot and carcass performance data for a large sample of feeder cattle. A widely-accepted dynamic biophysical model for beef cattle growth is adopted from the animal science literature and employed to simulate feedlot and carcass performance outcomes of a large set of feeder cattle under actual climatic conditions of Red Oak, Iowa and Dodge City, Kansas. Respectively, these two locations represent typical Midwestern and Great Plains cattle feeding conditions. Simulated feedlot and carcass performance data are then combined with historical price series to determine the optimal cattle feeding contracts under alternative fed cattle pricing methods and risk preference scenarios. The differences in the optimal incentive schemes for cattle feeding contracts in the two locations reflect the impact of climatic conditions on feedlot performance of the cattle and feed prices.

The biophysical model has the capability of representing a much wider variety of factors that reflect animal as well as weather attributes and determine both yield and quality of beef production than allowed by typical revealed preference contract data, even when such data are available. Thus, optimal contract sensitivity can be examined with respect to a rich set of contract forms and preference structures. In general, this research represents a unique approach to investigation of the optimality of various contract forms in livestock production.

Climatic Condition and Cattle Performance

Empirical animal science research has established that feedlot performance of cattle depends crucially on environmental attributes, especially temperature, humidity, sunshine, wind speed, precipitation, and mud depth (NRC 2000). These factors influence cattle performance by influencing voluntary feed intake and required energy for maintenance in a complex manner. Cattle consume more feed to produce more heat to support a higher metabolic rate in cold weather and consume less feed in hot weather to reduce heat production (Fox and Tylutki 1998). In particular, feed intake increases (decreases) as the temperature falls below (above) 20^{o}C. Other adverse environmental conditions such as level of precipitation and mud, and wind speed accentuate the effects of ambient temperature (NRC, 2000). In order to take account of the net effect of temperature on voluntary feed intake by cattle, NRC (2000) uses current effective temperature index (*CETI*) which is computed using the current average temperature, relative humidity, wind speed, and hours of sunlight (see Appendix Table 2). Voluntary feed intake by cattle decreases with the mud depth of the feedlot (NRC, 2000).

The energy requirement for maintenance increases when effective ambient temperature increases above the upper critical temperature (*UCT*) or decreases below the lower critical temperature (*LCT*). These effects are called heat and cold stresses, respectively. During cold stress, animals loose heat to the environment and increase metabolism to produce adequate heat to maintain body temperature. Alternatively, during heat stress, an elevated body temperature results in increased tissue metabolic rate and animals need to exert extra effort to dissipate heat (NRC, 2000). Both *UCT* and *LCT* are functions of how much heat an animal produces and how much heat is lost to the environment (see Appendix Table 2). Heat production by an animal is a function of metabolizable energy intake and retained energy. On the other hand, the amount of heat loss by an animal depends on the environmental condition as well as animal specific attributes. Thus, the effects of heat or cold stress depends both on environmental and animal factors.

In cold stress, factors primarily contributing to differences in animal heat loss include surface area, internal insulation, and external insulation. Surface area is a function of shrunk body weight and internal insulation is a function of an animal's body condition score (*BCS*) (see Appendix Table 2). External insulation of an animal is provided by hair coat plus the layer of air surrounding the body. However, the effectiveness of hair as external insulation is influenced by wind, precipitation, mud, and hide thickness (NRC 2000). For *CETI*>20^{o}C, Heat stress increases the required energy for maintenance (see Appendix Table 2).

The temperature to which an animal had been previously exposed has an effect on an animal's current basal metabolic rate, and the current temperature to which an animal is exposed affects the energy required to cope with the current direct effects of cold stress or heat stress (Fox and Tylutki, 1998). In addition to adjustment for the effects of current effective temperature (*CETI*) on the maintenance energy requirement, NRC (2000) also recommends adjustment for the effects of previous ambient temperature using previous effective temperature index (*PETI*).

Weight gain by an animal from voluntarily consumed metabolizable energy and protein is a function of the net energy available for growth (*NEFG*) after accounting for maintenance requirements. Biophysical growth of beef cattle is lower (higher) in a climatic condition in which voluntary feed intake is lower (higher) and/or maintenance requirement is higher (lower). Thus, for given animal characteristics and nutrient contents of feed, beef cattle's feedlot performance (e.g., average daily gain and feed efficiency) vary with climatic condition. This study examines how the variation in animal performance due to weather alters optimal cattle feeding contracts.

Potential Moral Hazard in Contract Cattle Feeding

Current U.S. cattle feeding contracts are of three major types: cost-of-gain (or fixed-price-per-pound-of-gain), yardage-fee-plus-feed-cost, and yardage-fee-plus-feed-cost-plus-markup (Weimar and Hallam 1990; Madsen 1996). With cost-of-gain contracts, cattle owners reimburse feeders at a fixed price per pound of weight gain, sometimes on a scale that depends on live weight levels (Madsen 1996). Because feed costs are borne entirely by cattle feeders, the incentive for reducing feed cost is very high, as also is incentive for higher and faster weight gain.

Under yardage-fee-plus-feed-cost contracts (hereafter yardage-feed contracts), payment to the feeder is based on a fixed fee per animal per day (e.g., $0.25/animal/day) plus reimbursement for the amount of feed consumed. Other costs such as veterinary and labor are included in the yardage fee, possibly with a clause for excess death loss. Thus, feed price and feedlot performance risks are assigned to the cattle owner, and feeders have no incentive to save on feed costs. On the other hand, a positive yardage fee adds an incentive for the feeder to keep animals in the feedlot longer than may be necessary.

The yardage-fee-plus-feed-cost-plus-markup contract (hereafter yardage-feed-markup contract) is a variant of the yardage-feed contract. It involves reimbursement of feed cost and a smaller yardage fee (e.g., $0.05 per animal per day), but includes a percentage markup, or a fixed amount per ton of feed, above actual feed costs (Weimar and Hallam 1990). Compared to a yardage-feed contract, this provides an incentive to feed at a higher rate and lowers the incentive for keeping animals in the feed lot.

Consistent feeding of a balanced diet with appropriate nutrient content and use of growth promoting implants (hereafter, implants) are the two most important cattle feeder choices that affect not only average daily gain and feed efficiency but also beef yield and quality. Animal science research shows that a high-grain (high-cost) ration during finishing increases the rate of gain and improves beef quality (Tedeschi, Fox, and Guiroy 2004; NRC 2000; Duckett et al. 1996). On the other hand, implants increase the rate of gain, feed efficiency, and yield but have a negative impact on quality (Tedeschi, Fox, and Guiroy 2004; Field and Taylor 2002; Duckett et al. 1996). Feedlot performance and carcass composition thus depend crucially on the feeder's ration and implant strategy given the biological characteristics of an animal and weather condition.

Feeders' choice of ration-implant strategy, in turn, alters cattle owners' net returns under different fed cattle pricing methods. Current U.S. fed cattle pricing can be divided into two broad categories: traditional lot-average pricing and modern value-based pricing. Lot-average pricing includes live-weight and dressed-weight (also known as "in-the-beef") pricing methods. Under live-weight pricing cattle are sold in lots on the basis of actual live weight and estimated lot-average beef yield and quality. All cattle in a lot receive the same price per pound of live weight regardless of differences in yield and quality. This emphasizes incentives for live weight gain rather than incremental yield and quality. Under, dressed-weight pricing, all carcasses in a lot receive the same average price per pound of dressed weight with an estimated average beef quality. Dressed-weight pricing compensates incremental yield. However, it does not offer clear incentives for quality.

Modern value-based pricing refers to various grid pricing schemes. Grid pricing rewards yield and quality as well as weight incrementally by animal Under grid pricing, each individual carcass is priced on the basis of actual dressed weight with additional premiums and discounts for various carcass traits. Most grids consist of a base price with specified premiums and discounts for incremental quality and yield grades, weight groups, and carcass and cattle types (Ward, Feuz, and Schroeder 2000).

Thus, incentive structures differ by fed cattle pricing methods and cattle feeding contracts. If incentives of cattle owners and feeders are not aligned, economic efficiency is unlikely. Under lot-average pricing, owners' and feeders' incentives can be aligned with the existing cattle feeding contracts as the rate of live weight gain and feed efficiency are of concern. Effects of climatic condition on cattle performance may be internalized with the choice of contract forms. However, under grid pricing, moral hazard is likely as none of the traditional contract types provide direct incentives for incremental beef quality.

Contracts contingent on ex post measures of yield and beef quality are not observed in reality. Typically, feeders' choice of ration-implant strategies are not observable or verifiable to cattle owners. Thus, contracts contingent on feeders' actions cannot be enforced, which raises a moral hazard problem. First-best outcomes are possible only if the owner's and feeder's contribution to actual yield and quality can be measured and rewarded separately. However, the actual yield and quality of the carcass can be measured only after slaughter. Thus, the feeder's contribution through the ration-implant choice cannot be distinguished from breeder's contribution through genetic traits. The only practical measurable and verifiable attributes are feed cost, live weight gain by each animal, and the length of time the animal stays in the feedlot (hereafter days-on-feed). These are the enforceable variables included in cattle feeding contracts in current use.

Multitask principal-agent analysis (Holmstrom and Milgrom 1991) suggests that if feeders' cost saving and beef quality improving activities are inseparable and substitutes, and the cost saving activity is verifiable but the quality improving activity is not, then a contract with a low incentive for cost saving (e.g., a yardage-feed contract) may be optimal if beef quality is a concern. This study determines the extent to which this is true under both traditional live- and dressed-weight pricing versus grid pricing under alternative climatic conditions.

The Empirical Framework

Suppose a cattle owner contracts the feeding of N cattle with a feeder having a one-time capacity to feed n cattle ($n \geq N$). Suppose the cattle feeding contract is represented by a triple, (α, β, γ), where α is the yardage fee per animal per day, β is the payment per pound of gain, and γ is the owner's share of feed cost. The feeder's net profit from feeding animal i is thus

(1) $$\pi_i = [\alpha + \beta g_i + (\gamma - 1) g_i f_i r - c] d_i \text{ for } i = 1.,,,.n,$$

where g_i is average daily weight gain in pounds, f_i is feed per pound of gain (feed efficiency), r is the price per pound of feed, c is non-feed cost per animal per day, and d_i is days on feed. Equation (1) represents a cost-of-gain contract if $\alpha = \gamma = 0,$ a yardage-feed contract if $\beta = 0$ and $\gamma = 1,$ and a yardage-feed-markup contract if $\beta = 0$ and $\gamma > 1.$

Beef cattle nutrition research shows that, for a given target weight gain, d_i and f_i

decrease with the grain (or energy) content of feed and implant potency, and that grain content of feed and implant potency are substitutes (NRC 2000). Feed cost is increasing in grain content, and implant cost is increasing in potency. Trivially, the incentive for feed cost saving is decreasing in the owner's share (γ). The minimum payment per pound of gain necessary to induce a feeder to feed the cattle, β, is highest when $\alpha = \gamma = 0$, and lower as α and γ are higher. Thus, the feeder's incentive for cost saving (i.e., the power of the incentive scheme) increases with β and decreases with α and γ.

The cattle owner's profit (incremental profit compared to selling feeder calves) from contracting a feedlot to feed and sell each fed animal *i* on a grid that uses the cash live-weight price, p_1, as the base price can be expressed as

(2) $$\Pi_i = P_1(W_i - w_i) - (\alpha + \beta g_i + \gamma g_i f_i r)d_i - p_0 w_i, \quad i = 1, \ldots, N,$$

where $P_1 = p_1 + (\theta_i - \bar{\theta})p_1 + (p_y \Delta y + p_q \Delta q)\theta_i$ is the grid price, θ_i and $\bar{\theta}$ are actual and expected dressing percentages, Δy and Δq are incremental yield and quality grades with respective premiums p_y and p_q for incremental yield and quality grades, W_i is the final shrunk body weight of the fed animal, w_i is the initial shrunk body weight of the feeder calf, and p_0 is the price of feeder calves (all cattle prices in cents per pound of live weight). Equation (2) nests dressed-weight pricing (where $p_y = 0$ and $p_q = 0$) and live-weight pricing (where additionally $\theta_i = \bar{\theta}$) within the grid pricing framework.

Both the cattle owner's choice of payment scheme and the feeder's ration-implant choice for a given payment scheme depend on risk preferences. Both are assumed to follow constant absolute risk aversion where outcomes with individual animals are random draws as described below. Because profits are spread over many cattle, a Central Limit result with bounded mean and variance motivates an assumption of normality of average profit per animal, $\pi = (1/n)\sum_{i=1}^{n}\pi_i$ and $\Pi = (1/N)\sum_{i=1}^{N}\Pi_i$, for both feeder and owner. Thus, respective expected utilities are represented as

(3) $$E(U(\pi)) = -E[\exp(-n\varphi\pi)]$$

(4) $$E(V(\Pi)) = -E[\exp(-N\psi\Pi)]$$

where U and V are utility functions with respective absolute risk aversion levels φ and ψ.

For given target weight gain, nutrient content of feed, and implant potency, d_i and f_i varies with weather condition, thus altering the feeder's and owner's profits and expected utility. However, the effects of weather condition on the optimal choice of α, β, and γ are ambiguous and needs to be determined empirically. While this model could be empiricized with ranch-to-rail data and revenues and costs for cattle fed under various contract arrangements, such data are proprietary and difficult to acquire, especially as a random sample. Further, even when compiled by survey methods, data typically lack the wide range of contract parameters and feeder actions that can affect carcass yield and quality, which are essential in identifying the motivation and potential for contracting. To overcome these obstacles, this study uses a dynamic bio-physical model for beef cattle growth developed by animal scientists (Tedeschi, Fox, and Guiroy 2004; NRC 2000), which permits consideration of a wide array of feeder behavior and prospective incentives of alternative contract types.

A Simulation Model of Biophysical Growth of Beef Cattle

Lofgreen and Garrett (1968) published a simple beef cattle growth simulation model to compute feed requirements for a given live weight gain given energy contents of feeds.

Fox and Black (1977) altered their model to predict performance when voluntary feed intake by individual animals is known. Fox and Black (1984) generalized the model to account for individual animal characteristics, implants, and feed additives. Successive modifications have improved accuracy under alternative management practices and circumstances (Fox, Sniffen, and O'Connor 1988; Fox et al. 1992; Tylutki, Fox, and Anrique 1994; Perry and Fox 1997). Upon critical evaluation with experimental data, successive Subcommittees on Beef Cattle Nutrition of the National Research Council (hereafter NRC) have fully accepted the revised model (see NRC 2000). Tedeschi, Fox, and Guiroy (2004) have further extended the model with daily time steps.

Combining the day-step model with other complementary sub-models published in various issues of the *Journal of Animal Science*, Rahman (2007) constructs an integrated dynamic growth simulation model that is capable of simultaneously predicting voluntary feed intake, resulting weight gain, and carcass composition for a wide range of ration-implant strategies. Major independent variables are biological characteristics of individual animal's (e.g., age, sex, initial shrunk body weight, breed, frame and body condition scores, hide thickness, and hair depth), energy and protein contents of feed, and the condition of the feeding environment (e.g., temperature, humidity, hours of sunlight, and wind speed). Implementation of the model requires either a given final shrunk body weight or a given length of feeding period. The complete model is available in an unpublished appendix.

The growth model is used to simulate feeding outcomes of 1,147 steers actually fed under the Tri-County Steer Carcass Futurity Program (hereafter TCSCF) in Iowa. The steers were placed in feedlots located in Red Oak, Iowa, during October-December of

1995-98 and slaughtered during April-June of the following year. The data contains individual cow and calf information provided by cow-calf producers, feedlot performance recorded by the feeders, and carcass data reported by the packers. After careful review, 22 observations were omitted because the daily gain or feed efficiency was both implausible and far out of range of the simulation model even with the most aggressive ration and implant strategy. Table 2 presents summary statistics of retained observations.

Six finishing rations are considered using four ingredients: corn grain, corn silage, soybean meal, and alfalfa hay. While the model can consider any practical ration, the feed choice is important only as it affects the energy and nutrient content of the ration. We choose a small number of alternatives representing the typical range of cattle feeding practices to facilitate reporting of the research. Composition of the rations and associated nutritional characteristics following the NRC (2000) are presented in table 3.

Following guidelines of Field and Taylor (2002) and Duckett et al. (1996), any implants are assumed to occur at the time of placement on the finishing ration and again after 90 days. Three alternative implant strategies are considered: no implant, moderate implant (estrogen only), and aggressive implant (estrogen plus Trenbolone Acetate). Thus, 18 (6×3) ration-implant strategies are considered.

Outcomes are simulated using actual environmental conditions during the feeding period in Red Oak, Iowa, and Dodge City, Kansas. Daily averages of temperature, relative humidity, hours of sunshine, and wind speed in these locations were obtained from National Oceanic and Atmospheric Administration (NOAA) and WeatherBank Incorporation, a meteorological consulting company. Monthly averages and standard deviations of these weather variables for the two locations are reported in table 4. As highlighted in table 4, monthly average temperature, wind speed, and hours of sunshine in Dodge City, Kansas are higher and relative humidity is lower than the averages in Red Oak, Iowa.

Simulation Results

Using final shrunk body weight as the terminal feeding point for each animal, the biophysical growth model is used to simulate the carcass performance of each of the 1,125 steers day-by-day for each of the 18 ration-implant strategies (see the unpublished appendix for details). To verify the growth model, a comparison of simulated outcomes with actual outcomes reported by the TCSCF showed that the model approximates with acceptable accuracy actual days on feed (for given final shrunk body weight), final body weight (for given days on feed), carcass weight, and quality grade (see Rahman 2007). For yield grade, the model predicts qualitative variation but understates quantitative variation (Rahman, 2007; Tedeschi, Fox, and Guiroy 2004), which is sufficient for determining optimal contract structure aside from biasing the optimal premium incentive for yield grade under grid pricing.

A summary of simulated outcomes for selected variables under the 18 ration-implant strategies is presented in table 5. The results indicate that for a target weight gain, days on feed and feed efficiency decrease with the grain content of the ration and potency of the implant. Yield grade increases and quality grade decreases with empty body fat percentage (not shown), which in turn increases with grain content of feed and decreases with more aggressive implants. Thus, yield (quality) grade increases (decreases) with grain content and decreases (increases) with implant potency. However, the grain effect is small (about 0.21-0.31 percent for a 10 percent substitution of silage for grain) but substantial for a change in implant strategy (4.9 and 5.1 percent from no to moderate and from moderate to aggressive, respectively).

The simulation results thus imply that grain content and implant potency affect days on feed and feed efficiency in the same direction, but have opposite effects on beef quality. The substitution effect has profound implications for the incentive structure of optimal cattle feeding contracts, especially if quality is not measurable or verifiable until after slaughter.

As highlighted in table 5, climatic condition affects feedlot performance only leaving carcass yield and quality the same. Compared to feedlot performance in Red Oak, Iowa, days required to reach a target weight gain is higher while average daily gain and feed required per pound of weight gain are lower in Dodge City, Kansas.

Price Data

The feedlot and carcass performance data generated by the simulation model are used in combination with price data, contract parameter values, and risk aversion coefficients to calculate owner’s and feeder’s expected profits and utilities following (1)-(4). For this purpose, January 1996-December 1999 five-area (Texas/Oklahoma, Kansas, Nebraska, Colorado, Iowa/So. Minnesota) weekly weighted average live- and dressed-weight prices for fed cattle, weekly average prices of feeder cattle of different weight groups and frame sizes, national weekly average yield and quality grade premiums and discounts paid in various grids, weekly average prices for corn in Iowa and Kansas during 1996-99, weekly average prices for soybean meal in Decatur IL, and weekly average prices for alfalfa hay in

Kansas were obtained from the U.S. Agricultural Marketing Service (AMS). The latter two are used in place of widely quoted prices in Iowa. Following the guidelines of the Iowa State University Extension Service, the price per ton of usable silage is determined as 9 times the per bushel corn price, with adjustment to 34% dry matter content for use in the growth model (Edwards, 2005).

Following Schroeder et al. (2003), base grid prices are calculated from live-weight prices with adjustment to an estimated dressing percentage (62.30%) plus $1.00 per hundred pounds of carcass. The estimate of the dressing percentage is obtained by regressing live-weight prices on dressed-weight prices without an intercept term. The costs of individual feeder animals are calculated from the prices for different weight groups and frame sizes using prices on the particular week of delivery of each feeder.

So that results apply to typical cattle feeding conditions, cattle prices and feed costs are simulated using 100,000 observations drawn randomly from a multivariate distribution estimated using a Gaussian kernel function. Non-feed costs (e.g., labor, utility, and interest on feed) per animal per day are obtained from historical profitability reports of three Iowa feedlots (Cody Feedlot, CRI Feeders, and Silver Creek Feeders). Prices for single doses of a widely used moderate implant (Synovex S) and high-potency implant (Synovex Plus) were obtained from Duckett et al. (1996), which are the same as quoted by www.CattleStore.com in August 2006. These costs are treated as nonrandom.

Feasible Contract Parameter Space

Because of minor nonconcavities in the simulation model, we determine optimal choices of both owner and feeder over all practical combinations of (α, β, γ) with a grid search of

0.01 accuracy. Imposing zero lower parameter limits and individual rationality with zero reservation incomes (revenues for both owner and feeder must be at least equal to their shares of feed cost), we consider all remaining combinations (α, β, γ). If the owner transfers all revenue from feeding (including sale of fed animals minus cost of feeder animals) to the feeder, then the owner's and feeder's participation constraints imply

$$(5) \qquad g_i f_i r + c \leq \alpha + \beta \cdot g_i + \gamma g_i f_i r \leq [P_1(W_i + w_i) - p_0 w_i] / d_i,$$

which implies maximum possible values $\alpha \leq 0.49, \beta \leq 0.47, \text{and}\, \gamma \leq 1.45.$ We call this the unrestricted parameter space.

To examine whether contract forms in current use can be explained by the model, a restricted parameter space is also considered where additionally either $\gamma = 0$ (the case of a cost-of-gain contract if $\alpha = 0)$ or $\beta = 0$ and $\gamma \geq 1$ (the case of a yardage-feed contract if $\gamma = 1$ or a yardage-feed-markup contract if $\gamma > 1$).

Risk Aversion Coefficients for the Owner and Feeder

Because estimates of relative risk aversion generally vary less than estimates of absolute risk aversion, the coefficients of constant absolute risk aversion are chosen to match plausible values of relative risk aversion. Saha, Shumway, and Talpaz (1994) report a brief survey of estimates of relative risk aversion that range from 0 to 18.8 with a median roughly near 2. A survey of cattle feeders and cow-calf producers shows that feedlot operations have capacities from 55 to 89,000 animals, averaging about 5,000, and cow-calf operations varies from 10 to 4,500 cattle, averaging about 500 animals (Feuz and Umberger, 2001). Mark, Schroeder, and Jones (2000) report that cattle feeders' averaged $15 profit per animal during 1980-1997, while Marsh and Feuz (2002) reported average returns to cow-calf producers of $93 per animal during 1980-96.

The possible range of feeder and owner constant absolute risk aversion are calibrated accordingly following $\hat{\varphi} = n\varphi\pi$ and $\hat{\psi} = N\psi\Pi$ where $\hat{\varphi}$ and $\hat{\psi}$ are respective relative risk aversion coefficients at mean profit levels. Substituting $\hat{\varphi} = \hat{\psi} =$18.8, high risk aversion is represented by φ = 0.023 for feeders and ψ = 0.020 for owners. Moderate risk aversion is represented by ψ = φ = 0.0025, which corresponds to relative risk aversion near 2, and low risk aversion is represented by ψ = φ = 0.00025, which corresponds to relative risk aversion near 0.2.

Optimal Cattle Feeding Contracts and Feeder Strategies

For each feasible combination of contract parameter values and absolute risk aversion coefficients, the mean and variance of owner and feeder profits from feeding each animal in the sample are calculated by combining simulated cattle performance data with 100,000 randomly drawn price vectors according to equations (1) and (2). The expected feeder utility per animal under each ration-implant strategy and the expected owner utility under each fed cattle pricing method are computed according to equations (3) and (4).

Searching the entire parameter space, the results find the Stackelberg equilibrium whereby the feeder chooses the optimal ration-implant strategy for each feasible (α, β, γ), and then the owner chooses the optimal incentive scheme represented by (α, β, γ) assuming the feeder maximizes utility with that incentive scheme. This procedure is repeated for live-weight, dressed-weight, and grid pricing methods with both the unrestricted and restricted parameter spaces and various levels of risk aversion.

The results for Red Oak, Iowa and Dodge City, Kansas are presented in tables 6 and 7, respectively. In general, the results show that optimal feeding contracts and strategies vary with the incentive structure depending on fed cattle pricing methods, risk aversion levels, and weather condition. Interestingly, the optimal contract coefficients and ration-implant strategies are identical under live- and dressed-weight pricing methods for each of the risk aversion scenarios. This is due to the similar incentive structures implied by the linear relationship between live and carcass weight in the growth model. Accordingly, these results are reported in a single group of columns.

Optimal Contracts in the Unrestricted Parameter Space

The unrestricted parameter optimization results of tables 6 and 7 show that the optimal β is higher and optimal values of α and γ are generally lower under traditional pricing than under grid pricing. This holds for each risk preference scenario except a few cases. The optimal α is slightly higher under traditional pricing with moderate owner risk aversion and γ is equal with high owner and feeder risk aversion in Iowa. The optimal α is higher under traditional pricing with high owner risk aversion in Kansas. Except in cases with low owner risk aversion in Iowa, which are not supported by further analysis below, these incentive differences generate the striking contrast whereby traditional pricing leads to a less costly ration (30-50 percent corn) along with an aggressive implant, whereas grid pricing induces a costly ration strategy (60-80 percent corn) but a moderate implant. These results illustrate that contract parameters have roughly opposite effects on cost saving and carcass quality. Comparing traditional and grid pricing, cost savings from low energy rations 1 and 3 is induced by a higher payment per pound of gain (β), a lower yardage fee (α), and a lower owner share of feed cost (γ), while carcass quality improvement with a moderate rather than aggressive implant is induced by opposite contract types.

Under traditional pricing, optimal unrestricted contract parameters are remarkably insensitive to risk preferences of both owner and feeder except in one case for Iowa, where the owner is risk neutral and the feeder is highly risk averse. With less risk aversion, the owner is willing to share more of the feed cost, while higher feeder risk aversion results in a greater response in ration selection to the feed cost share. Some of this tendency applies when the owner has low risk aversion and the feeder has high risk aversion, while some of the opposite effect is observed in the case where risk preferences are reversed.

Under grid pricing, higher owner risk aversion tends toward an incentive scheme with a higher yardage fee, higher incentive for gain, and less owner-sharing of feed cost. With less owner-share of feed cost, the feeder is induced to cut feed costs by selecting a lower energy ration. But interestingly, the highest energy ration (80 percent corn) is induced at a moderate level of owner risk aversion with either no or high feeder risk aversion in Iowa. Slight nonconcavities in the growth model may account for some of this peculiarity. But the major increase in gain incentive in moving from low to moderate owner risk aversion as β almost triples from 0.03 to 0.08 may explain the feeder's choice of a costly ration.

Optimal Contracts in the Restricted (Traditional) Parameter Space

The lower parts of tables 6 and 7 consider the restricted parameter space (traditional contract types). Remarkably, with traditional contract types the owner's optimal incentive scheme does not depend on feeder risk aversion except one case in Kansas moderate owner risk aversion and high feeder risk aversion. Unless owner risk aversion is moderate to high, the optimal contract is a yardage-feed-markup contract $(\beta = 0, \gamma > 1)$. Interestingly, the owner offers exactly the same contract under both traditional and grid pricing, which induces the feeder to choose the same high-energy-moderate-implant ration (80 percent corn). This outcome does not appear to match reality given the predominant use of aggressive implants. Thus, we conclude that typical owners have at least moderate risk aversion.

Considering moderate risk aversion by the owner in Iowa, the owner chooses a cost-of-gain contract $(\alpha = \gamma = 0)$ under traditional pricing, and a yardage-feed contract $(\beta = 0, \gamma = 1)$ under grid pricing. The case with high owner risk aversion is similar although the result under grid pricing is not quite in the form of a yardage-feed contract (γ is less than 1). In the case of moderate risk aversion by the owner in Kansas, the owner chooses a cost-of-gain contract $(\alpha = \gamma = 0)$ under traditional pricing unless the feeder has high risk aversion, and a yardage and feed cost sharing contract (γ is less than 1) under grid pricing. With moderate owner risk aversion and high feeder risk aversion, optimal incentive schemes are the same under traditional and grid pricing. The case with high owner risk aversion is similar to that of Iowa. These results generate the sharp contrast whereby traditional pricing leads to a low energy ration (30-50 percent corn) with an aggressive implant, whereas grid pricing leads to a moderately high energy ration (60-80 percent corn) with a moderate implant. This sharp contrast is similar to the unrestricted results, verifying that grid pricing indeed tends toward higher quality beef production by aligning incentives across the supply chain.

Remarkably, the optimal incentive schemes chosen from the restricted parameter space represent each of the three standard contract types (even though one of parameters is chosen freely in two cases, i.e., $\alpha = 0$ is not imposed when $\gamma = 0$ nor is $\gamma = 1$ imposed when $\beta = 0).$ is not imposed when $\gamma = 0$ nor is $\gamma = 1$ imposed when $\beta = 0).$ Thus, the model helps to explain contract variations observed in practice. Interestingly, a typical linear incentive structure with $\alpha > 0, \beta > 0,$ and $\gamma = 0$ (Holmstrom and Milgrom 1987, 1991), as is included in both restricted and unrestricted parameter spaces, never emerges as optimal, nor is it hardly observed in the reality of cattle feeding.

Effects of Weather Condition

Results in tables 6 and 7 clearly show that optimal contract coefficients and ration-implant strategies are different for the two locations considered in this paper. With both the unrestricted and restricted parameter spaces, the incentive for cost saving in Kansas is either lower or the same as in Iowa. The differences are due to the variation in animal performance attributed to weather condition and regional difference in feed prices.

Considering traditional contract types and less than moderate risk aversion by the owner, yardage-feed-markup contracts are optimal in both locations. However, optimal yardage fee is higher and markup on feed costs is lower in Kansas while the optimal ration-implant strategy is the same (80 percent corn with an aggressive implant) for both locations. With moderate owner risk aversion and less than high feeder risk aversion under traditional pricing, cost-of-gain contracts are optimal in both locations while the payment per pound of gain is higher for Kansas with costly ration (50-70 percent corn). Grain content of ration decreases with Kansas feeder risk aversion within none to moderate range. With moderate owner risk aversion and high feeder risk aversion, a cost-of-gain contract with a less costly ration-implant strategy (30 percent corn with an aggressive implant) is optimal for Iowa while a yardage fee plus cost share contract with a costly ration-implant strategy (40 percent corn with a moderate implant) is optimal for Kansas. With high owner risk aversion under traditional pricing, cost-of-gain contracts are optimal in both locations irrespective of feeder risk aversion. However, grain content of ration decreases with Kansas feeder risk aversion.

For moderate owner risk aversion under grid pricing, a yardage-feed contract is optimal in Iowa and a higher yardage plus feed cost share contract is optimal in Kansas. For high owner risk aversion, yardage plus feed cost share contracts are optimal in both locations while yardage fee is higher and the owner's share of feed cost is lower in Kansas. However, optimal ration-implant strategy is the same for both locations.

Congruence with Reality

Rahman (2007) suggests that feeders have a substantial interest in restricting the contract parameter space to traditional forms under the moderate to high owner risk aversion unless feeder risk aversion is high. Studies have found that cow-calf producers who retain ownership of feeder calves through slaughter face substantial price and production risks (Popp et al. 2007, Marsh and Feuz 2002). Given the small scale of beef production herds, moderate to high levels of risk aversion are likely. Only about 10 percent of U.S. cow-calf operations have more than 100 breeding cows (Field and Taylor 2002) and many have less than 30 (Ward 1997).

Further, restriction of the parameter space is feasible only if feeders have sufficient bargaining power to impose traditional (restricted) contract forms. While a feeder can certainly refuse certain contact forms, the fact that the traditional forms of contracts are observed in reality suggests that an owner can shop among feeders to find a traditional contract of preferred form, even though no feeder may consent to offer contracts outside of traditional forms. Thus, the results whereby the feeder can successfully restrict the parameter space but not the form of the restricted contract seem to fit reality. Certainly, cattle owners choose the fed cattle pricing method because they retain ownerships of the cattle until completion of feeding. Thus, given that feeders can restrict the parameter space while owners choose contracts within the restricted contract space as well as the fed cattle pricing method, results in tables 6 and 7 appear to both harmonize with reality and offer a rationalization of predominant choices.

As a check on these results, more than 30 feedlot operators in Iowa and 20 feedlot operators in Kansas were contacted directly by telephone or email in 2005. Majority of the Iowa feedlot operators reported that yardage fee ranged from $0.05 to $0.25 per animal per day while markup on feed cost ranged from 0 to 20 percent. Few Iowa feedlot operators reported the cost-of-gain to be around $0.40 per pound. As reported by Kansas feedlot operators, yardage fee ranged from $0.25 to $0.35 per animal per day and markup on feed cost ranged from 0 to 10 percent. While cost-of-gain contract is rare in Kansas, one feedlot operator reported $0.45 as the cost of live weight gain per pound. In the plausible case of moderate risk aversion, the yardage fees and costs-of-gain selected in tables 6 and 7 are within the range of the reported values. However, none of the feedlot operators reported cost sharing.

The results in the last two rows of table 6 and last six rows in table 7, which appear to be the likely cases of reality, also suggest that the introduction of modern grid pricing naturally leads to a shift from cost-of-gain contracts $(\alpha = \gamma = 0)$ to yardage-feed contracts

$(\beta = 0, \gamma = 1)$. Several feedlot operators in Iowa reported that they had switched from cost-of-gain contracts to yardage-feed contracts, while none of them reported switching from yardage-feed contracts to cost-of-gain contracts. However, for alternative levels of owner and feeder risk aversion, there appears to be a larger scope of cost-of-gain contracts in Iowa.

The optimization results further indicate that average beef quality improves with the adoption of grid pricing. For this set of cattle, the average resulting beef quality is "Select" under live- and dressed- weight pricing, and "Choice" under grid pricing. Thus, grid pricing indeed appears to promise improvement in beef quality as many have hoped. Thus, the model and its results appear to fit reality quite well and explain observed practices and tendencies in contract cattle feeding and marketing.

Summary and Conclusions

This article presents a unique approach to examine the optimal behavior of the cattle owners and feeders involved in contract cattle feeding under various contract provisions in different climatic conditions. A biophysical model for beef cattle growth is adopted from the animal science literature and applied under cattle feeding contract optimization to examine contract parameter sensitivity to climatic conditions. Results indicate that observed behavior is best rationalized by moderate levels of risk aversion, in which case the results explain several observed phenomena: (i) emergence of typical contract types, (ii) variant cattle feeding contracts across geographic locations with different climatic conditions, and (iii) a tendency to replace cost-of-gain contracts with yardage-feed contracts as grid pricing has emerged.

The examination of incentives and outcomes in an unusually comprehensive parameter and behavioral space in this study is made possible by using a biophysical model together with detailed data on a large lot of cattle and public price and weather data. Revealed preference data, even in the rare case where proprietary contract data can be collected, cannot hope to examine the extent of choice sets considered here. In the simulation model, carcass yield and quality improving inputs are substitutes in the production. These tradeoffs play a large role in determining the critical results, but would be hard to identify by means of econometric examination of revealed preference data with its likely narrow ranges of choice. In this respect, this study is an example of how more comprehensive answers can be gained from economic analysis by taking advantage of biophysical relationships that have been measured in substantial detail by the production sciences. Moreover, much more detail is facilitated by this approach than we can illustrate in the space of a journal article.

For future research, we suggest that finding an efficient approach that aligns incentives for the complete supply chain must also consider the packer's welfare. Packers are almost certainly a partial beneficiary of the reduced welfare obtained by the combination of feeder and owner in the prisoner's dilemma result. Important issues in this broader context include both risk sharing between the owner and packer, and selection of appropriate premiums and discounts in grid pricing structures, both of which are largely packer-determined but affect the owner-feeder relationship.

Footnotes

[1] The yield grade (Y) of a carcass is defined numerically as $Y = 2.5 + 2.5T + 0.2K + 0.0038H - 0.32R$ where T is thickness (in inches) of fat over the rib-eye muscle, K is kidney, pelvic, and heart fat as a percentage of carcass weight, H is hot carcass weight (in pounds), and R is the area (in square inches) of rib-eye muscle.

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Table 1. Weekly Average Grid Premiums and Discounts, 2001-2005 ($/Cwt)

Quality Grades	Yield Grades				
	1	2	3	4	5
Prime	6-14	5-12	4-10	(1-10)	(7-15)
CAB	3-9	2-7	1-5	(6-13)	(12-18)
Choice	2-4	1-2	Base	(11-14)	(17-19)
Select	(0-23)	(2-24)	(4-25)	(15-39)	(21-44)
Standard	(8-29)	(10-30)	(12-31)	(23-45)	(29-50)

Note: CAB stands for Certified Angus Beef. Numbers in parenthesis are negative. Additional discounts apply: light carcasses (1-6 for 550-599 lbs., 12-21 for 500-550 lbs., and 19-29 for 400-500 lbs.); heavy carcasses (0-2 for 901-950 lbs., 4-11 for 950-1,000 lbs., and 13-22 for over 1,000 lbs.); dark cutters (23-34); hard bones (20-31); dairy (0-8) and bullocks (17-28).

Source: Agricultural Marketing Service.

Table 2. Summary Statistics of the TCSCF cattle (1,125 observations)

Variable	Mean	Standard Deviation	Minimum	Maximum
Age on Placement (days)	217	29	122	337
Initial Body Weight (lbs)	548.6	83.1	272	838
Frame Score	4.7	1.1	0.8	7.9
Days on Feed	201	21	148	239
Final Body Weight (lbs)	1,154.2	87.5	896	1,530
Hot Carcass Weight (lbs)	703.4	59.1	512	938
Yield Grade	2.6	0.6	0.6	4.5
Quality Grade	3.4	0.7	1	5

Note: For frame scores, 1 is small and 9 is large. For yield grades, 1 is high and 5 is low. For quality grades, 1 is prime, 2 is CAB, 3 is choice, 4 is select, and 5 is standard.

Source: TriCounty Steer Carcass Futurity Cooperative (TCSCF).

Table 3. Composition and Nutrient Content (per kg Dry Matter) of Six Rations

Ration	Composition (Co:Si:SM:AH)	*NEm* (Mcal.)	*NEg* (Mcal.)	*ME* (Mcal.)	*MP* (Grams)
Ration 1	30:50:10:10	1.841	1.204	2.775	105.42
Ration 2	40:40:10:10	1.889	1.246	2.833	109.01
Ration 3	50:30:10:10	1.937	1.288	2.891	112.60
Ration 4	60:20:10:10	1.985	1.330	2.949	116.19
Ration 5	70:10:10:10	2.033	1.372	3.007	119.79
Ration 6	80:00:10:10	2.081	1.414	3.065	123.38

Note: The proportions of ingredients are ordered as corn (Co), corn silage (Si), soybean meal (SM), and alfalfa hay (AH); *NEm* is net energy for maintenance; *NEg* is net energy for growth; *ME* is metabolizable energy; and *MP* is metabolizable protein.

Source: National Research Council (2000).

Table 4. Average Weather in Red Oak, IA and Dodge City, Kansas (1984-2009)

Month	Temperature (^{o}C)		Rel. Humidity (%)		Wind Speed (kmph)		Sun Shine (hours)	
	IA	KS	IA	KS	IA	KS	IA	KS
January	-4.53	**0.34**	**75.37**	64.20	14.94	**20.42**	3.67	**6.58**
	(7.67)	(4.42)	(10.54)	(11.49)	(7.11)	(3.67)	(3.39)	(2.13)
February	0.66	**2.57**	**72.27**	63.65	14.77	**21.12**	4.18	**6.86**
	(6.96)	(4.7)	(11.06)	(11.99)	(6.6)	(3.31)	(3.45)	(2.19)
March	1.89	**7.13**	**69.81**	61.42	17.28	**43.33**	4.09	**7.81**
	(7.27)	(4.32)	(10.72)	(10.71)	(7.68)	(21.41)	(3.96)	(2.46)
April	10.70	**12.36**	**66.29**	60.45	17.69	**24.14**	4.51	**8.96**
	(4.91)	(3.73)	(14.29)	(9.21)	(8.04)	(3.33)	(3.92)	(2.34)
May	16.92	**18.24**	**69.70**	64.86	15.44	**22.52**	5.47	**9.57**
	(4.36)	(3.18)	(13.91)	(8.79)	(5.83)	(4.37)	(4.48)	(2.49)
June	22.80	**23.41**	**70.08**	63.45	13.33	**21.77**	7.11	**10.86**
	(3.96)	(2.82)	(10.89)	(8.5)	(5.54)	(4.21)	(3.99)	(2.49)
July	25.28	**26.45**	**73.57**	60.18	10.28	**20.39**	8.97	**11.69**
	(3.38)	(2.23)	(9.41)	(8.61)	(4.75)	(3.76)	(3.09)	(1.74)
August	24.14	**25.50**	**77.69**	62.72	8.31	**19.25**	7.21	**10.36**
	(3.47)	(2.58)	(8.26)	(9.07)	(4.1)	(3.59)	(3.45)	(2.22)
September	19.02	**20.55**	**71.44**	61.91	9.76	**21.03**	6.96	**8.98**
	(7.17)	(3.84)	(8.55)	(9.59)	(4.55)	(4.07)	(3.33)	(2.45)
October	13.01	**13.63**	**66.20**	62.24	13.44	**20.99**	5.91	**7.96**
	(6.73)	(3.93)	(13.99)	(11.18)	(6.94)	(3.34)	(3.34)	(2.32)
November	5.14	**6.28**	**71.00**	62.22	13.74	**20.96**	4.40	**6.71**
	(6.29)	(4.31)	(12.76)	(11.71)	(7.08)	(3.44)	(3.19)	(2.38)
December	-1.51	**0.84**	**73.78**	65.48	12.37	**20.34**	3.68	**6.35**
	(6.21)	(4.07)	(8.92)	(10.45)	(6.29)	(3.6)	(3.09)	(2.02)

Note: IA and KS represents Red oak, Iowa and Dodge City, Kansas, respectively. Standard deviations are reported in parentheses.

Source: National Oceanic and Atmospheric Administration and WeatherBank Inc.

Table 5. Average Beef Cattle Growth Simulation Results (1,125 Observations)

Feed Composition (see table 3)	Days on Feed (lbs)		Avg. Daily Gain (lbs)		Feed Efficiency (lbs)		Yield Grade		Quality Grade	
	IA	KS	IA	KS	IA	KS	IA	KS	IA	KS
No Implant										
30:50:10:10	282	**284**	**2.51**	2.49	7.56	7.56	3.15	3.15	3.00	3.00
40:40:10:10	273	**275**	**2.59**	2.57	7.25	7.25	3.16	3.16	3.00	3.00
50:30:10:10	266	**267**	**2.66**	2.65	**6.98**	6.97	3.18	3.18	3.00	3.00
60:20:10:10	259	**260**	**2.73**	2.72	**6.72**	6.71	3.19	3.19	3.00	3.00
70:10:10:10	253	**254**	**2.80**	2.78	**6.49**	6.47	3.20	3.20	3.00	3.00
80:00:10:10	247	**249**	**2.86**	2.84	**6.27**	6.25	3.21	3.21	3.00	3.00
Moderate Implant – Estrogen Only										
30:50:10:10	236	**237**	**3.00**	2.99	**6.80**	6.78	2.93	2.93	3.83	3.83
40:40:10:10	229	**230**	**3.09**	3.08	**6.54**	6.51	2.94	2.94	3.67	3.69
50:30:10:10	223	**224**	**3.18**	3.16	**6.29**	6.26	2.95	2.95	3.43	3.43
60:20:10:10	217	**218**	**3.26**	3.25	**6.06**	6.04	2.97	2.96	3.20	3.21
70:10:10:10	212	**213**	**3.34**	3.32	**5.85**	5.82	2.98	2.98	3.12	3.12
80:00:10:10	208	**209**	**3.41**	3.40	**5.66**	5.63	2.99	2.98	3.10	3.10
Aggressive Implant - Estrogen plus Trenbolone Acetate										
30:50:10:10	212	**213**	**3.35**	3.33	**6.31**	6.28	2.71	2.71	4.02	4.03
40:40:10:10	205	**206**	**3.45**	3.44	**6.06**	6.03	2.72	2.72	4.01	4.02
50:30:10:10	200	**201**	**3.55**	3.53	**5.83**	5.80	2.73	2.73	4.01	4.01
60:20:10:10	195	**196**	**3.64**	3.63	**5.62**	5.59	2.74	2.74	4.00	4.00
70:10:10:10	190	**191**	**3.73**	3.71	**5.42**	5.40	2.75	2.75	3.99	3.99
80:00:10:10	186	**187**	**3.81**	3.79	**5.24**	5.22	2.76	2.76	3.98	3.98

Note: IA and KS represents Red oak, Iowa and Dodge City, Kansas, respectively.

Table 6. Optimal Contracts and Corresponding Feeding Strategies, Iowa

Risk Preferences		Live- or Dressed-Weight Pricing				Grid Pricing			
Owner	Feeder	Contract			FS	Contract			FS
ψ	φ	α	β	γ		α	β	γ	
Unrestricted Parameter Space									
None-Low	None-Moderate	0.14	0.10	0.80	3/A	0.19	0.03	0.97	5/M
None	High	0.03	0.09	0.93	6/A	0.19	0.03	0.97	5/M
Low	High	0.13	0.10	0.81	5/A	0.19	0.03	0.97	5/M
Moderate	None-Moderate	0.14	0.10	0.80	3/A	0.13	0.08	0.87	6/M
Moderate	High	0.14	0.10	0.80	1/A	0.13	0.08	0.87	6/M
High	None-Moderate	0.15	0.11	0.76	1/A	0.23	0.08	0.78	4/M
High	High	0.14	0.10	0.80	1/A	0.21	0.08	0.80	4/M
Restricted (Traditional) Parameter Space									
None	All Levels	0.05	0.00	1.19	6/M	0.05	0.00	1.19	6/M
Low	All Levels	0.16	0.00	1.09	6/M	0.16	0.00	1.09	6/M
Moderate	All Levels	0.00	0.40	0.00	1/A	0.26	0.00	1.00	4/M
High	All Levels	0.00	0.40	0.00	1/A	0.37	0.00	0.90	4/M

Note: For risk aversion, $\psi = \varphi = 0.00025$ is low, $\psi = \varphi = 0.0025$ is moderate, and $\psi = 0.02$ and $\varphi = 0.023$ is high. Feeder strategy (FS) is denoted as *i*/*j* where *i* is the ration as defined in table 3 and *j* is the implant strategy (N if no implant, M if moderate, and A if aggressive).

Table 7. Optimal Contracts and Corresponding Feeding Strategies, Kansas

Risk Preferences		Live- or Dressed-Weight Pricing				Grid Pricing			
Owner	Feeder	Contract			FS	Contract			FS
ψ	φ	α	β	γ		α	β	γ	
Unrestricted Parameter Space									
None-Low	None-Moderate	0.12	0.10	0.84	6/A	0.18	0.01	1.04	6/M
None	High	0.12	0.10	0.84	6/A	0.18	0.01	1.04	6/M
Low	High	0.12	0.10	0.84	6/A	0.18	0.01	1.04	6/M
Moderate	None-Moderate	0.12	0.10	0.84	6/A	0.15	0.08	0.87	6/M
Moderate	High	0.12	0.10	0.84	6/A	0.15	0.08	0.87	6/M
High	None-Low	0.47	0.06	0.65	1/A	0.41	0.05	0.73	4/M
High	Moderate	0.47	0.06	0.65	1/A	0.31	0.07	0.76	4/M
High	High	0.47	0.06	0.65	1/A	0.44	0.03	0.76	4/M
Restricted (Traditional) Parameter Space									
None	All Levels	0.19	0.00	1.06	6/M	0.19	0.00	1.06	6/M
Low	All Levels	0.19	0.00	1.06	6/M	0.19	0.00	1.06	6/M
Moderate	None-Low	0.00	0.44	0.00	5/A	0.34	0.00	0.93	4/M
Moderate	Moderate	0.00	0.44	0.00	3/A	0.34	0.00	0.93	4/M
Moderate	High	0.34	0.00	0.93	4/M	0.34	0.00	0.93	4/M
High	None-Low	0.00	0.44	0.00	5/A	0.40	0.00	0.88	4/M
High	Moderate	0.00	0.44	0.00	3/A	0.40	0.00	0.88	4/M
High	High	0.00	0.44	0.00	1/A	0.40	0.00	0.88	4/M

Note: For risk aversion, $\psi = \varphi = 0.00025$ is low, $\psi = \varphi = 0.0025$ is moderate, and $\psi = 0.02$ and $\varphi = 0.023$ is high. Feeder strategy (FS) is denoted as *i*/*j* where *i* is the ration as defined in table 3 and *j* is the implant strategy (N if no implant, M if moderate, and A if aggressive).

Appendix 1: Step by Step Procedure for Biological Growth Simulation

According to the genetic information provided by the TCSCF, the breed effect coefficients for each individual animal are obtained from the NRC (2000). Initial body condition scores of the animals are calculated using initial empty body fat percentages following Fox et al. (1992). Based on NRC (2000), all feeder steers are assumed to have hair depth of 0.5 inches, average hide thickness (hide code 2), and medium hair coat with some mud on the lower body (hair coat code 2).

Step 1: Given the initial live body weight of an animal, calculate initial shrunk and empty body weights and the amount of initial empty body fat according to equations 1, 2, and 37 in appendix table 2, respectively.

Step 2: Determine the ration-implant strategy to be used during feeding the animal. Following the feed library of NRC (2000), determine energy and protein content of the feed on the basis of dry matter percentage (appendix table 2). Also, specify the type of growth promoting implant to be used and obtain the parameters for adjusting the expected final shrunk body weight and dry matter intake prediction.

Step 3: From the frame score of the animal, determine expected final shrunk body weight (*EFSBW*) according to Fox et al. (1992). Adjust *EFSBW* for the use of implant (minus 45 kg for no implant, and plus 45 kg for the use of estrogen and Trenbolone Acetate), and calculate initial equivalent shrunk body weights for a target final empty body fat percentage (e.g., $SRW = 478\ kg$ for medium frame steers at 28 percent empty body fat).

Step 4: Given energy and protein values of the ration, predict daily dry matter intake (*DMI*, *kg*/day) of the animal with necessary adjustment for body fat, breed, implants, current weather condition, and mud depth at the feedlot (equations 5 to 13 in appendix table 2).

Step 5: Compute required energy for maintenance with necessary adjustment for direct effect of cold or heat stress (equations 14 to 28 in appendix table 2).

Step 6: Calculate dry matter required for maintenance, dry matter available for growth and net energy available for growth (equations 29 to 31 in appendix table 2).

Step 7: Calculate shrunk weight gain and empty body gain according to equations 32 and 34 in appendix table 2.

Step 8: Determine empty weight gain and the amount of protein and fat in empty weight gain according to equations 35 and 36 in appendix table 2, respectively. Add fat in gain to initial empty body fat on the previous day, and calculate empty body fat percentage at the end of the day (equation 37 in appendix table 2).

Step 9: Compute accumulated shrunk and empty body weights at the end of the day according to the following equations:

$$SBW_t = SBW_{t-1} + SWG_t;$$

$$EBW_t = EBW_{t-1} + EWG_t.$$

Step 10: Calculate carcass weight following according to equation 40 in appendix table 2).

Step 11: Calculate empty body and carcass fat percentage following equations 38 and 39 in Appendix Table 2. Using the carcass fat percentage determine yield grade following Fox and Black (1984) (equation 41 in appendix table 2. Also determine quality grade from the accumulated empty body fat percentage following Guiroy et al. (2001).

Step12: Repeat steps 4 to 11 for each additional day until the animal reaches target slaughter weight.

Step 13: Compute and save the number of days required to reach the target harvest body, average daily shrunk weight gain, total amount of dry matter consumed during the feedlot regime, and overall feed efficiency (dry matter consumed per unit of weight gain). Also, save final carcass weight, yield grade, and quality grade.

Step 14: Repeat steps 2 to 13 for each of the available ration-implant strategies.

Step 15: Repeat steps 1 to 14 for each individual animal.

Appendix 2: The Comparative Returns Search Model in Algorithmic Form

Step 1: Save the means and variances of the outcomes of the biophysical growth simulation model performed for each of the TCSCF cattle using 18 alternative ration-implant strategies. For each of the ration-implant strategies, compute the variance-covariance matrix for the dependent variables of interest across all the cattle.

Step 2: Obtain historical weekly averages of live and dressed weight prices of fed cattle, feeder cattle, grid premiums and discounts, corn, soybean meal, and alfalfa hay prices. Calculate corn silage prices from corn prices. Estimate the multivariate densities of the price series using a Gaussian kernel function and randomly draw 10,000 price vectors from their multivariate distributions.

Step 3: Estimate dressing percentage from the randomly drawn live weight and dressed weight prices for fed cattle by linearly regressing the former on the later (without an intercept term). Calculate grid base prices per pound of beef from live weight prices and estimated dressing percentages according to the formula, Grid Base Price = 100 × (Live Weight Price/Estimated Dressing Percentage) + 0.01.

Step 4: For each individual animal and ration-implant strategy, compute the cattle owner's revenue from selling the fed cattle according to live, dressed and grid pricing methods using the outcomes of the growth model and randomly drawn prices.

Step 5: Calculate the costs per pound dry matter of each of the rations using the randomly drawn feed ingredient prices. From the total feed consumption data generated by the growth simulation model and ration costs, calculate average total feed cost for feeding each individual animal under alternative ration-implant strategies. Calculate total feeding cost under alternative strategies by adding implant and other costs to the total feed cost.

Step 6: Compute the variance-covariance matrix of the revenues, costs, and feedlot performance.

Step 7: Calculate average partial profits (across all the cattle) of the owner under alternative feeding strategies by subtracting corresponding average total costs and the average value of the feeder cattle from the revenues under alternative fed cattle pricing methods.

Step 8: Determine the lower and upper bounds of the contract coefficients (α, β, and γ) from the minimum and maximum attainable profits by the feeder and owner. Construct a parameter space with all plausible combinations of α, β, and γ for an increment of 0.01 within the corresponding intervals ($0 \leq \alpha \leq 0.49$, $0 \leq \beta \leq 0.47$, and $0 \leq \gamma \leq 1.45$). Save the feasible combinations of α, β, and γ in an array that satisfy the participation constraints of the cattle feeder and owner.

Step 9: For each combination of α, β, and γ in the feasible parameter space, compute the feeder's net return and utility per animal head (and also per hundred pounds of weight gain) for alternative cattle feeding strategies for a constant absolute risk aversion coefficient from the interval $0 \leq \varphi \leq 0.025$. Search for the feeder's profit and utility maximizing feeding strategies for each combination of α, β, and γ under each φ.

Step 10: For a constant absolute risk aversion coefficients in the range $0 \leq \psi \leq 0.019$, compute the cattle owner's profit and utility per animal head (and also per hundred pounds of weight gain) under alternative fed cattle pricing methods that result from the feeder's optimal strategies for all feasible combinations of α, β, and γ. Search for the owner's profit and utility maximizing α, β, and γ, and corresponding optimal feeding strategy of the feeder.

Step 11: Save the optimal combination of α, β, and γ, corresponding feeding strategies, and certainty equivalents of the cattle feeder and the owner for any particular combination of φ and ψ.

Step 12: Repeat Steps 9-11 for all plausible combination of φ and ψ with successive increments within the corresponding intervals of the risk aversion coefficients.

Step 13: repeat steps 9-12 for alternative fed cattle pricing methods and save the results.

Appendix Table 1. Glossary of the variables used in the growth model

Variable	Description	Unit
a_1	Fasting heat production coefficient (0.072 for beef cattle)	Mcal/kg$^{-0.75}$/day
a_2	Maintenance adjustment for previous temperature	Mcal/kg$^{-0.75}$/day
*Adj*DMI	*DMI* adjusted for breed, body fat, and weather condition	kg/day
*Adj*REM	*REM* adjusted for cold or heat stress	Mcal/day
BCI	Body condition score (1=emaciated, …, 9=obese)	
BE	Breed effect for maintenance	
CETI	Current month's effective temperature index	^{o}C
CFP	Carcass fat percentage	%
CW	Carcass weight	kg
DMFM	Dry matter available for maintenance	kg/day
DMFG	Dry matter available for gain	kg/day
DMI	Predicted dry matter intake	kg/day
DMIB	*DMI* adjustment factor for breed	
DMIBF	*DMI* adjustment factor for body fat content	
DMIIMP	*DMI* adjustment factor for the use of implant	
DMIM	*DMI* adjustment factor for mud depth in the feedlot	
DMIT	*DMI* adjustment factor for temperature	
DMITNC	*DMI* adjustment factor for temperature with night cooling	
EBF	Empty body fat	kg
EBFP	Empty body fat percentage	%
EBW	Empty body weight	kg
EI	External insulation	^{o}C/Mcal/m^2/day
EqSBW	Equivalent shrunk body weight	kg
EWG	Empty weight gain	kg/day
FIG	Fat in gain	
HCCode	Hair coat code (1=dry and clean, 2=some mud on lower body, 3=wet and matted, 4=covered with wet snow or mud)	
HD	Hair depth	cm
HE	Heat production	Mcal/day
HideCode	Hide depth code (1=thin, 2=average, and 3=thick)	
HideME	Hide depth adjustment for external insulation	
HRSc	Hours of sunshine in the current month	Hours

HRSp	Hours of sunshine in previous month	Hours
IF	Ionophore adjustment factor	
TI	Total insulation	^{o}C/Mcal/m^{2}/day
LCT	Lower Critical Temperature	^{o}C
MCP	Microbial crude protein	
ME	Dietary content of metabolizable energy	Mcal/kg
MEcs	Animal requirement for ME adjusted for cold stress	Mcal/day
MP	Dietary content of metabolizable protein	g/day
MPb	Digestible microbial protein	
MPf	Digestible undegraded feed protein	
MPg	Metabolizable protein required for gain	g/day
Mud	Mud depth in the feedlot	cm
MudME	Mud adjustment factor for external insulation	
NEg	Dietary content of net energy for growth	Mcal/kg
NEm	Dietary content of net energy for maintenance	Mcal/kg
NEmcs	Cold stress adjustment factor for *REM*	
NEmhs	Heat stress adjustment factor for *REM*	
NEFG	Net energy available for growth after maintenance	Mcal/day
NPg	Net protein required for gain	g/day
PEg	Protein efficiency for gain	
PETI	Previous month's effective temperature index	
PIG	Protein in gain	
PN	*NEm* adjustment for previous nutrition	
QG	Numerical quality grade	
RE	Retained energy	Mcal/day
REM	Required energy for maintenance	Mcal/day
RHc	Current relative humidity	%
RHp	Previous relative humidity	%
RMP	Total metabolozable protein required for maintenance	g/day
SA	Surface area	m^{2}
SBW	Shrunk body weight	kg
SRW	Shrunk reference weight (478 kg at 28% body fat)	kg
SWG	Shrunk weight gain	kg/day
Tc	Current average temperature	^{o}C

Tp	Previous month's average temperature	^{o}C
TI	Tissue (internal) insulation	$^{o}C/Mcal/m^2/day$
UCT	Upper critical temperature	^{o}C
UIP	Undegraded feed protein	
WSc	Current wind speed	km/hour
WSp	Previous wind speed	km/hour
YG	Numerical yield grade	

Appendix Table 2. Equations Used in the Biophysical Growth Simulation Model

Eq.	Condition	LHS	RHS
1		SBW_t	$0.96 \times LBW_t$
2		EBW_t	$0.891\times SBW_t$
3		$AFSBW$	$EFSBW + IMPEFSBW$
4		$EqSBW_t$	$(SBW_t \times SRW) / AFSBW$
5	Age ≤ 12 mos.	DMI_t	$(SBW_t^{0.75}\times(0.2435\times NEm_t - 0.0466\times NEm_t^2 - 0.1128))/NEm_t$
	Age > 12 mos.		$(SBW_t^{0.75}\times(0.2435\times NEm_t - 0.0466\times NEm_t^2 - 0.0869))/NEm_t$
6	$EqSBW_t \geq 350$ kg	$DMIBF_t$	$0.7714 + 0.00196 \times EqSBW_t - 0.00000371 \times EqSBW_t^2$
	$EqSBW_t < 350$ kg	$DMIBF_t$	1
7	Holstein	$DMIB_t$	1.08
	Holstein× British	$DMIB_t$	1.04
	All Other	$DMIB_t$	1
8	No Implant	$DMIMP_t$	0.94
	Estrogen	$DMIMP_t$	1
	Estrogen + TBA	$DMIMP_t$	1.03
9		$CETI_t$	$27.88 - (0.456\times Tc_t) + (0.010754\times Tc_t^2) - (0.4905\times RHc_t) + (0.00088\times RHc_t^2) + (1.1507\times(1000/3600)\times WSc_t) - (0.126447\times((1000/3600)\times WSc_t)^2)+ (0.019876\times Tc_t\times RHc_t) - (0.046313\times Tc_t\times((1000/3600)\times WSc_t))+(0.4167\times HRSc_t)$
10		$DMINC_t$	$(119.62 - 0.9708\times CETI_t)/100$
11	$Tc_t \leq -20^oC$	$DMIT_t$	1.16
	$-20^oC< Tc_t \leq 20^oC$	$DMIT_t$	$1.0433 - 0.0044\times Tc_t + 0.0001\times Tc_t^2$
	$20^oC< Tc_t \leq 28^oC$	$DMIT_t$	$((1 - DMINC_t) \times 0.75 + DMINC_t)/100 + 1.05$
	$Tc_t > 28^oC$	$DMIT_t$	$((1 - DMINC_t) \times 0.75 + DMINC_t)/100 + 1$
12		$DMIM_t$	$1 - 0.01 \times Mud_t$
13		$AdjDMI_t$	$DMI_t \times DMIBF_t \times DMIB_t \times DMIMP \times DMIT_t$
14		PN_t	$0.8 + (BCS_t - 1) \times 0.05$
15		$PETI_t$	$27.88 - (0.456\times Tp_t)+ (0.010754\times Tp_t^2) - (0.4905\times RHp_t) + (0.00088\times RHp_t^2) + (1.1507\times(1000/3600)\times WSp_t) - (0.126447\times((1000/3600)\times WSp_t)^2)+(0.019876\times Tp_t\times RHp_t) - (0.046313\times Tp_t\times((1000/3600)\times WSp_t))+(0.4167\times HRSp_t)$
16	$Tp_t \leq 20^oC$	a_2	$(88.426 - 0.785 \times Tp_t + 0.0116 \times Tp_t^2 - 77)/1000$
	$Tp_t > 20^oC$	a_2	$(88.426 - 0.785 \times PETI_t + 0.0116 \times PETI_t^2 - 77)/1000$

17		REM_t	$SBW_t^{0.75} \times ((a_1 \times BE \times PN_t) + a_2)$
18		SA_t	$0.09 \times SBW_t^{0.67}$
19		RE_t	$(AdjDMI_t - (REM_{t-1}/(NEm \times IF))) \times NEg$
20		HE_t	$((ME_t \times AdjDMI_t) - RE_t)/SA_t$
21	$HideCode_t \leq 2$	$MudME_t$	$(1 - HCCode_t - 2) \times 0.2$
	$HideCode_t > 2$	$MudME_t$	$(1 - HCCode_t - 2) \times 0.3$
22		$HideME_t$	$(1 – HCCode_t – 2) \times 0.2$
23		EI_t	$(7.36 - (0.296\times WSc_t) + (2.55\times HD_t)\times MudME_t\times HideME_t$
24		TI_t	$5.25 + 0.75 \times BCS_t$
25		IN_t	$EI_t + TI_t$
26		LCT_t	$39 - (IN_t \times HE_t \times 0.85)$
27	$LCT_t > Tc_t$	$MEcs_t$	$SA_t \times (LCT_t – Tc_t)/IN_t$
	$LCT_t \leq Tc_t$	$MEcs_t$	0
28		$AdjREM_t$	$REM_t + (NEm_t/ME_t) \times MEcs_t$
29		$DMFM_t$	$AdjREM_t/(NEm \times IF)$
30		$DMFG_t$	$AdjDMI_t – DMFM_t$
31		$NEFG_t$	$DMFG_t \times NEg$
32	$NEFG_t > 0$	SWG_t	$13.91 \times (EqSBW_{t-1}^{-0.6837}) \times (NEFG_t^{0.9116})$
	$NEFG_t \leq 0$	SWG_t	0
33		SBW_t	$SBW_{t-1} + SWG_t$
34		EWG_t	$0.956 \times SWG_t$
35		PIG_t	$0.254 - 0.0271 \times(NEFG_t/EWG_t)$
36		FIG_t	$0.123 \times(NEFG_t/EWG_t) - 0.154$
37	$t = 0$	EBF_t	$(0.00054 \times EBW_t^2 + 0.037 \times EBW_t - 0.61) \times 0.85$
	$t > 0$		$EBF_{t-1} + FIG_t \times EWG_t \times 0.85$
38		$EBFP_t$	$100 \times (EBF_t/EBW_t)$
39		CFP_t	$0.70 + 1.0815 \times EBFP_t$
40		CW_t	$0.73 \times EBW_t - 22.22$
41		YG_t	$0.15 \times CFP_t - 1.7$

Note: LHS = Left hand side of the equation; RHS = Right hand side of the equation.

Source: Tedeschi et al. (2004), NRC (2000), Fox et al. (1992), Garrett and Hinman (1969), and Fox and Black (1984).