

## **ABSTRACT**

Title of Dissertation: OPTIMAL CONTRACTING AND VERTICAL  
COORDINATION IN THE BEEF INDUSTRY: AN  
ASSESSMENT OF VALUE-BASED PRICING

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The purpose of this dissertation is twofold. The first purpose is to provide a theoretical economic explanation for the traditional and emerging governance structure of the U.S. beef industry, and then explain why a complete vertical integration has not yet occurred in the beef sector. The traditional USDA beef grading system has facilitated limited concern for beef quality and little incentive to invest in beef quality control. According to transaction cost economics (TCE) and property rights theory (PRT) in the industrial organization literature, open market operations are found to be the appropriate governance mechanism in the specific circumstances of the beef industry. With increasing consumer concern for relative quality and consistency of beef products, beef processors have attempted to market a higher proportion of superior quality beef and to further differentiate beef products with criteria other than USDA grades. In order to transmit signals about the value of beef quality to upstream producers and align their incentives, beef processors have

adopted *ex post* output measurement (e.g., grid pricing) and *ex ante* input control mechanisms (e.g., certification and process verification programs). Such measures have induced transaction-specific investments in successive vertical sectors of the industry. As explained by TCE and PRT theories, these have called for new governance structures such as marketing agreements for fed cattle transactions and strategic alliances. By TCE, the degree of idiosyncrasy of specific investments by each of the vertically-related sectors of the beef industry is not high enough that transaction costs could be further reduced by vertical integration. Further, PRT implies that vertical integration may not be an efficient governance structure for the beef industry because beef quality improvement requires specific investments by each of the relevant sectors of the beef industry (e.g., beef processing, cattle feeding, and cow-calf production), which give rise to holdup problems from each side of various transactions.

The second purpose of this dissertation is to examine optimal behavior of commercial cattle feeders under alternative cattle feeding contract provisions, and the implications for contract choice by cattle owners and feeders under traditional and value-based pricing methods for fed cattle. A multitask principal-agent model is developed to theoretically analyze optimal incentive structures for cattle feeding contracts under alternative fed cattle pricing methods and risk preferences of cattle owners and feeders. In order to evaluate theoretical economic predictions of the multitask model, a dynamic biophysical growth model for beef cattle is adopted from the animal science literature and employed to simulate feedlot and carcass performance outcomes of a large sample of feeder steers for various ration-implant

strategies typically used in cattle feeding. The biophysical model has the advantage of representing the effects of a relatively rich mix of ration and implant strategies by feeders on an equally rich mix of quantity and quality characteristics of fed beef. Simulated feedlot and carcass performance data are then combined with historical price series to calculate stochastic costs and returns of cattle owners and feeders with various degrees of risk aversion. The optimal (profit and expected utility maximizing) cattle feeding contract parameters for owners and corresponding production technologies (ration-implant strategies) chosen by feeders are then determined by performing a generalized search on a feasible contract parameter space under various levels of risk aversion.

The optimization results validate the main hypotheses of the multitask model as well as hypotheses about the benefits and implications of grid pricing. The main results of this research can be summarized as follows. First, carcass yield and quality improving inputs are substitutes in the production technology of feedlots. Second, overall beef quality improves under grid pricing with optimal owner and feeder behavior. Third, the power of the optimal incentive scheme for cattle feeding (i.e., the degree of the incentive for cost saving) is lower under value-based grid pricing than under traditional live- and dressed-weight pricing methods. Fourth, the power of the incentive scheme increases with the degree of cattle owners' risk aversion. Fifth, compared to traditional pricing methods, value-based grid pricing better aligns the incentives of cattle owners and feeders under feeding contract structures in current use (yardage-fee-plus-feed-cost contracts or cost-of-gain contracts). Sixth, asymmetry in the premium-discount structure in current grids and the additional risk

associated with carcass yield and quality under grid pricing are the main reasons for continued use of live-weight pricing and apparent slowness to adopt grid pricing. Seventh, more balanced premiums and discounts in grid pricing may be required to achieve further expansion of grid pricing and overall improvement of beef quality and consistency. Eighth, if cattle feeders can limit the contract parameter space to traditional forms of contracts and owners choose the contract parameters, then typical forms of cattle feeding contracts can be rationalized by optimal behavior under plausible levels of risk aversion. Finally, the introduction of grid pricing decreases (increases) the tendency toward cost-of-gain (yardage-fee-plus-feed-cost) contracts in commercial cattle feeding.

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BEEF INDUSTRY: AN ASSESSMENT OF VALUE-BASED PRICING

By

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## **DEDICATION**

I dedicate this dissertation to my parents –  
Shaikh Nawsher Ahmed and Hosneara Begum

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Words can hardly express my gratitude to the individuals without whom this dissertation would not have seen the light of day. First, I would like to thank the chair of my dissertation committee, Professor Richard Just, for his penetrating insights, advice, and guidance at every stage of the process. He spent many hours of his valuable time in reading and editing various drafts of this dissertation and offered valuable suggestions and comments. I would also like to thank other members of the committee, Professors Bruce Gardner, Wesley Musser, Jim Hanson, and Daniel Vincent, for their kind support and encouragement.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

With increasing consumer concern about the quality and consistency of beef products, a major challenge for the beef industry is to efficiently produce and maintain a high proportion of superior quality beef (highly palatable lean meat). This is extremely difficult in a vertically segmented industry. The final quality of beef primarily depends on animal characteristics (e.g., genetic breeding) as well as on the actions of the parties in three major sectors of the industry: cow-calf production, feedlot operation, and beef packing. Therefore, efficient production of high quality beef requires proper identification of individual animals as they move from one sector to another and efficient production and management practices in all the successive stages of production. This in turn depends in large part on how integrated are the different stages of production.

According to transaction cost economics literature, the efficiency of production is highest when the production system is fully integrated in one firm (Williamson, 1979). While the beef industry has undergone some major structural changes in the last 20 years, these changes have had more to do with the consolidation of firms within the packing and feeding sectors than with changes in the nature of the interface between the sectors (Barkema et al., 1993). In this situation, a frequently asked question is why the beef supply chain is not vertically integrated. The first purpose of my dissertation is to provide a theoretical economic explanation for the existing and emerging governance structure of the beef industry with the help of existing literature on industrial organization.

In the absence of vertical integration, beef industry participants have adopted a variety of alternative production, marketing, and organizational practices in recent years. The value-based grid pricing of fed cattle, with premiums (discounts) for higher (lower) yield and quality of beef, has become the most popular among the new marketing practices. It represents a potential to improve market coordination through a sophisticated quality-based pricing mechanism that sends more precise signals about the relative value of yield and quality of beef to the upstream firms in the production process. Recent market studies indicate that cattlemen are likely to continue adopting such value-based pricing systems at an increasing rate.

With the emergence of value-based grid pricing systems, another commonly raised question is whether, in the absence of vertical integration, such a mechanism is able to align the incentives of beef industry participants so that market efficiency and the well being of agents improves. The second purpose of this dissertation is to examine whether a grid pricing system can better align the incentives of cow-calf producers and cattle feeders with the existing cattle feeding contracts and thus improve their overall welfare. This issue is examined first by modeling optimal incentive structures for cattle feeding contracts under alternative fed cattle pricing methods, and then empirically evaluating the welfare of the contracting parties with the traditional lot-average and modern value-based pricing methods under existing cattle feeding contracts. Further detail of the background and motivation of this study is presented in the following section. Then specific research objectives are described. The organization of this dissertation is outlined in the last section of this chapter.

## **1.2 Background and Motivation**

Over the last two decades beef consumption in the United States has declined steadily both in terms of aggregate quantity and as a share of total U.S. meat consumption (Hueth and Lawrence, 2003). For example, per capita consumption of beef declined from 72.2 pounds in 1980 to 64.3 pounds in 2000 (USDA). The share of beef in per capita meat consumption declined from 42.9 percent in 1980 to 35.6 percent in 2000. The market share of beef in per capita total meat expenditure declined from 53.9 percent in 1980 to 39.8 percent in 1998 (Field and Taylor, 2002). The market share loss between 1980 and 1998 cost the beef industry about \$12.8 billion in consumer expenditures (Field and Taylor, 2002). While per capita consumption of pork remained almost the same over the last two decades, chicken consumption increased significantly during the same period. Per capita consumption of chicken increased from 33.1 pounds in 1980 to 52.6 pounds in 2000. Chicken's share in per capita meat consumption increased from 19.7 percent to 29.1 percent during the same period. Existing agricultural economics literature suggests that this is primarily due to reduction in the price of chicken relative to beef and increased consumer health concerns regarding the consumption of red meat (Hueth and Lawrence, 2003). However, relative improvements in the quality and consistency of chicken products are also cited as important contributing factors (Purcell, 2000; Schroeder et al., 2000). Researchers argue that coordination among the vertical sectors is behind this success of the broiler industry (Hayenga et al., 2000).

The broiler industry is essentially entirely vertically coordinated through ownership or contracts. Over the last 50 years, more than 90 percent of broilers were produced under contract with the remainder produced by integrated firms (MacDonald

and Korb, 2006; Hayenga et al., 2000). The hog industry appears to be following a similar course as it takes up a more vertically coordinated production system. Total hogs produced under contract in the U.S. increased considerable from 31 percent in 1994-95 to 63 percent in 2001-02, with specialized hog operations showing even larger increases (MacDonald and Korb, 2006; McBride and Key, 2003). The beef industry has lagged behind the broiler and hog industries in adopting vertical coordination mechanisms. As of 2003, three-fourths of feeder cattle were still acquired by feeders or packers through livestock auctions on a cash basis, while the rest were fed in custom feedlots on the basis of contracting or joint ownership programs (MacDonald et al., 2004). A 2000 survey of the fifteen largest beef packing firms shows that two-thirds of fed cattle slaughtered in 1999 were cash market acquisitions (Hayenga et al., 2000). The rest of the fed cattle were procured through short-term marketing agreements (not more than 14 days prior to slaughter). However, vertical integration by ownership of an entire beef supply chain is rare. While some tentative explanations are found in the existing literature, a clear explanation in terms of economic theory is needed for the virtual independence of the vertical sectors of the U.S. beef industry.

In the absence of vertical integration, beef industry participants are currently trying to sort out whether vertical coordination of the kind observed in the broiler and hog industries is necessary to regain the lost market share. In the mean time, legislation proposed in Farm Security and Rural Investment Act of 2002 to ban or limit the extent of contracting and vertical integration in cattle markets has obscured the future of such coordination in the beef industry (U.S. Congress, 2002). In this situation, it is not at all surprising that beef industry participants are looking for some alternative ways to

improve coordination within the industry. In recent years, a variety of novel production, marketing, and organizational practices have been adopted by beef industry participants in an apparent attempt to improve beef quality and increase overall profits. Individual cattle management systems, value based grid pricing of fed cattle, short- and long-term marketing agreements, and strategic alliances are examples of such innovations. The most widely adopted of these marketing practices is the so-called grid pricing mechanism. Grid pricing is a common mechanism in nearly all of the alliances. Alliances are a type of organization where different individuals and companies from different sectors of the beef industry operate somewhat independently of one another but still share in risks and profits through contractual arrangements (Field and Taylor, 2002).

A recent survey of cattle feeders suggests that traditional lot-average pricing methods for fed cattle such as live-weight and dressed-weight pricing are being increasingly replaced over time by grid pricing (Schroeder et al, 2002). Under grid pricing mechanisms, fed cattle are priced individually with premiums and discounts for various carcass traits. In addition, when carcasses are priced on the grid, packers record and report the distribution of carcass quality for a given lot of animals upon the request by the cattle owners (Hueth and Lawrence, 2003).<sup>1</sup> While grid pricing does not essentially introduce any formal vertical linkage, it is an attempt to improve vertical coordination by sending upstream in the production process more precise signals concerning the relative value of alternative carcass attributes.

Grid pricing mechanisms also offer cow-calf producers a new opportunity to recoup their costly investments in genetics and cow-calf management, and increase their

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<sup>1</sup> In alliances, packers report the carcass quality of each individual animal for a fixed charge of approximately \$3-\$8 (Hueth and Lawrence, 2003).

profits by retaining ownership of the cattle until they are ready for slaughter. However, by retaining ownership of the cattle beyond weaning, producers may also assume substantial price, production, and holdup risks. Price roll-backs are of particular concern as the value per hundredweight (cwt.) of live beef decreases as the weight of the animals increases. Cow-calf producers assume additional production risks (animal performance risks) and holdup risks (due to potential opportunistic behavior of feedlot operators) by retaining ownership of the cattle through an additional production stage. Death loss during the backgrounding and finishing stage can also have significant impacts on profitability. Finally, cash flow for the producers may be strained with retained ownership. Therefore, it is important for cow-calf producers to understand the costs as well as the benefits of holding the title of the animal through the feeding stage.

Cow-calf producers who retain ownership of their cattle through slaughter typically feed the weaned calves in commercial feedlots by making contractual arrangements (both formal and informal). A feedlot operator performs multiple tasks during the feeding phase, which affect the feedlot and carcass performance of the cattle (e.g., the rate of gain, feed efficiency, final carcass weight, and yield and quality grades of the carcass). Given that the feedlot operator's actions are unverifiable and unseparable, there arises a potential holdup problem.<sup>2</sup> While transaction cost economics and property rights theory literature prescribe vertical integration for the resolution of such holdup problems, a majority of the cattle in the United States are fed in commercial feedlots on the basis of custom feeding contracts. There are two major types of contracts for cattle

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<sup>2</sup> The holdup problem refers to the inability of an economic agent to fully capture the returns from his/her *ex ante* relationship-specific investments because of the opportunistic behavior on the part of his/her trading partner in *ex post* bargaining (Williamson, 1975, 1985). Given that the relationship-specific investments are sunk in nature and are non-contractible and outputs are non-verifiable, the uncertainty about the future behavior of the trading partner may lead to sub-optimal levels of *ex ante* investments.

feeding in practice: yardage-fee-plus-feed-cost (with or without markup) and cost-of-gain contracts. Given the potential holdup problem, there is a need for formal analyses of the issues related to the optimal incentive structure for cattle feeding contracts with retained ownership of cattle through slaughter, as well as the welfare implications of modern value-based grid pricing systems.

### **1.3 Specific Research Objectives**

The research topics of this dissertation are premised on the hypothesis that some sort of vertical coordination between the stages of the beef industry is necessary for the beef industry to produce high quality beef and compete more efficiently with chicken and pork for consumer demand. In the absence of a complete vertical integration of the beef supply chain, this study explores whether the industry can potentially achieve this goal through recently adopted practices of value-based marketing of fed cattle. The specific objectives of this research are as follows:

1. Analyzing the organizational details of the U.S. beef industry and reviewing relevant theoretical and empirical literature, provide a plausible rationale in economic theory for the existing governance structure of the beef supply chain.
2. Theoretically examine the optimal incentive structure for cattle feeding contracts with retained ownership of cattle through slaughter and marketing fed cattle using alternative fed cattle pricing methods including:
  - i. Live-weight pricing,
  - ii. Dressed-weight pricing, and

- iii. Grid pricing.
3. Empirically test the predictions of the theoretical model.
  4. Empirically examine whether the modern value-based grid pricing method for marketing fed cattle is able to align the incentives of cattle owners and feeders with existing cattle feeding contracts. Also, evaluate the welfare impacts of the grid pricing system on the cattlemen with the two predominant cattle feeding contract forms:
    - i. Yardage-fee-plus-feed-cost (with or without a markup) contracts, and
    - ii. Cost-of-gain (or flat rate per pound of gain) contracts.

#### **1.4 Organization of the Dissertation**

The dissertation consists of seven chapters. The next chapter presents an overview of the nature and extent of vertical coordination in the U.S. beef industry. The existing forms of cattle feeding contracts and fed cattle pricing methods are also discussed. Chapter 3 attempts to explain why a complete vertical integration has not yet occurred in the U.S. beef industry. The issue is addressed from the perspective of the industrial organization literature on vertical coordination, focusing on incomplete contract theory in particular. First, theoretical and empirical research in transaction cost economics and property rights approaches of incomplete contract theory are reviewed. Second, agricultural economics research employing incomplete contract theory are summarized. Finally, implications of incomplete contract theory for the vertical coordination in the U.S. beef industry are analyzed. In particular, this summary provides understanding of



the potential role of value-based grid pricing in beef quality improvement given that vertical integration has not occurred in the beef industry.

Chapter 4 presents a multitask principal-agent model for cattle feeding contracts under alternative fed cattle pricing systems and risk preference scenarios. The model captures the organizational details of cattle feeding and fed cattle marketing, and yields several comparative static results. The main prediction of the theoretical model is that a relatively lower powered incentive scheme is optimal for cattle feeding when beef quality is not measurable before slaughter and fed cattle are priced in the grid. The multitask model also suggests that the power of the incentive scheme increases with the level of the cattle owner's risk aversion and decreases with the feeder's risk aversion level and the degree of substitutability of the feeder's actions under certain conditions.

In order to evaluate the predictions of the multitask model, a dynamic biophysical growth simulation model for beef cattle is adopted from the animal science literature. A detailed description of the growth model is presented in Chapter 5. The biophysical growth model is capable of systematically predicting the outcomes of feeding each individual animal when nutrient content of feed, weather, and the animal's genetic and biological information are available. The growth model is employed to simulate feedlot and carcass performance of a large lot of feeder cattle under alternative production technologies. Predictive efficiency of the model is evaluated by comparing the simulated and actual outcomes. Describing necessary data and simulation procedures, the cattle growth simulation outcomes under alternative production technologies and the results of the tests of predictive efficiency of the model are presented in Chapter 6.

In order to determine the optimal incentive schemes for cattle feeding under alternative fed cattle pricing methods and risk aversion scenarios, the cattle performance data generated by the biophysical growth simulation model are combined with historical price data. Optimal incentive schemes for cattle feeding and corresponding production technologies under alternative fed cattle pricing methods and risk aversion scenarios are presented and analyzed in Chapter 7. The empirical results confirm the principal predictions of the theoretical model and justify the convergence of the empirical contract payment schemes to typical forms. More importantly, the results show that overall beef quality increases under grid pricing with optimal owner and feeder behavior, grid pricing better aligns the incentives of the cattle feeder and owner with the current structures of cattle feeding contracts, and possibilities exist for further expansion of the grid pricing system with sensible adjustment of the premiums/discounts scheme in the grid. However, conditioning prices on ex post information may not be beneficial for risk-averse agents because incorporating this information in contracts adds greater risks in the pricing. A summary of the results are presented in the concluding section of Chapter 7. Finally, Chapter 8 presents general conclusions and reflections of this study.

CHAPTER 2  
AN OVERVIEW OF VERTICAL COORDINATION  
IN THE U.S. BEEF INDUSTRY

**2.1 Introduction**

Although the term *beef industry* implies that beef production is a unified operation subject to an overall management program, it includes several distinct production stages such as breeding, weaning, feeding, and marketing cattle with the eventual processing and merchandising of retail products to consumers. Typically, each of these production stages are performed by specialized sectors: seedstock firms control genetic selection and breed development; cow-calf producers (ranchers) manage cow/calf herds and raise young cattle from birth to weaning; yearling-stocker operators add weight to weaned calves prior to their shipment to feedlots; cattle feeders feed weaned or backgrounded animals high energy rations until they are ready for market, and packers slaughter, cut and process carcasses in their plants. Removing much of the bone and excess fat from primal and sub-primal cuts, packers sell the beef in boxes to purveyors and distributors, or directly to retailers. Figure 2.1 provides a schematic representation of the beef supply chain.

While every individual segment of the beef industry specializes in the production of its end product, consumers value palatable lean beef products which are the final output for the entire industry. Therefore, economic efficiency in the beef industry requires cost-efficient production of an output mix that appropriately reflects the value placed by consumers on highly palatable lean meat. The primary components of beef

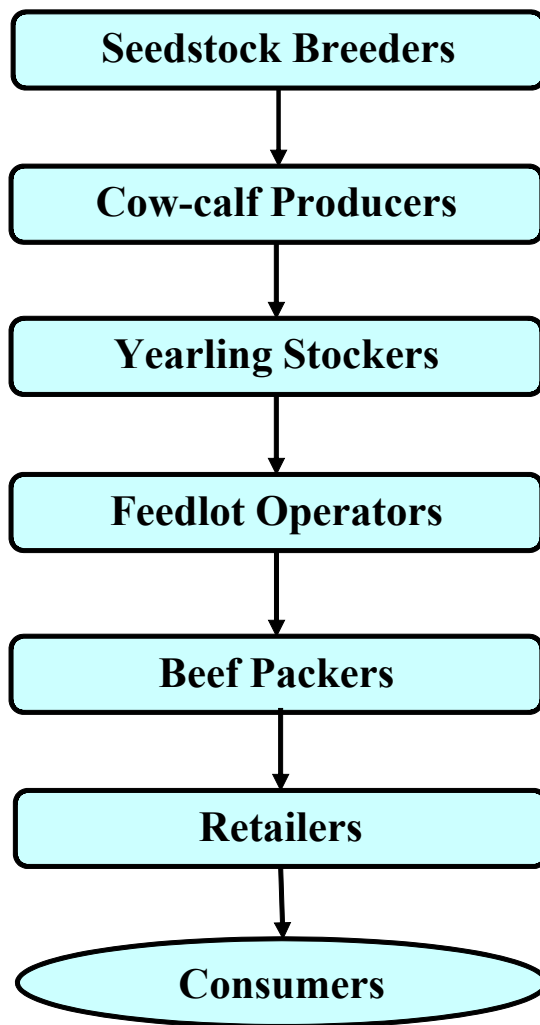


Figure 2.1: Vertical sectors of the beef industry.

palatability are tenderness, flavor, and juiciness. While consumers rate tenderness as the most important attribute, quality of beef is evaluated by the combination of all three attributes. Marbling (flecks of intramuscular fat distributed in muscle tissue) has a positive relationship to all three attributes of beef palatability. The higher the marbling, the more palatable the beef is. Scientific research shows that breeds vary in muscle fiber color, which is related to the ability to deposit marbling. Factors other than marbling that

affect tenderness of beef include age of the animal, feedlot gain, rate of carcass cooling, carcass weight, fat cover, aging of carcass or retail cuts, and electrical simulation (Field and Taylor, 2002). Although method of cooking, cooking temperature, and serving method also affect tenderness, animal characteristics (breeds) and management practices at the farm, feedlot, and packing plant are the primary contributors to the tenderness of beef.

As the final quality of beef products depends on the actions of the parties in different segments of the industry, efficient production of high quality beef requires proper identification of individual animals as they move from one sector to another and efficient production and management practices in all the successive stages of production, which in turn depends largely on how integrated different stages of production are. Lamb and Beshear (1998) and Schroeder and Mark (1999) suggest that much of the beef product quality problem has resulted from poor coordination of the vertical beef production and marketing system. The following section of this chapter presents a brief overview of the nature and extent of vertical coordination along the beef supply chain. The existing forms of fed cattle pricing methods are described in subsequent sections.

## **2.2 The Nature and Extent of Vertical Coordination in the Beef Industry**

The U.S. beef industry has been going through some major structural changes since the 1980s. The changes, however, have had more to do with the concentration of firms within the packing and feeding sectors than with vertical integration. The most noticeable concentration in the beef industry has occurred in the packing sector. As of 2000, the number of packing plants was half of what it was in the 1980s (Field and

Taylor, 2002). Four large packing plants, such as IBP, ConAgra, Excel, and Farmland National Beef, slaughter approximately 80 percent of the steers and heifers and handle approximately 85 percent of the boxed beef annually. These packers controlled only about one-third of the total fed cattle slaughter in 1980 (Field and Taylor, 2002).

Economies of scale have been cited as the primary reason for such concentration in the beef packing sector. Concentration has also occurred in the cattle feeding sector, but less dramatically than in the packing sector. The number of feedlots has decreased from 122,000 in 1970 to 41,000 in the mid 1990s, and is projected to decrease further to 21,000 in 2010 (Field and Taylor, 2002). In 2000, the largest 25 cattle feeding companies operated 106 feedlots and marketed 38 percent of total fed cattle (Field and Taylor, 2002). Concentration is least apparent in the cow-calf management sector. Still, more than 50 percent of the total breeding cows are owned by only about 10 percent of cow-calf operations that have an inventory of more than 100 head (Field and Taylor, 2002).

However, different forms of vertical coordination are in practice such as integration by ownership, strategic alliances, fed cattle procurement through forward contracts and marketing agreements, and contract cattle feeding. The extent of such coordination methods are discussed in detail below.

### ***Integration by Ownership***

There are only a few examples of vertical integration by ownership of two or more sectors. National Beef Packing, the fourth largest beef packer in the U.S., is jointly owned by Farmland, a farmer-owned cooperative. Farmland also owns a large commercial feedlot named Supreme Feeders. U.S. Premium Beef, a closed cooperative, is

comprised primarily of cow-calf producers and cattle feeders. Harris Ranch, originally a cattle producer located in California, owns a beef slaughter plant. Monfort, the third largest beef packer, was started by a cattle feeder in Colorado. However, the total number of cattle fed by these farms represents a relatively small and stable share (around 3 percent) of total cattle slaughter per year. Other beef packers also purchase feeder cattle and feed them in different feedlots by making custom feeding arrangements. The beef packers' practice of feeding their own cattle in their own or others' feedlots is known as 'packer feeding'. Table 2.1 shows the percentages of slaughtered steers and heifers owned and fed by the 15 largest beef packers in their own or others' feedlots during 1988-97.

**Table 2.1: Percent of annual slaughter cattle sourced from packer feeding, forward contracts, and marketing agreements, 15 largest beef packers, 1988-97.**

Year	Packer Feeding (%)	Forward Contracts and Marketing Agreements		Total (%)
			(%)	
1988	5.0		14.3	19.3
1989	5.2		17.2	22.4
1990	5.0		13.9	18.9
1991	4.5		12.7	17.2
1992	4.1		15.3	19.4
1993	4.1		13.3	17.4
1994	4.0		16.5	20.5
1995	3.3		17.8	21.1
1996	3.3		18.8	22.1
1997	3.7		14.9	18.6
<b>Average</b>	<b>4.2</b>		<b>15.5</b>	<b>19.7</b>

Source: Hayenga et al. (2000), based on data obtained from the Grain Inspection, Packers and Stockyards Administration (GIPSA).

Hayenga et al. (2000) suggest that the primary reasons producers integrate into beef packing are to capture packing margins. However, closed cooperatives like U.S. Premium Beef and others have acquired packing plants to improve transmission of value signals to producers, and also to develop branded beef products and capture increased margins associated with higher wholesale prices for branded and processed products.

### ***Forward Contracts and Marketing Agreements for Fed Cattle Procurement***

Fed cattle procurements by beef packers through forward contracts and marketing arrangements with feedlot operators have been in practice for a long time. The USDA Grain Inspection Packers and Stockyards Administration (GIPSA) defines forward contracts as contracts entered into two or more weeks prior to slaughter. A marketing agreement is defined by GIPSA as “an oral or written agreement between a packer and a seller in which the seller agrees to ship all or part of its slaughter cattle to the packer when the cattle are ready for slaughter, with price determined at or after slaughter.” Forward contracts and marketing agreements represented 14.0–19.4 percent of the 4 largest beef packers’ annual slaughter and 12.7–18.8 percent of the 15 largest beef packers’ annual slaughter during 1988-97 (Table 2.1).

The Agricultural Marketing Service (AMS) of the USDA collects and reports the number of cattle delivered weekly to beef packers that are marketed on a non-cash basis. Non-cash deliveries include fed cattle sold using forward contracts, marketing agreements, grid pricing, packer fed cattle, and cattle delivered against futures contract positions. The AMS data shows that non-cash fed cattle deliveries as a percentage of total weekly market volume have increased over the last decade in major cattle feeding states.



For example, in Colorado, Kansas, and Texas, non-cash fed cattle deliveries represented less than 30 percent of weekly slaughter volume during the early 1990s, but often exceeded 60 percent in the late 1990s (AMS-USDA, 2000). While other states show similar trends, the Southern Plains states tend to have higher percentages of non-cash deliveries relative to Northern Plains states like Nebraska. Most of this increase in non-cash fed cattle marketing is a result of an increase in the number of fed cattle marketed through formula pricing (Hayenga et al., 2000). Formula pricing refers to establishing a transaction price using a formula based on some other price as a reference. Usually, average price (cost) of fed cattle purchased by the packing plant or highest reported local cash price for the week prior to or the week of slaughter is used as the reference in the formula..

Hayenga et al. conducted a survey on the fifteen largest beef packing plants in April 2000. Percentages of fed cattle procured by the respondent firms (10 out of 15) through various methods in 1999 are reported in Table 2.2. Survey respondents reported that 36 percent of total fed cattle slaughtered in 1999 were purchased in the cash market on a live weight basis, and 29 percent on a carcass weight or grid basis. Thus, two-thirds of cattle slaughtered were cash market acquisitions. Long term (more than 14 days) formula priced contracts linked to cash market (live cattle or wholesale beef prices reported by USDA, plant cost average, or retail beef prices) or futures market prices accounted for 19 percent of 1999 fed cattle procurement by the respondent firms. Only 5 percent of the cattle slaughtered in 1999 by these firms were fed by themselves. Another 4 percent of the fed cattle were purchased via short-term contract arrangements based on the Chicago Mercantile Exchange futures (basis contract, or fixed price based on futures

market prices, with deliveries typically several months in the future). The other 3 percent percent of the cattle were acquired through risk and profit sharing contract arrangements with cattle feeders.

**Table 2.2: Use of various methods for fed cattle procurement by the 15 largest beef packing firms in 1999, results of a 2000 survey.**

<b>Procurement Method</b>	<b>Percentage</b>
Cash market purchases on live weight basis	36
Cash market purchases on dressed weight or grid basis	29
Formula-priced contract purchases based on a reported live cash market, reported dressed price, plant average, CME cattle futures price, quoted boxed beef or retail beef price	20
Packer-fed cattle	5
Fixed price or basis contract purchases based on CME futures	4
Risk sharing contract purchases	3
Other purchases	4

Soutrce: Hayenga et al., (2000).

The two most important reasons cited by the packers to enter into contracts and marketing agreements with cattle producers were to “secure higher quality cattle” and to “secure more consistent supply of quality cattle” (Hayenga et al., 2000). Risk management, reducing plant operating costs by improving utilization rates of slaughter plant capacity, and assuring food safety were the next most important reasons. Packers perceptions were that producers’ primary incentives to enter into contracts and marketing agreements were to secure a quality premium/discount matrix followed by enabling producers to obtain a higher price for quality cattle (Hayenga et al., 2000).

A recent survey of cattle feeders located in Iowa, Kansas, Nebraska, and Texas indicates that use of marketing agreements for cattle delivery is increasing over time (Schroeder et al, 2002). In 1996, 23 percent of survey respondents' fed cattle were sold under some type of marketing agreement. This increased to 52 percent in 2001. The survey also reports that producers' primary motivations to enter into marketing agreements were to obtain yield and quality grade premiums and to get increased access to data (Schroeder et al, 2002).

### ***Contract Cattle Feeding***

There are two basic types of cattle feeding operations: the farmer feeder and the commercial feeder. The two types are generally distinguished by feedlot size and type of ownership. Farmer feedlots are usually defined as having less than 1000-head capacity, and are owned and operated by an individual farmer (or a family). Farmer feeders typically manage several different enterprises at the same time with cattle feeding being only one of those. Commercial feedlots are defined as specialized cattle feeding operations having more than 1000-head capacity and may be owned by an individual, a partnership, or a corporation, with the last type being more common as feedlot size increases. While farmer feeders often feed their own farm-born calves, both types of feedlot operators may acquire feeder cattle from cow-calf producers, stocker operators, investors, and beef packers by direct purchase, joint ownership programs, and custom feeding contracts.

The National Animal Health Monitoring System (NAHMS) estimated that approximately 37 percent of the cattle placed in the U.S. commercial feedlots (with more

than 1000-head one-time capacity) in 1999 were fully owned by the feedlots (USDA, 2000). Only 8 percent of the cattle were acquired by the feedlots through joint ownership programs, while the other 55 percent were acquired by custom feeding contracts (USDA, 2000). The report of a survey conducted through *Beef* magazine indicates that cattle ownership by all types of feedlots averaged 37 percent and 41 percent in 1995 and 2000, respectively (Ward et al., 2002). Retained ownership of feedlot cattle by cow-calf producers and stocker operations accounted for 36 percent in both years. Investor ownership of feedlot cattle changed slightly, from 14 percent in 1995 to 15 percent in 2000, while packer ownership remained stable at 1 percent (Ward et al., 2002).

Feuz and Umberger (2001) report that approximately 71.3 percent of the cattle placed in Nebraska feedlots in 1999 were fully owned by the feedlots, 7.5 percent were partially owned by the feedlots (joint ownership), and 21.2 percent were acquired through custom feeding contracts (Table 2.3). The upper panel of Table 2.3 shows that smaller feedlots owned a relatively larger share of the cattle in their lots and large feedlots owned a relatively smaller share of the cattle. Feuz and Umberger further report that 48.2 percent of the custom fed cattle were owned by cow-calf producers or stocker operators, and 51.7 percent of them were investor owned (Table 2.3). The share of packer fed cattle was very low (0.15 percent). A more recent survey indicates that approximately 54 percent of the cattle in North Dakota feedlots were custom fed (Rime et al., 2006).

Cattle feeding under joint ownership programs usually involve a feedlot operator and a cow-calf producer or an investor. A common form of joint ownership program is that the two parties share the ownership of the cattle and the feeding cost, and they split

net profit or loss by a negotiated method (e.g., 50-50 division of net profit or loss). In another type of joint ownership program, net profit or loss is divided according to the

**Table 2.3: Percent of cattle placed in Nebraska feedlots by type of ownership and by operation capacity, 1999.**

	Feedlot Capacity (No. of Animals)			All Feedlots (%)
	< 1000 (%)	1000-5000 (%)	> 5000 (%)	
<b>Cattle Ownership</b>				
Fully owned by feedlots	96.08	62.91	43.10	71.27
Partially owned by feedlots	1.79	11.13	10.48	7.53
Custom fed	2.13	25.96	46.43	21.20
<b>Custom Fed Cattle</b>				
Retained ownership	67.50	45.38	47.81	48.15
Investor owned	32.50	54.62	51.75	51.70
Packer owned	0	0	0.44	0.15

Source: Feuz and Umberger (2001).

basis of each party's inventory. In either of these joint ownership programs, price and production risks are borne by both parties.

Custom cattle feeding refers to contractual arrangements between feeder cattle owners and feedlot operators for feeding the cattle until they are ready for slaughter. Under such arrangements, feeder cattle are shipped to the feeder's premises where the feedlot operator provides all other inputs (e.g., shelter, feed, labor, equipment and other needs of the animals during the feeding period) to raise the cattle and is reimbursed according to the payment method specified in the contract. Custom feeding contracts are

typically classified on the basis of the payment method. There are two major types of custom feeding contracts in practice: yardage-fee-plus-feed-cost contracts and cost-of-gain (or flat rate per pound of gain) contracts (Weimar and Hallam, 1990; Madsen, 1996).

### ***Yardage-Fee-Plus-Feed-Cost Contracts***

Under a yardage-fee-plus-feed-cost contract, a cattle owner pays the feedlot operator a two-part fee for feeding the cattle. The fee is based on a fixed yardage charge per animal per day (e.g., \$0.25/head/day) plus reimbursement for the amount of feed consumed, with other costs such as veterinary and labor costs included in the yardage charge (Weimar and Hallam, 1990). Sometimes the reimbursement for feed is calculated using the actual market price or a standardized price per pound of feed delivered to the cattle. In other cases, feedlots charge a fixed price for feed per animal head per day. Some contracts specify the responsibilities of extra death loss (over 3 percent). However, the risks associated with fluctuating fed cattle prices, feed prices, and performance of the cattle in the feedlot is borne by the cattle owner (Weimar and Hallam, 1990).

A variant of the yardage-fee-plus-feed-cost contract is the yardage-fee-plus-feed-markup contract. This contract involves a smaller yardage fee (e.g., \$0.05/head/day ) but includes a percentage markup on feed costs, or a fixed amount per ton of feed provided to the cattle (Weimar and Hallam, 1990). As the variability in feed cost is magnified by the markup, the cattle owner's return from the contract will be more variable than a simple feed cost plus yardage fee contract.

### ***Cost-of-Gain Contracts***

Under a cost-of-gain contract, the owner reimburses the feeder for his service on the basis of an agreed amount per pound of weight gained by an animal during the entire feeding phase. The fee per pound of gain is determined prior to feeding the cattle and is usually based on feed costs, cost of equipment and overhead, death loss, and shrink. Sometimes a sliding scale is used as another method of payment. In this method, the payment is based on weight gain for different weights. For example, the owner may pay the feeder \$16 for the first 100 pounds of gain, \$17 for the second 100 pounds, \$20 for the third hundred pounds, and \$24 for the fourth hundred pounds (Madsen, 1996). The payment increases with successive gain because the weight of the animal increases at a decreasing rate while under continuous feeding. Some contracts also specify a bonus per hundredweight of gain paid by the owner to the feeder if the cattle gain on the average more than certain number of pounds per head per day.

The risk characteristics of a cost-of-gain contract are primarily determined by animal performance. This contract assigns risks of feed price and feed efficiency of the animals to the feeder. Even if the animals' feed conversion rates are affected by their genetic breed or poor weather condition, the loss is borne by the feedlot owner. However, fed cattle price risk is borne by the cattle owner.

### ***Vertical Beef Alliances***

Sporleder (1992) defines an inter-firm alliance as an agreement for cooperation among independent firms designed to serve a strategic purpose. He further suggests that vertical alliances are around the middle point of a continuum between open market

transactions and vertical integration and are preferred when participating firms believe that “malleable vertical control” is more beneficial than “no control” (open market operation) or “full control” (vertical integration). Vertical alliances have been emerging in the beef industry since the 1990s. The common stated goal of such alliances is to increase overall profits by improving the flow of products and information along the vertical segments of a beef supply chain. Members of vertical beef alliances operate somewhat independently of one another but still share in risks and profits on the basis of a contractual arrangement when cattle and beef products meet certain specifications.

While alliances can differ widely from one to another, most current vertical alliances in the beef industry can be categorized into three major types: marketing alliances, breed alliances, and specialty beef alliances (closed cooperatives). Marketing alliances are organizations that provide producers (cattle feeders and cow-calf producers) access to a beef processor’s value-based pricing mechanism and carcass information in exchange for a nominal fee. Alliances in this category include Angus America, Angus Gene Net, Farmland Supreme Beef Alliance, U.S. Premium Beef, Western Beef Alliance, etc. Breed alliances represent initiatives to increase markets for specific breeds. Several purebred cattle associations have established programs to encourage commercial cattlemen to use their breed’s bulls by providing additional marketing angles for their progeny. The American Hereford Association (Certified Hereford Beef), American International Charolais Association (Beef-Charolais), Red Angus Association of America, American Gelbvieh Association (Gelbvieh Alliance), and North American Limousin Foundation are examples of breed alliances. Specialty beef alliances are member-owned closed cooperatives that attempt to bring together all income generating



segments of the beef industry by combining producers, processors, and retailers into one coordinated business. Examples of this type of alliance are natural or implant-free beef production cooperatives such as Coleman's Natural Meats, Laura's Lean Beef, Maverick Ranches Beef, and B3R Country Meats. A common characteristic of these three types of alliances is that they all use some kind of a value-based grid or formula pricing system to determine the value of each individual carcass. The process of determination of the premiums and discounts for incremental yield and quality, however, depend on the type of the alliance.

Cattle-Fax estimates that as many as 60 different beef alliances are currently operating in the U.S. Field and Taylor (2002) provide information about 38 beef alliances and their production and marketing practices. A 2000 survey by *Beef* magazine shows that approximately 40 percent of beef producers were involved or planned to be involved in some type of marketing alliance (Field and Taylor, 2002). *Beef* magazine's *Alliance Yellow Pages* report information about 33 beef alliances obtained from a voluntary survey in 2000 and 2001. Peck (2001) reports that fed cattle slaughter by alliances increased from 3.9 million head (10.7 percent of the total slaughter) marketed in 2000 to 4.7 million head (13.2 percent) in 2001.

A survey of cattle feeders located in Iowa, Kansas, Nebraska, and Texas conducted in early 2002 revealed that about 11 percent of respondent firms marketed at least some of their cattle through some form of an alliance in 1996 (Table 2.4). The participation increased to 45 percent by 2001 (Table 2.4). About 55 percent of the respondents anticipated that they would market some of their fed cattle through alliances by 2006. The survey further revealed that the average percentage of each of the

respondent's fed cattle that were marketed through an alliance was about 4 percent in 1996 and 20 percent in 2001. The respondents anticipated that they would market about 31 percent of their fed cattle through an alliance in 2006. The respondent feedlots indicated that their primary motives to enter into marketing agreements with beef packers were to acquire yield and quality grade premiums as well as to obtain detailed carcass data.<sup>3</sup> Securing a cattle buyer was another important motive for the respondent feedlot operators who were involved in an agreement of some type in 2001.

**Table 2.4: Fed cattle marketing through marketing agreements and beef alliances, results of a 2002 survey on cattle feeders in Iowa, Kansas, Nebraska, and Texas.**

<b>Marketing Method</b>	<b>1996</b>	<b>2001</b>	<b>2006*</b>
	(%)	(%)	(%)
	(Percentage of respondents marketing at least 1% of their fed cattle using the method)		
Marketing agreement with beef packer	25.1	33.7	37.4
Marketing agreement with an alliance	11.3	45.2	55.3
	(Average percentage of the respondent's fed cattle marketed using the method)		
Marketing agreement with beef packer	14.2	25.0	26.3
Marketing agreement with an alliance	4.2	20.1	30.7

\*Information for 2006 represent anticipation of the respondent feeders.

Source: Schroeder et al. (2002).

<sup>3</sup> Detailed carcass performance data are helpful for cattle feeders in evaluating adopted feeding strategies, identifying problem areas, and making appropriate adjustments for improvement in production efficiency.

## 2.3 Fed Cattle Pricing Methods

Existing fed cattle pricing methods can be divided into two groups: lot-average pricing and value-based pricing. Lot-average pricing includes live weight and dressed weight (in-the-beef) pricing methods. Value-based pricing includes grade-and-yield pricing and grid pricing. While live-weight, dressed-weight, and grade-and-yield pricing methods are used in spot market transactions, grid pricing is used in non-spot transactions, such as in short-term marketing agreements with packers and in alliances.<sup>4</sup>

### *Live-Weight Pricing*

The live-weight pricing method is used in conventional open outcry livestock auctions, where cattle are sold in lots (typically 100 head) on a live weight basis. Buyers (mainly packers) in a cattle auction place their bids on the basis of the expected value of the beef when processed. When calculating the expected value of the cattle, packers start with a base Choice carcass price and add or subtract expected quality and yield grade premiums or discounts associated with quality traits the particular lot of cattle are expected to yield when processed (Schroeder and Davis, 1999). The adjusted carcass price is converted to a live animal price by multiplying it by the expected dressing percentage including a 4 percent shrink in the live weight of the cattle. This live price is credited with by-products and hide values and adjusted for slaughter costs, transportation costs, and the packer's profit margins to establish an estimated live animal bid price (Schroeder and Davis, 1999). However, live-weight pricing establishes a uniform price

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<sup>4</sup> Spot market transactions are defined as those where the price, along with any premiums or discounts for carcass characteristics (dressed weight and/or grade and yield), are negotiated at the time ownership is transferred. With non-spot transactions, these are negotiated some time in advance of the actual sale. Grid pricing differs from grade-and-yield pricing because the premiums and discounts for grade and yield, as well as any rule governing the base price, are negotiated ahead of the actual sale.

per hundred pounds of live weight. Thus, the total amount paid for a lot of animals is simply the total live weight of the cattle multiplied by the price.

### ***Dressed-Weight Pricing***

An alternative to live-weight pricing methods is dressed-weight pricing. In dressed-weight pricing, the buyer pays one price for each hundred pounds of dressed weight for all cattle in a lot; the amount paid for a lot of cattle is the total dressed weight multiplied by the price. While dressed-weight pricing compensates for higher yield (the amount of lean meat versus fat, and bone in the carcass) using the exact dressing percentage, it does not take account of differences in carcass quality (marbling, lean color, and firmness and texture of lean tissue). Typically, transportation costs are borne by the seller when cattle are priced using the dressed weight method.

### ***Grade- and-Yield Pricing***

Grade-and-yield pricing, is a value-based pricing method, which was introduced in the 1980s (Ward, 1987). Unlike live-weight or dressed-weight pricing where a single average price applies for the entire sale lot, in grade-and-yield pricing each individual animal is priced on the basis of actual dressed weight with adjustments for yield and quality grades of the carcass. In particular, grade-and-yield pricing starts with a specified dressed-weight base price for a carcass with USDA Choice quality grade and Yield Grade 3. Carcasses with yield and quality grades below this benchmark receive discounts from the base price. For example, a grade-and-yield pricing system may specify that carcasses with quality grade USDA Select will receive a discount of \$11/cwt while

carcasses with quality grade USDA Standard will receive a discount of \$18/cwt (Field and Taylor, 2002). Carcasses with yield grade 4 or 5 typically receive the same amount of discount in grade-and-yield pricing (Feuz et al., 1993). Carcasses lighter than 600 lbs or heavier than 900 lbs are also discounted in this method. However, grade-and-yield pricing does not offer any premium for yield grade or quality grade higher than the benchmark (Feuz et al., 1993).

Transactions under grade-and-yield pricing may be called spot transactions because the base price and discounts are determined by direct negotiation between buyers (packers) and sellers (cattle owners) at the time of fed cattle transactions. As soon as the base prices and discounts are settled, the ownership of animals is immediately shifted to packing plants for slaughter. Actual yield and quality grades of each individual carcass are then measured and the revenue is calculated according to the predetermined base price and agreed premiums and discounts for yield and quality grades. However, grade-and-yield pricing is being gradually replaced by the modern grid pricing system that offers a schedule of premiums and discounts for various carcass attributes and involves non-spot transactions.

### ***Grid Pricing***

Grid pricing is the modern value-based pricing method characterized by non-spot transactions such as marketing agreements and contracts. Instead of using a predetermined base price as in the grade-and-yield pricing method, grid pricing uses a base price that is determined after the transaction is negotiated between the buyer and seller. Typically, transactions under grid pricing are negotiated approximately two weeks prior to slaughter. At the time of transaction negotiation, both the buyer and seller are uncertain about the base price. Rather, they agree on a

price which is to be revealed one or two weeks after the agreement. The base price in a typical grid is often calculated from an average price reported by the Agricultural Marketing Service (AMS) of the USDA or from average prices paid by the packer for cattle purchased on the spot market during the week of slaughter or the previous week. Thus, in contrast to grade-and-yield pricing, the base price and premium-discount schedule as well as the actual carcass yield and grade are unknown at the time of transaction negotiation. More importantly, grid pricing offers a series of premiums and discounts for various carcass traits which are not included in grade-and-yield pricing.

Most grids consist of a base price with specified premiums and discounts for quality and yield grades, weight groups, and carcass and cattle types. Typically, the base price is for a USDA Choice, Yield grade 3, 600-900 pound carcass. Table 2.5 represents a basic pricing grid with ranges of premiums and discounts for various carcass attributes. The horizontal axis of the upper panel of Table 2.5 shows the ranges of premiums and discounts for various yield grades and the vertical axis shows the ranges of premiums and discounts for different quality grades of carcasses. The lower panel of Table 2.5 shows the ranges of discounts for lighter and heavier carcass weight groups and undesired carcass and cattle types. Once the base price is known for the grid, the net price can be computed for an individual carcass with adjustments for premiums and discounts. If the distribution of carcasses by quality and yield grades from a sale lot of fed cattle is known, the net price for the sale lot can also be easily computed.

In general, with the grid pricing method, higher quality cattle receive higher prices and lower quality cattle receive lower prices, thereby improving pricing accuracy and rewarding cattlemen who market desirable types of cattle. It also improves information linkages between meat packers and fed cattle sellers by rewarding desirable

carcass traits and penalizing undesirable traits. However, in order to capture the benefits of grid pricing, cattle producers need to know the quality of their cattle and how the base and premiums in grids are determined (Feuz et al., 2002).

**Table 2.5: Range of grid premiums and discounts, weekly averages 2001-2005**  
**(\$/cwt. Carcass Basis)**

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)
<b>Choice</b>	2 - 4	1 - 2	<b>Base</b>	(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)
<b>Light Carcass</b> (lighter than 600 lbs.)					
400-500 lbs			(19 - 29)		
500-550 lbs.			(12 - 21)		
550-600 lbs.			(1 - 6)		
<b>Heavy Carcass</b> (heavier than 900 lbs.)					
900-950 lbs.			(0 - 2)		
950-1000 lbs.			(4 - 11)		
>1000 lbs.			(13 - 22)		
<b>Dark Cutter</b> <sup>1</sup>			(23 - 34)		
<b>Hard Bone</b> <sup>2</sup>			(20 - 31)		
<b>Dairy Type</b>			(0 - 8)		
<b>Bullock</b>			(17 - 28)		

<sup>1</sup>Color of the lean muscle in the carcass has a dark appearance, usually caused by relatively long period of stress to the animal prior to slaughter.

<sup>2</sup>Appearance of overly matured carcass with dried out white bones and minimal cartilage.

Note: Numbers in parentheses are negative.

Source: The Agricultural Marketing Services (AMS) of the USDA.

### ***Establishing Base Prices in Grids***

A variety of methods have been used to establish base prices in grid marketing. Results of a survey of cattle feeders conducted by Schroeder et al. (2002) revealed that 78 percent of fed cattle sold by the respondents on a grid during 2001 used local cash fed cattle market prices or adjusted plant average prices to establish base prices. The second most popular technique for establishing base prices is direct negotiation (11 percent of fed cattle marketed using a grid). Other techniques for establishing base prices relied on formulas using wholesale boxed beef prices (8 percent) or live cattle futures prices (3 percent). Schroeder et al. (2003) examined the advantages and disadvantages associated with these alternative methods of establishing grid base prices. They recommend that grid base prices should be established using wholesale boxed beef prices because this aligns the incentives of the transacting parties. They also recognize that variability in the firm-to-wholesale marketing margin markedly affects the relationship between wholesale and firm-level prices.

### ***Carcass Premiums and Discounts***

As shown in Table 2.5, most grids start with a base price and adjust that price for each individual carcass according to the USDA quality and yield grades, carcass weight, and carcass and cattle types. While grid pricing offers significant price premiums for certain quality attributes, the discounts for undesirable attributes are much larger (Table 2.5). Thus, one discounted carcass may offset the premium earned by several. This method is much more discriminating with regard to beef carcass quality traits than average live- or dressed-weight pricing. There are five quality grades: Prime, Certified



Angus Beef (CAB), Choice, Select, and Standard. The factors used to determine quality grades are (1) bone maturity, (2) marbling, (3) lean color, and (4) firmness and texture of lean tissue. A major difficulty with current premiums and discounts for quality grades is the discrete nature of the grades and that measurement of the quality attributes is subjective in nature. For example, the difference in value between a Choice and Select 750-pound carcass with a \$7 per hundredweight Choice-to-Select spread is greater than \$50 per head, while a fine (subjective) line separates the two on a continuous quality scale.

Yield grades refer to pounds of boneless, closely trimmed retail cuts (BCTRC) from the round, loin, rib, and chuck. Yield grades are determined from four carcass characteristics: (1) amount of fat over the rib-eye muscle, measured in tenths of inches; (2) Kidney, pelvic, and heart (KPH) fat, which is usually estimated as a percentage of carcass weight; (3) area of rib-eye muscle (REA), which is measured in square inches; and (4) hot carcass weight. Yield grades are a continuous measure, but they are grouped into discrete whole numbers for most grids. Official USDA yield grades range from 0.1 to 5.9, but are typically estimated by graders and recorded as whole numbers for determining premiums and discounts in grids, i.e., yield grades 1, 2, 3, 4, or 5. As a result, like quality grades, some price differences can be large. Hot carcass weights are also continuous, but are usually grouped into discrete categories in most grids, resulting in similar magnitudes of value differences.

The report of the 2002 survey of cattle feeders in Iowa, Kansas, Nebraska, and Texas suggest that live-weight and dressed-weight pricing methods are being replaced by grid pricing over time (Table 2.6). In 1996, the share of fed cattle that respondent feedlots

marketed using live or dressed weight methods was 90 percent, but this share declined to 54.7 percent by 2001 (Table 2.6). Fed cattle marketed using grid pricing methods by the respondent cattle feeders increased from 8.1 percent to 43.5 percent during the same time period (Table 2.6). The respondents anticipated that their use of grid pricing for fed cattle marketing would further increase to about 60 percent by 2006. The revealed motive of the cattle feeders for adopting grid pricing was primarily to obtain yield and quality grade premiums and to get access to detailed carcass data (Schroeder et al., 2002).

**Table 2.6: Use of various pricing methods for marketing of fed cattle, results of a 2002 survey on cattle feeders in Iowa, Kansas, Nebraska, and Texas.**

Pricing Method	1996 (%)	2001 (%)	2006* (%)
(Average percentage of the respondents' fed cattle marketed using the method)			
<b>Spot transactions</b>			
Live weight	53.5	28.8	18.3
Dressed Weight	36.5	25.9	17.7
<b>Total</b>	<b>90.0</b>	<b>54.7</b>	<b>36.0</b>
<b>Grid Market (non-spot) Transactions</b>			
Grid (Base: Cash mkt. or plant average)	6.9	33.7	32.5
Grid (Base: Futures price)	0.4	1.0	5.6
Grid (Base: Boxed beef price)	0.3	2.8	11.2
Grid (Base: Negotiated)	0.5	5.9	10.4
<b>Total</b>	<b>8.1</b>	<b>43.4</b>	<b>59.7</b>
<b>Other Non-spot Transactions</b>			
Fixed Price Contracts	0.7	1.2	1.8
Futures (Basis) Contracts	0.8	0.6	1.1
Other	0.4	0.1	1.4
<b>Total</b>	<b>1.9</b>	<b>1.9</b>	<b>4.3</b>
<b>All Transactions</b>	<b>100</b>	<b>100</b>	<b>100</b>

\*Information for 2006 represent anticipation of the respondent feeders.

Source: Schroeder et al. (2002).

## **2.4 Conclusion**

This chapter presents a detailed description of the nature and extent of vertical coordination in the U.S. beef industry. Different forms of vertical coordination such as integration by ownership, strategic alliances, contracts, and marketing agreements are observed along the beef supply chain. However, the extent of vertical integration by ownership of two or more segments of the beef supply chain is very low and stable. While distinct vertical sectors of this industry still rely heavily on spot market transactions, the use of short-term marketing contracts or agreements with beef packers and alliances is increasing over time. Such non-spot market transactions usually involve value-based pricing of fed cattle. Increased profit margins by acquiring yield and quality grade premiums and obtaining detailed carcass data for further improvement in production efficiency are cited as the primary motives of the cattlemen for entering into non-spot marketing arrangements.

More than half of the feeder cattle are currently fed in the U.S. feedlots on the basis of various contractual agreements. Increasing use of value-based pricing systems indicates that retained ownership of cattle through slaughter and contract feeding practices are likely to increase further. Reviewing relevant theoretical and empirical literature, the next chapter attempts to explain the existing as well as emerging governance structures of the U.S. beef industry.

## CHAPTER 3

# INCOMPLETE CONTRACT THEORY AND THE GOVERNANCE STRUCTURE OF THE BEEF INDUSTRY

### 3.1 Introduction

The neoclassical analysis of production and distribution tends to assume that the operation of markets is costless. This theory is very useful for analyzing how a firm's production choices respond to exogenous changes in the economic and physical environment, and the consequences of strategic interactions between firms under conditions of imperfect competition. However, it does not explain how production is organized within a firm, how conflicts of interest between the firm's various owners, managers, workers, and consumers are resolved, or, more generally, how the goal of profit-maximization is achieved (Hart, 1989).

Principal-agent theory recognizes conflicts of interest between different economic actors in a firm, and formalizes these conflicts through the inclusion of information asymmetries and the problems of unobservability (e.g., Stiglitz, 1974; Grossman and Hart, 1983; Milgrom and Roberts, 1992). This theory investigates the nature of optimal incentive schemes that align the objectives of different actors. In this way, principal-agent theory modifies neoclassical theory significantly, but it still fails to answer the questions about organizational forms.

Theories that describe firms in organizational terms and deal with specific investment and optimal allocation of asset ownership can be categorized into two groups: transaction cost economics (Coase, 1937; Williamson, 1975, 1985; and Klein et al.,

1978), and property rights theory (Grossman and Hart, 1986; Hart and Moore, 1990, and Hart 1995). Both of these approaches deal with a firm's make-or-buy decision through a setup where contracts are incomplete (complete contingent claims contracting between trading partners is impossible due to bounded rationality), and contracting parties are bilaterally dependent through asset specificity. However, these two approaches are different in their formal settings and implications.

Theoretical developments and empirical research in transaction cost economics and property rights theory are presented in sections 3.2 and 3.3, respectively. Section 3.4 discusses the agricultural economics literature that applies incomplete contract theory. Section 3.5 analyzes the existing as well as emerging organizational structures of the U.S. beef industry in the light of transaction cost economics and property rights theory. While this chapter provides some rationale for why vertical integration has not yet occurred in the beef industry, its purpose is to provide a clear understanding of the potential role of value-based grid pricing in the absence of vertical integration.

### **3.2 Transaction Cost Economics**

Coase (1937) pointed out that markets do not operate costlessly. He argued that accomplishments of market transactions often involve various types of costs such as the costs of writing, executing, and enforcing contracts, which can be termed as transaction costs. Coase proposed that, the higher is the cost of transacting in the market, the greater will be the comparative advantage of organizing resources within the firm, *ceteris paribus*.

Alchian and Demsetz (1972) take Coase's conjecture a step further. In the light of Coase's proposition, they subscribe to a theory of the firm based on the cost of managing resources in the team production process, which asserts that, *ceteris paribus*, the lower is the cost of managing the greater will be the comparative advantage of organizing resources within the firm. They identify the essence of the classical firm as a contractual structure with (1) production by joint inputs owned by several owners, (2) a residual claimant or monitor of the team who (a) is common to all the contracts of the joint inputs, (b) has rights to renegotiate any input's contract independently of contracts with other input owners, and (c) has the right to sell his contractual residual status.

In order to align the goals of the monitor and the team, Alchian and Demsetz propose assigning the team's net earnings to the monitor, net of payments to other input agents. This reduces the monitor's incentive to shirk his duties since that directly affects his payment stream. Team members maximize their returns by employing the monitor who reduces shirking not only by the prices he agrees to pay to the owners of the inputs, but also by observing and detecting the actions or uses of these inputs. The arrangement is simply a contractual structure subject to continuous renegotiation with the central agent (firm's owner and employer) without any authoritarian control. The contractual structure arises as a means of enhancing efficient organization of team production. In particular, the ability to detect shirking among owners of jointly used inputs in team production is enhanced (detection costs are reduced) by this arrangement and the discipline (by revision of contracts) of input owners is made more economic (Alchian and Demsetz, 1972).

Williamson (1979, 1985) expands the definition of transaction costs to include the behavioral dimensions of opportunism and bounded rationality of economic agents. Opportunism refers to the possibility that economic agents act in a self-interested way “with guile,” as Williamson puts it. That is, agents may not be entirely honest and truthful about their intentions and might attempt to take advantage of unforeseen circumstances that give them the chance to exploit others. Although all agents need not be regarded as opportunistic to an identical degree, it is difficult to ascertain which ones are less opportunistic than others *ex ante*. Bounded rationality refers to the fact that decision makers have limited memories and limited cognitive processing power, which also differ among individuals. No matter how intelligent or knowledgeable an individual decision maker is, s/he cannot consider all the feasible courses of actions, especially when uncertain behavior of other agents also affects the outcome. Under these assumptions, transaction costs refer to both *ex ante* and *ex post* costs of arms-length transactions.<sup>5</sup> Williamson argues that the firms’ objective is to minimize the production costs net of transaction costs and that minimizing transaction costs is the primary motivation for adopting different governance structures.

Williamson identifies three critical dimensions for characterizing transactions: uncertainty, the frequency with which transactions recur, and the degree to which transaction-specific investments in human and physical capital are incurred. These three dimensions determine the magnitude of transaction costs under alternative governance structures. Williamson describes three main types of governance structures of

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<sup>5</sup> Conceivably, *ex ante* costs of transactions refer to search and information costs, drafting, bargaining and decision costs, and cost of safeguarding an agreement, while *ex post* costs include monitoring and enforcement costs, adaptation and haggling costs, and maladaptation costs (Williamson, 1985).

transactions: market governance, trilateral governance, and transaction-specific (bilateral and unified) governance. He then indicates how and why different types of transactions can be matched with alternative institutional settings in a discriminating way.

Williamson classifies frequency of transactions into three categories: one-time, occasional, and recurrent. Because one-time transactions are rarely observed, he maintains only occasional and recurrent frequency distinctions. Williamson also divides transaction-specific investments into three classes: nonspecific, mixed (semi-specific), and idiosyncratic investments. Transactions that do not require specific investments in physical or human capital are termed as non-specific or standardized transactions. On the other hand, transactions that require an extremely high level of specific investments (the opportunity cost of which is much higher in alternative uses) are termed as specific or idiosyncratic transactions. Semi-specific transactions with mixed (semi-specific) investments fall between the nonspecific and idiosyncratic extremes. Comparing transaction costs under alternative institutions, Williamson determines the appropriate governance structures for all three types of transactions across occasional and recurrent frequency distinctions. Figure 3.1 presents Williamson's governance structures for alternative transaction types.

Williamson claims that a traditional open market is the appropriate governance structure for nonspecific transactions of both occasional and recurring frequencies. With recurring nonspecific transactions, both parties only have to consult their own experience in deciding whether or not to continue a trading relationship. Little transaction costs are involved in switching to an alternative partner since no specific assets are required and the market is full of homogeneous, well defined, standard agents. Nonspecific but



occasional transactions are ones for which the parties in an exchange relation are less able to rely on their own experience to safeguard against opportunism. However, given that the good or service is of a standard kind, agents can rely on formal or informal rating services or experience of others which provides incentives for parties to behave responsibly. Abundance of market alternatives is mainly what protects each party against opportunism by the counterpart.

When transactions require mixed (semi-specific) or idiosyncratic (specific) investments and are occasional in nature, trilateral governance such as contracting with third party assistance is the appropriate institution form. Once the principals to such transactions have entered into a contract, strong incentives are established to see the contract through to completion. The interests of the principals in sustaining the transaction relation are especially great for highly idiosyncratic transactions. Traditional market governance cannot sustain these types of transactions, and setting up a transaction-specific (bilateral) governance structure to guard against opportunism is costly. Therefore, an intermediate institutional form is evidently needed. Third party assistance to resolve disputes and evaluation performance often has advantages over litigation in these situations.

The two types of transactions for which specialized governance structures are commonly devised are recurring transactions requiring mixed and highly idiosyncratic investments. The non-standardized nature of these transactions makes primary reliance on market governance hazardous, while their recurrent nature permits the cost of the specialized governance structure to be recovered. Williamson distinguishes two types of transaction-specific governance structures: bilateral structures (where the autonomy of

the parties is maintained) and unified structures (where transactions are removed from the market and are organized within the firm subject to an authority relation). Partnerships and alliances are examples of bilateral structures. Unified structures involve complete vertical integration.

**Table 3.1: Williamson's governance structures for alternative transaction types.**

	Investment Characteristics		
	Non-specific	Mixed	Idiosyncratic
<b>Frequency</b>			
<b>Occasional</b>	Market Governance (Open Market)	Trilateral Governance (Contracting with Monitoring/Arbitration)	
<b>Recurrent</b>		Bilateral Governance (Partnership/Alliance)	Unified Governance (Vertical Integration)

Williamson suggests that a bilateral governance structure such as joint ownership or a strategic alliance is appropriate for semi-specific (mixed) transactions. Because the degree of asset specificity is less complete in such transactions, outside procurement may be favored by scale-economy considerations. Outside procurement may also be better than vertical integration in eliciting cost control for a steady-state supply. However, a problem arises when contract negotiations or adaptations become necessary. Outside procurement often involves affecting adaptation across some market interface, which can be accomplished only by mutual agreements. Therein rests the potential conflict. On the one hand, both parties have an incentive to sustain the relationship in order to avoid the

sacrifice of valued transaction-specific economies. On the other hand, each party appropriates a separate profit stream and cannot be expected to accede readily to any proposal to adapt the contract. In order to successfully accomplish needed adaptations, the parties must have some way of declaring admissible dimensions for adjustment such that flexibility is provided under terms in which both parties have confidence. This can be accomplished by recognizing the hazards of opportunism and how those vary with the type of adaptation proposed, restricting adjustments to those where the hazards are least, and performing adjustments with an attitude that is conducive to a long-term relationship.

Incentives for trading decrease as transactions become progressively more idiosyncratic. This is because, as the specialized human and physical assets become more specialized to a single use and, hence, less transferable to other uses, economies of scale can be fully realized by the buyer. Thus, the decision centers on choosing the organizing mode with superior adaptive properties. Vertical integration becomes an obvious choice in these circumstances. The advantage of vertical integration is that adaptations can be made in a sequential way without having to consult, complete, or change inter-firm agreements. Since a single entity spans both sides of the transactions with an objective of joint profit maximization, price adjustments in vertically integrated enterprises are more complete than in inter-firm trading. Likewise, quantity adjustment can also occur at any needed frequency to maximize the joint gain of the transaction.

Williamson also attempts to explain how the governance of transactions is affected by increasing the degree of uncertainty. Non-specific transactions have little value for continuity because new relations can easily be arranged. Uncertainty does not alter that fact, so open market transactions continue and the market mechanism governs

all transactions regardless of the level of uncertainty. For mixed or idiosyncratic investments, uncertainty is important because parties have a larger stake in working out mutually agreeable contract terms. As uncertainty increases, unified governance structures (vertical integration) replace bilateral structures (partnership/alliances) in recurrent transactions.

Klein et al. (1978) add further content to the analysis of transaction cost economics by arguing that when transactions are characterized by specific investments in physical or human capital, a contractual relationship between a separately owned buyer and seller is plagued by opportunistic and inefficient behavior in situations in which there are large amounts of surplus to be divided *ex post*. And, because of the impossibility of writing a complete, contingent contract, the *ex ante* contract does not specify a clear division of this surplus. In that situation, the transaction should be organized within the firm by integration, assuming that integration yields the outcome that would arise under complete contracts.

### ***Empirical Research in Transaction Cost Economics***

Empirical economic research that applies transaction cost economics (hereafter TCE) examines whether and when particular contracting practices provide efficiency benefits. Early empirical work in this area focuses on the presence of transaction-specific investments as the critical determinant of vertical integration and long-term contracting (see Monteverde and Teece, 1982; Anderson and Schmittlein, 1984; Masten 1984; Joskow, 1985, 1988, 1990; Shelanski and Klein, 1995; Masten and Saussier, 2000). While not exhaustive, six distinct types of asset specificity are predominantly featured in

these empirical TCE applications: physical asset specificity, site specificity, human asset specificity, temporal specificity, brand name capital, and dedicated assets. Empirical results of these studies lend support to TCE suggesting that substantial efficiency gains from specific investments might be prime motives for long-term contractual relationships and vertical integration.

A number of recent papers also examine the effects of various types of asset specificity on organizational forms. In an examination of the semiconductor industry, Monteverde (1995) finds that the decision to integrate product design with manufacturing is systematically related to required investments in specific human capital. Weiss and Kurland (1997) investigate the ways that inter-organizational relationships (e.g., distribution channels) hold together and find that the level of specialized investment made by downstream partners influences manufacturers' decisions to terminate these relationships. Human asset specificity is also at issue in Hamilton's (1999) examination of prenuptial contracts. Couples signing such contracts tend to choose joint ownership of property when wives are particularly important to the "household enterprise." Ulset (1996) also finds that asset specificity, proxied by sunk costs, significantly affects the decision of Norwegian IT firms to integrate commercial research and development (R&D) projects.

An interesting historical examination of vertical integration and relationship-specific investment is Bindseil's (1997) analysis of the provision of physical assets to the London and New York Stock Exchanges. Bindseil explains the historical emergence of a vertically integrated exchange by the increasingly specific nature of the physical assets that were required to perform trades. He argues that the vertical integration of the

professional traders' association into the asset-providing firm became the optimal form of governance.

Another set of studies explore the interaction of asset specificity with other transactional characteristics that are hypothesized to affect governance choice (see Lyons, 1995; Regan, 1997; Joshi and Stump, 1999; and Saussier, 2000). Lyons (1995), for example, finds specific investments are more influential than scale or scope economies for in-house production over market procurement for the purchasing of inputs in the United Kingdom's motor vehicle, electronics and metal processing industries. Taken together, these empirical papers support the view that asset specificity in combination with other transactional considerations is an important determinant of vertical integration.

A large body of empirical TCE research examines long-term contracting and, in particular, the structure and duration of contractual relationships. Crocker and Masten (1988) examine the distortions in contract terms occasioned by non-price competition for natural gas in the presence of wellhead price regulation. They observe that deviations from optimal contract incentives significantly raise the cost of being bound to long-term agreements and shorten the duration of contracts. Pirrong (1993) argues that although transactions costs are important in bulk shipping markets, the considerations that influence contracting practices in these markets are somewhat different than those usually emphasized in TCE. Examining the markets for the shipment of fourteen separate bulk commodities, he finds that asset specificities in ocean shipping are considerably less acute than in other industries such as mine mouth coal plants and auto-body manufacturing. Thus, even if the costs of physically redeploying assets are low (as is the case in bulk shipping), spot trading may be less efficient than exchanges governed either

by more formal, enduring bilateral relationships or by direct ownership, unless the number of buyers and sellers of the assets is relatively large . These findings present a challenge to transaction cost theory.

However, more recent empirical studies have reestablished the validity of TCE. Saussier's (2000) analyzes the duration of contracts between private firms and the French state-owned power utility (EDF) for the transportation and unloading of coal to EDF power plants. Using detailed contract data, Saussier finds that the amount of site, physical and human asset specificity associated with a given transaction, as well as the presence of dedicated assets, significantly increases the duration of EDF coal contracts while greater uncertainty significantly decreases the duration of these contracts. Adler and Scherer's (1999) examination of defense procurement contracts similarly suggests that transaction cost factors, including asset specificity, incompleteness, and uncertainty have a significant influence on the specific type of contract that is employed. Dahl and Matson's (1998) analysis of the U.S. natural gas industry contracts and regulatory action presents similar findings between contract duration and specific transaction cost factors. Other notable studies that confirm the predictions of TCE include Masten and Saussier (2000) and Libecap and Smith (1999).

### **3.3 Property Rights Theory**

While the transaction cost approach aids understanding when the cost of contracting between separately owned firms is high, it does not clearly explain the costs and benefits of organizing transactions within the firm. Moreover, it does not provide a sufficiently clear definition of integration for its costs and benefits to be assessed.

Grossman and Hart (1986) develop a theory of costly contracts emphasizing that contractual rights can be of two types: specific rights and residual rights. When it is too costly for one party to specify a long list of the particular rights it desires over the other party's assets, it may be optimal for the party to purchase all rights except those specifically mentioned in the contract. Ownership is the purchase of these residual rights. Integration is the purchase of the assets of one of the parties by the other for the purpose of acquiring the residual rights of control.

Grossman and Hart argue that the relevant comparison is not between the nonintegrated outcome and the complete contract outcome but instead between a contract that allocates residual rights to one party and a contract that allocates them to another. Hart and Moore (1990) extend the theory of Grossman and Hart by analyzing a framework which is broad enough to encompass more general control structures (partnerships or cooperatives) than simple ownership. In addition, Hart and Moore specialize the meaning of residual control rights relative to Grossman and Hart by defining the sole right possessed by the owner of an asset as his ability to exclude others from the use of the asset. Hart and Moore demonstrate that, if investments are non-contractible and outcomes are non-verifiable, then the inability to fully capture incremental payoffs in *ex post* bargaining may lead to suboptimal levels of *ex ante* investment, which is known as the holdup problem. The development of property rights theory (hereafter PRT) is attributed to the works of Grossman and Hart (1986) and Hart and Moore (1990).

As a solution to the holdup problem, PRT considers the *ex ante* distribution of property rights over the physical assets. Allocation of ownership rights determines the



bargaining power of agents over the returns to investment which enhances the productivity of the assets. This in turn determines incentives to invest.

There are three ways ownership of the assets can be assigned *ex ante*: to agent A, to agent B, or to both agents jointly. Single-agent ownership entitles the agent in question to use the asset to trade with an outsider, which strengthens the agent's bargaining position in *ex post* negotiation. This gives the owner a greater incentive to invest in the relationship. Joint ownership, by contrast, prevents either agent from using the assets for third party trading (outside options) without the other's permission. According to PRT, joint ownership of an asset is suboptimal because it provides lower investment incentives for every co-owner.

The PRT approach, however, asserts that when ownership rights of the assets are assigned to a single agent, they are lost by the other, and this inevitably creates distortions. They show that, to the extent that the marginal and average values of investments move together, the allocation of ownership rights will affect the level of investment by changing the average investment return. If firm A owns firm B, firm A will use its residual rights of control to obtain a large share of the *ex post* surplus, and this will cause firm A to overinvest and firm B to underinvest. Thus, integration shifts the incentives for opportunistic and distortionary behavior, but it does not remove these incentives. However, the main implication of the PRT approach is that integration is optimal when one firm's investment decision is particularly important relative to the other firm's investment decision, whereas non-integration is desirable when both investment decisions are somewhat important.

Whinston (2003) notes that predictions of the PRT approach differ significantly from those of the TCE approach, and that the existing empirical evidence that supports the TCE approach sheds little light on the empirical relevance of the PRT approach. The TCE approach seeks to determine whether firms A and B should be separately owned and operated or if the ownership and operation of two stages should be unified. If independent, then each stage appropriates its net receipts but opportunistic behavior can arise during contract execution. In contrast, PRT views vertical integration in a directional way; either A buys B or B buys A, otherwise they remain independent and each stage appropriates its net receipts. The most significant difference between the TCE and PRT setups is that the TCE approach holds that maladaptation (opportunism) in contract execution is the principal source of inefficiency, whereas the PRT approach excludes *ex post* maladaptation by assumptions of common knowledge and costless *ex post* bargaining. All of the inefficiency in the PRT approach is concentrated in the *ex ante* investment. In addition, the TCE approach maintains that each generic mode of governance differs in incentive intensity, administrative control, access to the courts, and informal organization, while the PRT approach assumes that incentive intensity, administrative control, and informal organization are unchanged by ownership and that courts are irrelevant (because of costless renegotiation).

Since its inception, the PRT approach has been under attack. Maskin and Tirole (1999a) argue that as long as agents are able to perform dynamic programming (by the assumption of unbounded rationality, which is always invoked in the incomplete contract literature) transaction costs are irrelevant. In particular, they show that even if transaction costs prevent agents from describing physical contingencies *ex ante*, they do not

constrain the set of payoffs that can be reached through contracting in the absence of contract renegotiation. Evaluating Maskin and Tirole's (hereafter MT) critique, Hart and Moore (1999) provide a rigorous foundation for the idea that contracts are incomplete. Applying MT's irrelevance theorems in their model, Hart and Moore (1999) show that the optimal contract without describability of trades cannot be worse than the optimal contract with describability. More importantly, they find that the assumptions behind MT's irrelevance theorems are quite restrictive, and that describability matters if the assumptions are relaxed.

Chiu (1998) argues that outside options do not always confer as much bargaining power upon agents as the PRT approach suggests. He shows that the presence of a nonbinding outside option has no effect on the bargaining outcome at all. More importantly, because the presence of a binding outside option makes the agent the residual claimant of his investment, he may have a greater incentive to invest when owning fewer assets. While dealing with similar issues, De Meza and Lockwood (1998) suggest that if genuine outside options are available, then asset ownership may discourage investment. Rajan and Zingales (1998) develop a more general theory of power in organization and show that asset ownership has adverse effects on the incentive to specialize. They argue that regulation of access to critical resources can be a better mechanism than allocation of asset ownership because the power acquired by agents from access is more contingent on their making the right investment.

Revisiting the proposition of PRT that joint ownership is suboptimal, Maskin and Tirole (1999b) argue that ownership by a single party is dominated by joint ownership with put options. Cai (2003) and Matouschek (2004) investigate the situations in which

joint ownership is optimal. Cai offers a theory of joint ownership by extending the property rights theory of the firm to situations where parties can endogenously choose the degree of specificity of their investments. He shows that when specific and general investments are complements, the standard PRT results are obtained and joint ownership is suboptimal. But, when specific and general investments are substitutes, joint ownership is optimal as long as trade takes place within the relationship. Matouschek shows that joint ownership is optimal if the managers' expected gains from trade are large and that either integration or non-integration is optimal if the expected gains from trade are small. While both the PRT and TCE approaches play down the role of natural risk in the organization of the firm, Hanson (1995) views the choice of ownership structure as involving a trade-off between minimizing holdup risk and spreading natural risk.

A growing theoretical literature has suggested contractual solutions to the hold-up problem where two parties can mitigate the incompleteness of their contract by incorporating a scheme for renegotiating the terms of trade *ex post* into their initial non-contingent contract (Hart and Moore, 1988; Aghion et al., 1990; Chung, 1991; Hermalin and Katz, 1993; Noldeke and Schmidt, 1995) or by stipulating an efficient remedy to breach, such as expectation damages (under this rule, an agent may unilaterally decide to breach a contract if he pays the other agent an amount sufficient to give her what her profit would have been under performance, measured *ex post*) or specific performance (MacLeod and Malcomson, 1993; Edlin and Reichelstein, 1996; Zhu, 2000). Rogerson (1992), De Fraja (1999), and Che and Chung (1999) show that investment sequentiality makes these contractual solutions immune to the additional complication of two-sided direct externalities introduced by Che and Hausch (1999). Some studies have introduced a

third party, viewed as an outsider who does not invest (Aghion and Bolton, 1997; Spier and Whinston, 1995) or an insider who invests (Fares, 2004), in the bilateral relationship. In either case, the contracting parties extract rents from the third party by increasing expectation damages and thus reducing the possibility of breach.

Another solution to the holdup problem is self-enforcing relational contracts, which are informal agreements and unwritten codes of conduct sustained by the value of a future relationship. Relational contracts within and between firms help circumvent difficulties in formal contracting only if they are self-enforcing, i.e., the long-run value of the relationship must be greater than the short-run value of renegeing such that neither party wishes to renege. Self enforcement depends crucially on continuity in the relationship. Formal modeling of relational contracts usually takes the form of a repeated game.

Baker, Gibbons, and Murphy (2002, hereafter BGM) develop a repeated game model showing why and how relational contracts within firms (vertical integration) differ from those between firms (nonintegration). They consider a production chain where an upstream party uses an asset to produce a good that can be used either in a downstream party's production process or in an alternative use where the upstream party's actions affect the value of the good in both of these uses. Employing Grossman and Hart's (1986) terminology of integration (i.e., when the upstream party owns the asset, the transaction is called nonintegrated, and when the downstream party owns the asset, the transaction is called integrated) and assuming that ownership of the asset conveys ownership of the good, BGM examine whether choosing appropriate asset ownership (integration or nonintegration) can make a given promise self-enforcing. The main proposition of BGM

is that integration affects the parties' temptations to renege on a relational contract, and hence affects the best relational contract the parties can sustain. It immediately follows that firms cannot mimic the spot market outcome after a transaction is brought inside the firm because the renegeing temptation is too great. This proposition has two principal implications: first, vertical integration is an efficient response to widely varying supply prices because this reduces renegeing temptations in such situations and, second, high-powered incentives create greater renegeing temptations under integration than under non-integration.

### ***Empirical Research in Property Rights Theory***

Whereas empirical applications of TCE have been growing exponentially since the 1980s (the number of published studies exceeds 500, Williamson 2000), Oliver Hart reports that "Unfortunately, there has to date been no formal test of the property rights approach..." (Hart, 1995, p. 49). This is mainly because the data relevant to PRT are limited and inaccessible. Williamson (2000) points out that the shift from *ex post* maladaptation to *ex ante* investment distortions is responsible for PRT making limited contact with the data. However, a few recent studies attempt to test the property rights model using firm-level data.

Hanson (1995) uses aggregate data on Mexican apparel subcontracting to test a version of the Grossman and Hart model incorporating natural risk. He examines a garment manufacturer's choice of how to divide ownership of physical assets between himself and a subcontractor in the presence of natural and holdup risks. From the risk-adjusted holdup model, Hanson predicts that the manufacturer concentrates ownership

(subcontracts a relatively small share of production) when natural risk is low and decentralizes ownership (subcontracts a relatively larger share of production) when holdup risk is low. Empirical results from a Tobit estimation technique support the predictions from his risk-adjusted holdup model that manufacturers subcontract a high share of production when demand is highly variable and a low share when they make large relation specific investments.

Woodruff (2002) provides a test of PRT using data on manufacturer-retailer integration in the Mexican footwear industry. Drawing a distinction between the transaction cost approach and property rights approach, he notes that efficient ownership depends not only on the degree of specificity of investments (as TCE suggests), but also on the importance of those investments in determining the profits of the trading relationship (as PRT suggests). Empirical results from a probit model provide support for prediction from the property rights framework that independent ownership is more likely in segments with high fashion turnover.

Baker and Hubbard (2003) find that independent ownership of long-haul trucks in the US decreased following technological changes allowing greater contracting scope. More recently, Elfenbein and Lerner (2003) examine the structure of ownership and control rights of more than 100 alliances by Internet portals and other firms between 1995 and 1999. Their empirical tests provide support for predictions of two property rights models: the PRT model, which predicts that assets in a bilateral relationship should be owned by the party whose marginal effort has the greatest impact on the value of the relationship; and Aghion and Tirole's (1994) model of contracting for innovation, which

suggests that relative bargaining power, in addition to the marginal impact of effort, is an important determinant of the allocation of property rights.

### **3.4 Agricultural Economics Research Employing Incomplete Contract Theory**

There has been little systematic analysis of the organization of agriculture from the incomplete contracting perspective. Masten (2000) notes that “agricultural transactions provide a rich and largely unexplored area for application and refinement of transaction cost theory” (Masten 2000, p. 190). Barry et al. (1992) recognize the theoretical developments in TCE and urge that “agricultural economists have important potential contributions to offer in evaluating the changing structure of relationships in agriculture” (p 1224).

A number of case studies analyze different forms of vertical coordination in agriculture employing TCE. Hendrikse and Veerman (2001a) analyze the relationship between the financial structure of a marketing cooperative and the requirement of the domination of control by the members from a transaction costs perspective. Masten (2000) examines the nature of agricultural production, processing, and distribution. He argues that physical and human asset specificities play a less important role in agricultural transactions in comparison to the temporal and location specificities.

Hennessy and Lawrence (1999) examine the vertical transaction relations between growers and processors in the U.S. hog industry in the context of existing theories on the nature of the firm. Knoeber examines the governance structure of fruit and vegetable processing and dairy processing (1983), and broiler production contracts (1989) from a TCE perspective. Other notable studies include Read’s (1983) analysis of the evolution of



organizational arrangements in the U.S.-Caribbean banana trade, Gallick's (1996) study of the relations between tuna harvesters and processors, and Cozzarin and Westgren's (2000) and Cozzarin and Barry's (1998) studies of the choice of organizational form in industrialized hog production.

Several empirical studies examine the extent and use of contracting in agriculture. Allen and Lueck (1992a) investigate how the choice between crop sharing and fixed rent contracts is related to the level of production risk associated with particular crops. Allen and Lueck (1992b) also examine oral and short-term rental contracts in US farmland employing TCE. Lajili et al. (1997), Alston and Higgs (1982), and Allen and Lueck (1993; 1996) are other notable empirical studies on agricultural contracting issues. Studies on agricultural policy issues that make use of TCE reasoning include Frank and Henderson's (1992) analysis of downstream food markets, Globerman and Schwindt's (1986) and Goedecke and Ortman's (1993) study of forestry, and Vatn's (1998) examination of environmental taxes. Recently, Huffman and Just (2004) have analyzed land tenancy contracts, both in developed and developing countries, applying modern agency theory.

Two notable studies on the beef industry which employ the TCE approach are Purcell (1990) and Purcell and Hudson (2003). Purcell studies the growth of long-term contracting and the prevalence of integration between feedlots and beef processors due to site specificity. Based on TCE, agency theory, and the resource theory literature, Hudson and Purcell develop a conceptual framework for strategic alliances in the beef industry and analyze strategies for sharing feeding and packing margins.

Whereas the literature applying TCE to explain the changing structure of agriculture has been growing, the potential of PRT has yet to be well recognized by agricultural economists. Recently, in the light of PRT, Johnson and Melkonyan (2003) have developed a model explaining the consolidation pattern in the agricultural biotechnology industry. Hendrikse and Veerman (2001b) formulate a theory regarding the choice of governance structure in agricultural chain production from a property rights perspective.

### **3.5 Implications of Incomplete Contract Theory for the Traditional and Emerging Governance Structures of the Beef Industry**

While increasing trends in some forms of vertical coordination such as short-term marketing agreements and forward contracts for fed cattle procurement, alliances, and custom cattle feeding contracts have increased in recent years, distinct vertical sectors of the U.S. beef industry still rely heavily on spot market transactions. Field and Taylor (2002) suggest that although contractual arrangements are likely to become predominant, vertical integration by ownership is unlikely in the beef industry for two main reasons. First, since the cow-calf and stocker sectors are land-based and have low margins, players further down the supply chain are unlikely to be interested in assuming the related risk and debt. Second, the size and scope of the beef industry is too cumbersome to facilitate total ownership. Lawrence and Hayenga (2002) suggest that greater length and breadth of the multiple stage supply chain and little differentiation in intermediate and final products are the main reasons for the beef industry sectors to rely on spot market transactions. They further mention that most cattle producers prefer independent decision making in their production management and marketing decisions.

Ward (1997) identifies several impediments to vertical integration in the beef industry. First, the extent of physical and human capital required to organize breeding, cow-calf operations, intensive feeding, and slaughter and packing within one firm is immense. Second, diversity of physical and human capital needed for distinct production stages increases the difficulty in managing a vertical beef production unit. Third, with the diverging genetic base and the relatively long biological cycle of beef cattle, controlling quality and consistency of beef products is difficult. Finally, since beef is primarily marketed in fresh form as a commodity rather than as differentiated products, the economic incentive to vertically integrate, develop value-added products, and use product differentiation as a profit opportunity is weak.

Ferrier and Lamb (2007) argue that federal regulation of beef production has played a critical role in shaping the structure of the industry from the ranch through the feedlot and the supermarket. The USDA beef grading system began as a voluntary one-year experimental program in 1927 and marked the first national effort to create federal quality assurance standards for beef products. The voluntary beef grading system was formalized by the Agricultural Marketing Service Act of 1946, and its original format has remained basically unchanged despite adjustments in terminology and individual grade requirements (Ferrier and Lamb, 2007). The USDA grading system assigns two grades to beef: yield grade (1, 2, 3, 4, and 5) and quality grade (Prime, Choice, Select, Standard, Commercial, Utility, Cutter, and Canner). Grading of beef products according to the USDA yield and quality grades has grown substantially since about 1950 (Pierce, 1976). Currently, nearly all beef products sold through commercial outlets in the US are subject to USDA grading (Ferrier and Lamb, 2007). Ferrier and Lamb suggest that the embodied

incentive structure of the USDA's beef grading system encouraged product homogeneity at the expense of product differentiation, which led to the eventual commoditization of the intermediate and consumer products.

While the above explanations are valuable, incomplete contract theory offers further insights for analyzing traditional as well as emerging governance structures of the beef industry. According to the incomplete contract theory literature (such as for TCE and PRT), when transactions between two parties involve specific investments, they may engage in opportunistic behavior in an attempt to appropriate the quasirents generated by the specific investments.<sup>6</sup> This gives rise to a potential holdup problem, which leads to efficiency losses in production and market transactions because the specific investments in different stages become suboptimal in the presence of opportunistic behavior. Such circumstances call for an efficient governance structure under which first best outcomes can be achieved if possible. While complete contingent contracts designed to eliminate the incentive for opportunism could restore efficiency in production and transactions, contracts in reality are often incomplete because of unforeseen contingencies and the costs of writing and enforcing contracts. Considering the degree of idiosyncrasy of transaction-specific investments and the nature of transaction relations, TCE and PRT suggest alternative governance mechanisms that appear to fit the beef industry organization.

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<sup>6</sup> Throughout this section, specific investments refer to the investments that are only valuable (or are much more valuable) in the context of a specific transaction relation between two parties (i.e., the investments have high opportunity cost without the transaction relation). Investment specific to an industry not necessarily be transaction-specific in that sense.

### ***Traditional Governance Structures: Spot Market Transactions***

Historically, open market operations have been the predominant transaction mechanism for cattle and beef products. Supermarket retailing in the US grew rapidly after World War II (Ferrier and Lamb, 2007). Organized primarily as resale outlets for finished food products, supermarkets sought consistent supply of uniform retail beef cuts differentiated by USDA grades. In order to meet supermarkets' demand, meat packers eventually absorbed many of the processing activities of the butchers. Starting with Iowa Beef Packers (IBP) in the 1960s, meat packers began dividing carcasses into individual cuts, sorting various cuts according to USDA grades, packing them into separate boxes, and shipping "boxed beef" to supermarkets (Ferrier and Lamb, 2007). Thus, with the USDA grading system in place, supermarket retailing provided incentive to beef packers for investing in beef processing and *ex post* sorting of carcasses according to quality grades and retail cuts. Such investments were unlikely to be specific to a particular transaction relation as there were several national (e.g., A&P, Kroger, Piggly Wiggly, Safeway, Supervalu, etc.) and local supermarket chains. Moreover, given that USDA grades captured the quality of beef, supermarkets could advertise and sell boxed beef of the same grade as homogenous products. According to TCE, a market mechanism is the appropriate governance structure for transactions of such homogeneous products.

With the emergence of supermarket retailing of beef products of various USDA grades and cuts, beef packers did not have an incentive for investment in product differentiation by other criteria. Nonetheless, *ex post* sorting of carcasses induced *ex ante* sorting of live animals in fed cattle markets. Historically, beef packers acquired fed cattle through transactions in open outcry auction markets with numerous buyers and sellers.

With the growth of the USDA grading system, beef packers (usually through commissioned buyers) started subjectively evaluating the probability of carcass grades based on the physical appearance of the live cattle and building those probabilities into their bid prices.<sup>7</sup> However, because of the high sunk costs of slaughter and packing plants, beef packers have been primarily concerned with the capacity utilization of their plants by means of a consistent supply of fed cattle, which have been secured through the use of traditional livestock auction markets.

With the coarse fed cattle grading system in place (e.g., 20%-35% Choice, 35%-65% Choice, 65%-80% Choice, etc.), and fairly narrow price differentials across grades, cattle producers have had little incentive to invest in beef quality improvement. Cattle producers have been motivated primarily by the goal of producing more beef at a lower cost. Technological developments in agricultural production and animal husbandry have helped achieve this goal. With the development of high yielding variety seeds and availability of improved fertilizer, corn yield increased dramatically by the mid-1950s. Availability of cheap corn allowed feedlots to use corn extensively in feedlot rations, which, in turn, increased average daily gain and harvest weight of feedlot cattle (Ferrier and Lamb, 2007). On the other hand, average live- and dressed-cattle weights further increased and feed conversion ratios decreased with the development of artificial insemination and new hybrid breeds in the 1960s (Field and Taylor, 2002).<sup>8</sup> Animal science research shows that hybrid breeds, such as Beefmaster and Brangus, produce a

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<sup>7</sup> Typically, each individual lot of fed cattle in auction barns is graded according to the probability of Choice carcasses such as 20%-35% Choice, 35%-65% Choice, 65%-80% Choice, etc.

<sup>8</sup> Beefmaster, Braford, Brahmousin, Brangus, Nellore, Red Brangus, Santa Gertrudis, Simbrah, etc. are commonly used hybrids in the United States for beef production (IMS, 2001).

less tender meat than the traditional European breeds, but tend to perform adequately within the USDA grading system (Ferrier and Lamb, 2007; Wheeler et al. 1994, 1999).

Thus, commercial cattle feeders have paid little attention to quality control, but more attention to feedlot performance of the cattle (e.g., feed efficiency and average daily gain) and animal turnover rates. Apart from the genetic potential, feedlot performance of an individual animal also depends crucially on feeding and animal health management practices. Commercial cattle feeders therefore invest in specialized production and management skills which improve feed efficiency and average daily gain. Such investments traditionally have not been specific to any transaction relation and, thus, provide no incentive for feeders to enter into non-market transaction relations with beef packers or cow-calf producers.

For cow-calf producers, beef cattle production is typically one of many on-farm production activities. Traditional cow-calf operations have been relatively small but, in some cases, have somewhat flexible investments in grazing land (often rented or leased) and specialized but liquid investments in their breeding animals. Thus, even though some of the investments by the cow-calf sector are specialized (for example, as in the case with poultry or hog contracting where contractor-specific standards are often required on production barns), they are not specific to a particular transaction relation. Incomplete contract theory (TCE and PRT) implies that open market transactions are the appropriate governance structure for traditional cattle transactions in such circumstances.

A steady rise in beef demand beginning from the end of World War II until the mid-1970s also suggests that open market mechanisms had been, at least in part, successful in transmitting signals about consumer preferences to upstream producers.

However, demand for beef began to decline by the end of the 1970s and continued to decline through the late 1990s (Ferrier and Lamb, 2007). Researchers argue that the erosion in beef demand was due mainly to increasing consumer concern for quality and consistency of meat products and a decline in beef quality relative to the quality of other meat products such as chicken and pork (Purcell, 1999; Schroeder et al., 1998; and Lamb and Beshear, 1998). Ferrier and Lamb (2007) further argue that the fairly coarse USDA grading system is responsible for the decline of relative beef quality because it provides incentives to cattle producers to introduce larger and heartier cattle breeds that produce less tender beef while performing reasonably well on the USDA grading system.

While beef producers were looking for a solution to the problem of declining beef demand, the Beef Promotion and Research act of 1985 allowed “generic advertising” of beef at the national level. But, the effects of generic advertising in raising beef demand were found to be only marginal (Brester and Schroeder, 1995; Coulibaly and Brorsen, 1999; Kinnucan et al. 1997). In such circumstances, beef processors have made further attempts to improve the overall quality and consistency of beef products and introduce superior quality retail beef cuts differentiated by criteria other than the traditional USDA grades (e.g., branded and process-verified beef products). A consistent supply of superior quality beef products, in turn, requires a consistent supply of high quality fed cattle with the advertised product differentiation to processing plants. But, with a fairly narrow price differential across lot-average fed cattle grades in conventional auction markets, cattle producers have had little incentive to supply high quality animals given requirements for specialized and costly investment in animal quality control. Beef processors, therefore, have adopted a variety of non-spot fed cattle procurement methods to secure a consistent



supply of animals with desirable characteristics in their plants. Such initiatives have introduced new governance structures in the beef industry such as short-term marketing agreements for fed cattle transactions and strategic alliances.

### ***Emerging Governance Structures: Marketing Agreements and Strategic Alliances***

In an attempt to provide a clear signal about the quality of their products to consumers, and also to identify their products and differentiate their offerings from competitors, beef processors have adopted several certifications (or brands) and process verification programs. Such programs require *ex ante* control of inputs (including the animal) in different stages of production in addition to *ex post* sorting of outputs (carcasses) into narrowly identified quality groups that provide the necessary consistency. Alternatively, beef processors have adopted value-based grid pricing mechanisms to supplant traditional lot-average pricing methods for fed cattle procurement. Under grid pricing, each individual animal is valued according to *ex post* measures of yield and quality of the carcass. Thus, grid pricing is a way to control beef quality by *ex post* output measurement.

### ***Certification and Process Verification Programs: Ex Ante Input Control in Addition to Ex Post Output Measurement***

Apart from the traditional USDA quality grades, beef processors have introduced an additional quality grade for beef products of certain brands qualifying for USDA certification programs (e.g., Certified Angus Beef and Certified Hereford Beef). The USDA certification programs require animals to meet independent quality standards (e.g., breed, age, and weight) at the time of slaughter. The quality standards are typically set by

beef packers (or private producer organizations) and are inspected by USDA graders at the time of slaughter. The rank of the quality grade of such certified (branded) beef products typically falls between Prime and Choice.

The use of USDA certification programs increased dramatically in the mid-1990s (Ferrier and Lamb, 2007). At the same time, beef processors also introduced process-verified beef products. A process verification program is typically characterized by process criteria set by a beef packer (or a producer organization) and the USDA agents auditing the entire production process by inspecting the ranches, feedlots, and packing plants to ensure that process criteria are met (Ferrier and Lamb, 2007). Most process verification programs specify the breed and age of the animal, the source of the animal's origin, feed mix to be used, and that growth hormones are not to be used. Thus, process verification programs explicitly control inputs.

The trademark for each certification and process verification program and its standards are owned and controlled by a private party (e.g., a beef packer or a producer organization such as the PM Beef Group of Kansas City or US Premium Beef), while the Agricultural Marketing Service of the USDA administers the program by acting as the independent inspector (Ferrier and Lamb, 2007). However, introduction of branded and process-verified beef products typically involves significant investments in the development of new market outlets, advertising, promotion, and related reputation risks. Such investments have little value in alternative uses and thus can be termed as idiosyncratic following TCE.

USDA certification programs involve highly specialized investments by different sectors of the beef industry. While beef packers make significant investments in brand

development and promotion, most large certification programs require cattlemen to deliver cattle of specific breeds (e.g., Angus or Hereford) and carcasses to meet at least the Choice grade standard. Moreover, the standards of each certification program are specific to the owner of the trademark, and are thus often different than others. For example, the requirements for breed, age, and weight of the animal and minimum carcass quality standards may be different in alternative branded beef programs. When cattlemen raise cattle targeted to a particular certification program, their cattle will likely not qualify for other certification programs. Thus, cow-calf producers' investment in producing calves of a particular breed and post-natal management and feedlot operator's investments in raising those cattle are transaction-specific. Compared to the certification programs, the degree of idiosyncrasy of the cattlemen's specialized investments is thus even higher with process-verification programs, because such programs require specific inputs in every stage of the production process.

Transaction cost economics implies that, when the levels of specialized investments by the vertically-related beef sectors are very high (idiosyncratic), vertical integration is the appropriate governance structure for recurrent transactions between the parties, and contracting with third party arbitration or monitoring is appropriate for occasional transactions.<sup>9</sup> When the level of specialized investments is moderate (mixed or semi-specific), joint ownership or an alliance is appropriate for recurrent transactions, and contracting with third party arbitration is appropriate for occasional transactions. This

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<sup>9</sup> According to TCE, vertical integration is also appropriate when recurrent transactions are conducted under a high degree of uncertainty. Also, for occasional transactions, the need for a more elaborate arbitration apparatus increases with the degree of uncertainty (Williamson, 1979).

classification of governance structures appears to fit well the emerging organization of (non-spot) transactions in the U.S. beef industry.

Since the goal of the packers in breed alliances and closed (natural/implant-free) cooperatives is to market branded or process-verified beef products, the level of their specific investments is higher compared to the marketing alliances.<sup>10</sup> The levels of other alliance members' (cow-calf producers' and cattle feeders') specific investments are also higher compared to other cases. For example, as a member of such an alliance, a cow-calf producer must adopt a particular genetic/breeding program and follow specific pre- and post-natal production practices. Similarly, member feeders also must adopt a prescribed nutritional and health management program. While TCE suggests a unified governance structure in this case, members in breed alliances and closed cooperatives are still independent business entities. Usually, they share the joint surplus of their cooperative activities on the basis of a rule (equity or non-equity based) set by themselves. A plausible explanation for this particular organizational form may be that the degree of idiosyncrasy of the alliance members' specific investments is still not high enough so that transaction costs could be further reduced by vertical integration.

However, input control systems like certification and process verification programs are difficult to develop and administer because of the high degree of asset specificity and relevant holdup issues. Moreover, because of a diverse genetic base of beef cattle, their long biological cycle, and the small scale of beef production herds, monitoring producer actions that influence beef quality is prohibitively expensive (Ferrier and Lamb, 2007). Most beef quality improvement programs in the United States are,

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<sup>10</sup> A significant amount of investment is required for product development and promotion, the opportunity cost of which is very high as such investments are not recoverable elsewhere.

therefore, oriented primarily towards *ex post* measurement of carcass attributes with greater accuracy rather than *ex ante* input controls in successive production stages.

### ***Value-Based Grid Pricing: Ex Post Measurement of Carcass Attributes***

With value-based grid pricing, producers are compensated according to *ex post* measures of yield and quality of carcasses (e.g., marbling, fat thickness, rib eye size, etc.), reflecting USDA grades. In contrast to traditional lot-average pricing methods, grid pricing offers premiums (discounts) for higher (lower) quality attributes of each individual carcass, thus improving pricing accuracy and rewarding cattlemen who deliver desirable types of cattle. However, *ex post* measurement of carcass attributes requires investment in physical capital (e.g., equipment and devices for measuring carcass attributes) and human capital (e.g., skills for grading carcasses). Although such investments are somewhat specialized, they usually are not specific to a particular transaction relation. For example, the scale for measuring rib eye area and the certified USDA grader can be used repetitively in measuring and grading carcasses obtained from different producers.

Pricing of fed cattle based on *ex post* carcass attributes provides an opportunity for the producers (feedlot operators and cow-calf producers) to realize potential returns against their costly investments in superior quality animal production. The grid pricing system provides incentives for feedlot operators to procure better quality feeder cattle and adopt appropriate feeding and animal health management practices that ensure efficient weight gain by the cattle with a desirable percentage of carcass fat. Such activities require specialized investment in physical as well as in human capital. For example, proper

identification and monitoring of individual animals in the feedlot requires additional investment in physical capital (e.g., digital ear tags and scanners), while investments in human capital are required for proper feedlot management practices (e.g., special training of cattlemen for beef cattle nutrition and Total Quality Management practices) and documentation. The opportunity costs of some of those investments are likely to be high because they may not have much value in alternative uses. For example, investment in digital ear tags and keeping biological history and performance records of each individual animal are sunk costs once these tasks have been completed.

With the grid pricing system, cow-calf producers have a higher incentive to produce calves with greater feedlot and carcass performance potential, which also requires specialized investment. Cow-calf producers' investments in pre- and post-natal management (e.g., genetic selection, breeding, and feeding in the post-weaning period) determine initial marbling and lifetime growth potential of an animal. But, producers are yet to find the right breed of beef cattle that consistently and efficiently produces superior quality meat.<sup>11</sup> While cow-calf producers have been searching for the appropriate breed using planned crossbreeding programs, a cow produces only one calf per year and about 24 months of growth are required to learn whether the breeding process resulted in beef with desirable quality traits (Ward, 1997). Thus, with a long biological cycle and a wide genetic base for beef cattle, cow-calf producers' costly investments in breed development for a particular set of incentives do not have alternative uses.

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<sup>11</sup> While technological development contributed to the improvement in beef production efficiency, the genetic base of beef cattle widened with the scientific research in seedstock breeding (Field and Taylor, 2002). Currently, there are more than 250 breeds of beef cattle in the world. More than 60 of these breeds are present in the United States (Greiner, 2002).

The grid pricing system typically involves short-term marketing agreements in which the cattle owners (the feedlot or cow-calf producer) are not locked-in with the packers until two to four weeks prior to slaughter. The cattle owners (the feedlot operators or cow-calf producers) can choose between competing grids and traditional pricing methods (live- and dressed-weight pricing) before committing to such an agreement. Typically, cattle owners compare the pricing schemes in several available grids and choose the one that fits their cattle. Since several competing packer grids are available, the frequency of marketing agreements between a particular cattle owner and a packer is most likely to be occasional. Moreover, transactions of fed cattle on the basis of grid pricing are typically characterized by a mix of generalized and idiosyncratic investments by the cattle owner. Examples of generalized investments include feedlot operators' investments in facilities, equipments, and feed, and cow-calf operators' investments in herd management. Feedlot operators' investment in and use of disposable ear tags for identifying and monitoring individual animals and cow-calf producers' investment to increase initial marbling during the post-weaning period are idiosyncratic, because traditional live- and dressed-weight pricing do not offer any return against such investments.. Thus, according to TCE, grid pricing of fed cattle through a short-term marketing agreement is an appropriate governance structure given the nature of investments and frequency of transactions.

Ward and Bliss (1989) suggest that beef packers have an incentive to procure fed cattle through long-term marketing agreements and forward contracts to maintain year-round slaughter schedules. Cattle feeders may also have an incentive to enter into such contracts or agreements to secure a market outlet for their cattle. However, cattle feeders

have been less willing to enter into such long-term transaction relations with beef packers mainly because of the uncertainty about the performance potential of feeder cattle with a diverse genetic base. Since cattle are traditionally fed in open lots, climatic conditions influence animals' performance (e.g., feed efficiency and average daily gain). As a result, the extent of use of long-term marketing agreements and forward contracts has remained low and stagnant during the last two decades.

As discussed in the previous chapter, fed cattle are also priced on the basis of a grid in marketing alliances (commercial beef carcass alliances) between beef packers, cattle feeders, and cow-calf producers. Members of such an alliance make frequent transactions among themselves. However, the levels of their specific investments are likely to be the same as in short-term marketing arrangements. This is because in both types of organizations (marketing alliances and marketing arrangements) the goals of the beef packers (procure high quality cattle through an incentive scheme) and cattle owners (earn quality premiums for marketing high quality cattle) remain the same. Typically, the alliance manager supervises the transaction between the parties in exchange for a fee. Thus, following TCE, the difference in the forms of these two organizational structures is simply a result of the differences in the frequency of transactions.

Compared to certification and process verification programs, the degree of idiosyncrasy of specialized investment is much lower with grid pricing. The development and implementation of a grid pricing system is also less expensive. Moreover, grid pricing can be applied more widely in the industry whereas branded and process verified beef programs are highly specialized. Thus, as an alternative way to improve beef quality,



grid pricing (*ex post* output measurement) appears to have a greater potential than certification and process verification programs (*ex ante* input control measures).

### ***Other Forms of Governance***

In the case of retained ownership of their cattle until slaughter, cow-calf producers usually feed them in commercial feedlots on the basis of contractual arrangements or joint ownership programs. Such transactions may also be characterized by semi-specific investments by one or both parties and occasional or recurrent frequencies. In the case of occasional frequency, contract cattle feeding with monitoring minimizes transaction costs according to TCE. Joint ownership programs are optimal for recurrent transactions. Both forms of such governance structures are observed in reality.

A possible source of transaction costs in the beef industry is site-specificity of vertical business entities. The cost of transportation (freight charges and shrink) of feeder cattle from ranch to feedlot and fed cattle from feedlots to packing plants have led some feedlots and packing plants to locate near one another. Also, because feeder animals and feed grains are the principal inputs in the feedlot, the location of cattle feeding operations is generally concentrated where calves are raised or in places where feed grains are produced.<sup>12</sup> Such investments are thereafter not moveable except at prohibitive costs. In such situations, recurrent transactions between the parties are most likely and they may engage in opportunistic behavior giving rise to a potential holdup problem. A unified governance mechanism is suggested by TCE as the most efficient organizational form in

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<sup>12</sup> In the 1960s, the economies of specialization and scale in cattle feeding, and increased feed grain supply in the High Plains, led to the rapid industrialization and relocation of cattle feedlots (Lawrence and Hayenga, 2002).

this situation. But, there is little empirical evidence of integration between packers and feedlots or feedlots and cow-calf operations.<sup>13</sup>

While TCE seems unable to explain why the vertical beef sectors are not integrated even in the case of site-specificity, PRT provides a plausible explanation. It predicts that integration may not be efficient when the investment decisions of all the parties in a transaction are somewhat important, because there may be holdup from both sides. In such situations, independent operation and spot market transactions may be preferable to both parties. However, with independent vertical segments and spot market transactions, the holdup problem remains unsettled and PRT does not yield a solution.

The subsequent property rights literature that seeks contractual solutions (with a provision for renegotiating the terms of trade *ex post*) to the holdup problem may be helpful to better understand the organizational structure in this case. Recent property rights literature (e.g., BGM) postulates that ownership of the asset conveys ownership of the good (the asset could simply be the legal title of the good) and examines whether appropriate ownership of the good can make a given promise self-enforcing. From this perspective, in the absence of integration of the beef supply chain, retained ownership of cattle in combination with contract cattle feeding and value-based pricing of fed cattle may enforce the first best outcome.

### **3.6 Conclusion**

This chapter provides a theoretical economic explanation for the traditional and emerging governance structures of the US beef industry. First, relevant theoretical and

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<sup>13</sup> Very recently, there have been a few attempts to fully integrate the beef production process with a single firm coordinating genetic selection, feeding practices, slaughter and fabrication, and marketing (Hueth and Lawrence, 2003; GIPSA-USDA). Those attempts are, however, minor in the overall beef industry.

empirical industrial organization literature, such as TCE and PRT, are revisited. Then, the historical and contemporary governance structures of the beef industry are analyzed in the light of TCE and PRT perspectives. Open market mechanisms have been the predominant form of governance structure for transactions of intermediate and final products of the industry. Analyzing the organizational details of the beef industry, traditional transactions are characterized by generalized investments (not specific to particular transaction relations). Accordingly, with the traditional USDA grading system, breeders and feeders have had limited concern for beef quality and little incentive to invest in beef quality control. According to TCE and PRT, open market operations are the appropriate governance mechanism in this situation.

However, as demand for beef started to decline with increasing consumer concern for relative quality and consistency of beef products, beef industry participants have attempted to market a higher proportion of superior quality beef and to further differentiate beef products with criteria other than USDA grades. Spot market transactions of cattle have been found to be inadequate in transmitting signals about the value of beef quality to upstream producers and unable to align the incentives of successive vertical sectors in the supply chain for the case of differentiated products. In this circumstance, some beef processors have adopted *ex post* output measurement (e.g., grid pricing) and *ex ante* input control (e.g., certification and process verification programs) mechanisms as alternative ways to control beef quality. In terms of TCE and PRT, such measures have induced transaction-specific investments in successive vertical sectors of the industry. As explained by TCE and PRT theories, these have given rise to new governance structures such as marketing agreements for fed cattle transactions and

strategic alliances. Following TCE, I argue that the degree of idiosyncrasy of specific investments by any of the sectors of this industry is still not high enough so that transaction costs could be further reduced by vertical integration. Following PRT, I further argue that vertical integration may not be an efficient governance structure because beef quality improvement requires specific investments by all relevant sectors of the beef industry (e.g., beef processing, cattle feeding, and cow-calf production) which cause holdup from each side in a transaction.

As an alternative way to control beef quality, grid pricing appears to have a greater potential than certification and process verification programs, which are characterized by highly specific investments and holdup issues. Moreover, grid pricing can be applied much more broadly in the industry whereas branded and process verification beef programs are highly specialized. Thus, the remainder of this dissertation focuses on analysis of grid pricing in contrast to traditional pricing methods.

While TCE and PRT appear to be useful in explaining the changing governance structure of the beef industry, a mathematical model incorporating the insights of incomplete contract theory might also be helpful in formalizing the analysis. However, this is beyond the scope of this dissertation. The next chapter presents a multitask principal-agent model that examines the optimal incentive schemes for cattle feeding contracts under traditional lot-average and modern grid pricing methods for fed cattle.

## CHAPTER 4

### A MULTITASK MODEL FOR CATTLE FEEDING CONTRACTS

#### 4.1 Introduction

The analysis of Chapter 3 suggests that, in the absence of vertical integration in the beef industry, value-based grid pricing may be applied as an alternative way to improve overall quality and consistency of beef products. Grid pricing provides an opportunity for cow-calf producers to retain ownership of animals until slaughter and realize potential returns against their costly investments in genetic selection, breeding, feeding, and health management in the post-weaning period. In cases of retained ownership of animals through slaughter, cow-calf producers typically have feeder cattle fed in commercial feedlots on the basis of contractual arrangements.

Commercial cattle feeders undertake several tasks when feeding beef cattle. While the primary duty of a feedlot operator is to add weight to the live animal, a cattle feeder is also responsible for the growth rate, feed efficiency, and potential yield and quality of the carcass. These outcomes crucially depend on the nutrition and health management practices adopted by the feeder during the entire feeding phase. Consistent supply of a balanced diet with appropriate energy and protein content and the use of growth promoting implants are the two most important choices of the commercial cattle feeder. Feeding a high-grain ration during the finishing stage increases the rate of weight gain and carcass quality but decreases carcass yield. On the other hand, the use of a growth-promoting implant increases the rate of gain, feed efficiency, and yield but at the cost of carcass quality (Tedeschi et al., 2004; Field and Taylor, 2002; Duckett et al.,

1996). Thus, a potential moral hazard problem arises when the feeder's actions are not observable or verifiable to the owner and beef quality is not measurable upon delivery of the fed cattle. While these complex interactions determine the cattle owner's net returns under alternative fed cattle pricing methods, the feeder's optimal choice of actions vary with the incentive provisions of alternative cattle feeding contracts. This chapter attempts to characterize the optimal contracts for cattle feeding under alternative fed cattle pricing methods and risk aversion scenarios.

In the classical moral hazard problem, a risk-neutral principal contracts with a risk-averse agent to perform a task. The agent chooses an action, which affects the performance outcome. The principal cares only about the outcome, but the action is costly to the agent. The principal compensates the agent for incurring the cost. When the agent's action is not observable to the principal (i.e., actions are hidden), it is the best for her to align the incentive of the agent by making compensation contingent to the performance outcome (Bolton and Dewatripont, 2005). Since the outcome is typically a noisy signal of the agent's action, such a compensation scheme is most likely to entail a loss in efficiency. Under uncertainty about the outcome, this moral hazard problem demonstrates the basic trade-off between risk sharing and incentives: if the agent is risk averse, then more incentives come at the cost of a risk premium that the principal must pay the agent (Mirrlees, 1974, 1976; Holmstrom, 1979; Grossman and Hurt, 1983).

In most real world contracting problems, however, an agent typically performs several tasks. So the basic contracting problem can no longer be reduced to a simple trade-off between risk sharing and incentives. Holmstrom and Milgrom (1991) suggest that, when there are inseparable multiple tasks, incentive pay serves not only to allocate

risks and induce higher efforts, but it also serves to direct the allocation of the agent's attention among various tasks. Their main argument is that if the agent's performance is easy to measure in one task but not in the others, then a payment scheme with an incentive for the first task may lead the agent to allocate full attention towards that task and ignore the others. For example, if volume of output is easy to measure but the quality is not, then a system of piece rates for output may lead the agent to increase the volume of output at the expense of quality. Considering a normally distributed performance measure together with constant absolute risk-averse preferences for the agent and linear incentive contracts, Holmstrom and Milgrom show that the desirability of providing incentives for any one activity decrease with the difficulty of measuring performance in any other activities that make competing demands on the agent's time and effort. In other words, when activities for multiple tasks are substitutes, an incentive for any given task can be provided either by rewarding that activity or by reducing the incentive for the other tasks.

Since commercial cattle feeding is characterized by a multiple-task problem, a multitask principal-agent model for optimal cattle feeding contracts is developed following Holmstrom and Milgrom (1991), as described below in detail. The model captures the organizational details of cattle feeding and fed cattle marketing in current practice. In contrast to the model developed by Holmstrom and Milgrom, this model incorporates complementarities among multiple inputs in the production and cost functions and allows both the principal and the agent to be risk averse.

## 4.2 The Model

Consider a principal-agent relationship in which a feeder cattle owner (hereafter the principal in this section) makes contractual arrangements with a feedlot operator (hereafter the agent in this section) to feed the cattle until they are ready for slaughter. Upon agreement between the two parties on the terms of the contract, the principal delivers the cattle to the agent's premises. The agent then starts feeding the cattle by choosing a two-element vector of actions  $a = (a_1, a_2)$  at cost  $c(a) = a^T C a / 2$  per hundred pounds of live weight gain, where  $C = (c_{ij})$  with  $i, j \in \{1, 2\}$ . The quadratic cost function of the agent is twice continuously differentiable, strictly increasing, and strictly convex in both of its arguments. The off-diagonal elements  $c_{ij} = c_{ji}$ ,  $i \neq j$ , in the symmetric matrix  $C$  is a measure of the degree of complementarity (substitutability, if the sign is negative) between the agent's actions. When  $c_{ij} = 0$ ,  $i \neq j$ , the agent's actions are technologically independent.

The agent's actions  $a$  primarily affect yield  $y$  and quality  $q$  of the beef procured from each hundred pounds of live weight. The actions are not directly observable or verifiable by the principal. Neither does the principal observe the final yield and quality of beef upon delivery of the fed cattle. However, she observes the additional weight gained by the cattle at the end of the feeding period and the number of days that the cattle were on feed. Based on this information and also on some other objective or subjective measures, the principal makes an assessment of potential yield and quality of beef.<sup>14</sup> Let the measures of yield and quality be linear functions of the agent's actions given by  $y = y_0 + m_{11}a_1 + m_{12}a_2 + \varepsilon_1 = y_0 + \Delta y$  and  $q = q_0 + m_{21}a_1 + m_{22}a_2 + \varepsilon_2 = q_0 + \Delta q$ , where  $y_0$  and  $q_0$

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<sup>14</sup> While yield can be measured objectively upon slaughter, the measurement of beef quality is subjective.



are threshold levels of yield and quality (e.g., choice, yield grade 3),  $\Delta y$  and  $\Delta q$  are incremental yield and quality of beef, parameters  $m_{ij}$  with  $i, j \in \{1, 2\}$  represent coefficients of production corresponding to the actions of the agent, and  $\varepsilon_1$  and  $\varepsilon_2$  are random disturbances representing random biophysical responses or errors in measurement of yield and quality.<sup>15</sup>

The agent's actions  $a_1$  and  $a_2$  are assumed to be yield and quality improving, respectively, such that  $m_{ii}$  for  $i \in \{1, 2\}$  are positive. The production coefficients  $m_{ij}$  for  $i \neq j$  are measures of complementarity (or substitutability, if the sign is negative) between the actions in the production functions. The linear production functions for  $y$  and  $q$  nest two standard cases: (i) one dimensional effort ( $m_{12} = m_{22} = 0$ ) where attempts to improve yield also increase the quality of beef, and (ii) unproductive multitasking ( $m_{12} = m_{21} = 0$ ) where the attempt to increase yield is costly but does not affect the quality of beef, and vice versa. For analytical simplicity, I assume that  $M$  is symmetric ( $m_{12} = m_{21}$ ) and positive definite.

In matricial form, if  $\varepsilon$  is a vector of random variables that have a bivariate normal distribution, incremental effects of the feeder's actions can be represented simply as

$$(\Delta y, \Delta q)^T = M a + \varepsilon \quad \text{where } \varepsilon \sim N(0, \Sigma) \text{ and } \Sigma = (\sigma_{ij}), \quad i, j = \{1, 2\}. \quad (4.1)$$

The variance  $\sigma_{ii} = \sigma_i^2$  of the random variable  $\varepsilon_i$  is a measure of both the difficulty that the agent has in controlling yield and quality of beef, and the difficulty that the principal has in measuring the output or implicitly observing the actions of the agent. The covariance

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<sup>15</sup> Additively linear production functions allow one to separately consider the effects of the cow-calf producer's and the feedlot operator's actions on beef yield and quality in successive production stages.

between  $\varepsilon_i$  and  $\varepsilon_j$ ,  $\sigma_{ij}$  is a measure of random complementarity (or substitutability) between the actions of the agent.

When the cattle are ready for slaughter, the principal takes control of the animals upon making payments to the agent according to the contract. As compensation, the principal pays a fixed fee,  $\alpha$ , that covers feed cost and yardage charges for each hundred pounds of live weight gain, and incentives  $\beta_1$  and  $\beta_2$  for incremental yield and quality per hundred pounds of added weight, respectively.<sup>16</sup> Thus, the payment scheme is linear in the principal's measures of beef yield and quality,

$$w = \alpha + \beta^T (Ma + \varepsilon). \quad (4.2)$$

The power of the incentive scheme in equation (4.2) increases with  $\beta$ . Feed cost plus yardage fee and flat-rate-per-pound-of-gain are two special cases of this linear payment scheme. Equation (4.2) represents a feed cost plus yardage fee contract when  $\beta_1 = 0$  and  $\beta_2 = 0$  and a flat-rate-per-pound-of-gain contract when  $\alpha = 0$  and  $\beta_2 = 0$ . Actual cattle feeding contracts may also have a provision for cost sharing when cost is at least partly contractible. In this model, the principal is assumed to cover any intended share of the agent's cost by transferring income through  $\alpha$ . This assumption aids analytical simplicity without loss of generality.

The agent's average net income per hundred pounds of live weight gain,  $x$ , is the average payment he receives from the principal minus his cost,

$$x(a) = \alpha + \beta^T (Ma + \varepsilon) - \frac{a^T CA}{2}. \quad (4.3)$$

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<sup>16</sup> Attention is restricted to limited payment schemes with a fixed fee and a linear incentive based on the full vector of contractible variables. A theoretical justification for the use of linear contracts can be found in Holmstrom and Milgrom (1987) and Bhattacharyya and Laffontain (1995).

Suppose the agent has constant absolute risk averse (CARA) preferences with absolute risk aversion  $\varphi$  so that his utility follows a negative exponential utility function

$$U(X(a)) = -\exp(-\varphi X(a)) \text{ where } X(a) = \sum_{i=1}^k x_i(a), x_i(a) \text{ represents net income from}$$

the  $i$ th hundred pounds of live weight gain, and  $k$  is the number of hundred pound increments of meat (the scale of operation) the feedlot is able to produce. If the distribution of net income from each one hundred pounds of gain follows

$$x_i(a) \sim N(\mu_x(a), \sigma_x^2(a)) \text{ and each is an independent draw from the same distribution of errors in the measured yield and quality grades, then } X(a) \sim N(k\mu_x(a), k\sigma_x^2(a)).^{17} \text{ Thus,}$$

the assumptions of CARA and normality lead to the linear mean-variance certainty equivalent decision criterion, such that the agent's objective is to

$$\max_a E(X(a)) - (\varphi/2)V(X(a)) = k\mu_x(a) - (\varphi/2)k\sigma_x^2(a), \text{ which is equivalent to}$$

$$\max_a E(x(a)) - (\varphi/2)V(x(a)) = \mu_x(a) - (\varphi/2)\sigma_x^2(a) \text{ where } X(a) = kx(a) \text{ and } x(a) \text{ from}$$

(4.3) represents net return from the typical one hundred pounds of gain. With this background, the agent's certainty equivalent income per hundred pounds of weight gain associated with (4.3),

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<sup>17</sup> In reality, the assumption of independence of random draws for each incremental one hundred pounds of gain is somewhat extreme. However, it is a useful simplifying assumption for this conceptual exercise for several reasons. First, the assumption that successive increments in weight gain are perfectly correlated is also not plausible. Rather, reality likely lies somewhere between no correlation and perfect correlation because of variation in weather and animal characteristics. Second, the model becomes excessively complicated while providing little additional conceptual understanding if imperfect correlation is introduced. The main point of this conceptual exercise is to demonstrate which factors play a role and the theoretical ambiguities that arise. A more general model would likely have only more ambiguities. Third, constant absolute risk aversion is also an extreme assumption. According to arguments by Arrow (1965), constant relative risk aversion likely better reflects reality. The assumption used here generates a model in which the risk premium scales up by firm size as under constant relative risk aversion when successive increments of weight gain are perfectly correlated. Thus, the assumptions used here seem to balance, in some sense, the error in reflecting correlation in order to better reflect risk aversion more plausibly.

$$ACE = \alpha + \beta^T M a - \frac{a^T C a}{2} - \frac{\varphi}{2} \beta^T \Sigma \beta, \quad (4.4)$$

is a meaningful and relevant behavioral criterion where the absolute risk aversion coefficient is the same as in maximization of the expected utility of total short-run profit. Thus, the agent's certainty equivalent income is his expected compensation from the linear payment scheme, minus his private cost, minus the risk premium.

For given values of  $\alpha$  and  $\beta$ , the agent chooses  $a$  to maximize this certainty equivalent compensation  $ACE$  in (4). The optimization problem of the agent is therefore

$$a \in \arg \max_a \left[ \alpha + \beta^T M a - \frac{a^T C a}{2} - \frac{\varphi}{2} \beta^T \Sigma \beta \right].$$

The first order condition of the agent's maximization problem yields

$$a^* = C^{-1} M \beta. \quad (4.5)$$

Differentiating (4.5) with respect to  $\beta$  and assuming  $a$  is strictly positive in all components obtains  $\partial a_i / \partial \beta_i = |C|^{-1} (c_{jj} m_{ii} - c_{ij} m_{ij})$  and  $\partial a_i / \partial \beta_j = |C|^{-1} (c_{jj} m_{ij} - c_{ij} m_{jj})$  for  $i, j \in \{1, 2\}$  and  $i \neq j$ , where  $|C|$  is the determinant of  $C$ . For positive values of  $m_{ii}$  and  $c_{ii}$ , the sign of  $\partial a_i / \partial \beta_i$  is non-negative and the sign of  $\partial a_i / \partial \beta_j$  is non-positive if  $m_{ij} \leq 0$  and  $c_{ij} \geq 0$ ,  $i \neq j$  (strict inequalities hold if strict inequality holds in the sufficient conditions). In other words, if the actions are substitutes in both the production function (i.e.,  $m_{ij} \leq 0$ ,  $i \neq j$ ) and the agent's cost function (i.e.,  $c_{ij} \geq 0$ ,  $i \neq j$ ), then the agent chooses an action  $a_i$  that increases with  $\beta_i$  and decreases with  $\beta_j$ . Similarly, the signs of  $\partial a_i / \partial \beta_i$  and  $\partial a_i / \partial \beta_j$  for  $i, j \in \{1, 2\}$  and  $i \neq j$  are non-negative (positive with strict inequality in the sufficient conditions) if the actions are complements in the production and cost function (i.e., if  $m_{ij} \geq 0$  and  $c_{ij} \leq 0$ ,  $i \neq j$ ).

The principal sells fed cattle to a beef packer and realizes revenue. The principal can sell fed cattle either through open outcry livestock actions on a live weight basis where the packers are bidders, or sell them to an individual packer using a dressed weight or a grid pricing method through some kind of marketing agreement. When fed cattle are priced on a grid, the packer pays a base price for the threshold yield and quality combination, plus premiums (or discounts) for higher (lower) yield and quality. Suppose  $B$  denotes the base payment for yield and quality combination  $y_0$  and  $q_0$  per hundred pounds of live weight,  $p_1$  denotes the price premium for the incremental yield  $\Delta y$ , and  $p_2$  denotes the premium for the incremental quality  $\Delta q$ . Thus, the principal's revenue per hundred pounds of live weight from the grid is  $B + p^T (Ma + \varepsilon)$  where  $p$  is a vector of incremental yield and quality grade premiums,  $p = (p_1, p_2)$ . The grid revenue nests the revenues from live- and dressed-weight pricing methods. When there is no premium for beef quality (i.e.,  $p_2 = 0$ ),  $B + p^T (Ma + \varepsilon)$  represents the revenue from dressed-weight pricing, and when there is no premium for incremental yield and quality grades (i.e.,  $p_1 = 0$  and  $p_2 = 0$ ) it represents the revenue from live-weight pricing.

The principal's returns per hundred pounds of live weight gain,  $z$ , is her revenue from the grid minus the payment to the feeder.

$$z(a) = B + p^T (Ma + \varepsilon) - \alpha - \beta^T (Ma + \varepsilon) \quad (4.6)$$

Suppose that the principal's preference is also characterized by constant absolute risk aversion (CARA) with absolute risk aversion  $\psi$ . The risk preference of the principal can thus be represented by a negative exponential utility function  $U(Z) = -\exp(-\psi z)$ , where

$Z(a) = \sum_{i=1}^{k^*} z_i(a)$ ,  $z_i$  represents net return's from the  $i$ th hundred pounds of live weight gain, and  $k^*$  is the number of hundred pounds of live weight added to the feeder cattle (the

scale of the cattle owner's operation). If the distribution of net income from each one hundred pounds of gain follows  $z_i(a) \sim N(\mu_z(a), \sigma_z^2(a))$  and each is an independent draw from the same distribution, then  $Z(a) = N(k^* \mu_z(a), k \sigma_z^2(a))$ . Thus, CARA and normality yields the linear mean-variance certainty equivalent criterion,

$$\max_{\alpha, \beta} E(Z(a)) - (\psi/2)V(Z(a)) = k^* \mu_z(a) - (\psi/2)k^* \sigma_z^2(a), \text{ which is equivalent to}$$

$$\max_{\alpha, \beta} E(z(a)) - (\psi/2)V(z(a)) = \mu_z(a) - (\psi/2)\sigma_z^2(a) \text{ where } z(a) \text{ from (4.6) represents net}$$

returns of the principal from the typical one hundred pounds of gain and  $Z(a) = k^* z(a)$ .

Thus, the principal's certainty equivalent income from each hundred pounds of live weight gain is

$$PCE = B + p^T M a - \alpha - \beta^T M a - \frac{\psi}{2}(p - \beta)^T \Sigma(p - \beta) \quad (4.7)$$

The principal chooses  $\alpha$  and  $\beta$  to maximize  $PCE$  in (4.7) subject to the agent's incentive compatibility and individual rationality (participation) constraints. Let  $\bar{w}$  denote the minimum acceptable monetary certainty equivalent of the agent's compensation contract. The principal's problem is then to solve

$$\max_{\alpha, \beta} B + p^T M a - \alpha - \beta^T M a - \frac{\psi}{2}(p - \beta)^T \Sigma(p - \beta)$$

subject to

$$a^* = C^{-1} M \beta \quad (\text{IC})$$

and

$$\alpha + \beta^T M a - \frac{a^T C a}{2} - \frac{\psi}{2} \beta^T \Sigma \beta \geq \bar{w}. \quad (\text{IR})$$

The (IR) constraint is binding at the optimum, so that  $\alpha$  and  $a^*$  can be substituted into the principal's objective function to obtain the unconstrained maximization problem

$$\max_{\beta} B + p^T M a - \frac{a^T C a}{2} - \frac{\psi}{2} (p - \beta)^T \Sigma (p - \beta) - \frac{\varphi}{2} \beta^T \Sigma \beta - \bar{w}.$$

Assuming  $a^* > 0$ , the first-order necessary conditions for this unconstrained problem yield

$$\beta^* = [M + (\hat{\varphi} + \hat{\psi})CM^{-1}\Sigma]^{-1}[M + \hat{\psi}CM^{-1}\Sigma]p. \quad (4.8)$$

where  $\beta^*$  represents the optimal incentive for yield and quality improving activities. This expression for  $\beta^*$  provides useful insights about the optimal incentive structure in cattle feeding contracts under alternative scenarios.

### ***Risk Neutrality (or Certainty)***

If either there is no uncertainty (i.e.,  $\Sigma = 0$ ) or the agent is risk neutral (i.e.,  $\varphi = 0$ ) then equation (4.8) reduces to

$$\beta^* = p. \quad (4.9)$$

This behavior reduces the principal's risk premium to zero so that risk aversion on the part of the principal does not matter. This implies that the principal transfers the yield and quality premiums earned in the grid directly to the agent. If the fed cattle are sold according to dressed weight, the principal transfers only the yield premium, as under the dressed-weight pricing method,  $\beta_2 = p_2 = 0$ . Under the live weight pricing method,  $p_1 = p_2 = 0$ , which implies that  $\beta_1 = \beta_2 = 0$ . However, the principal can extract a part (or all) of the transferred premiums from the agent through the use of  $\alpha$  (if fed cattle are priced in a grid

or according to dressed weight). Thus, the special case with no uncertainty or risk neutrality is a standard transfer pricing problem.

### ***Unrelated Agent Activities (No Multitasking)***

When the agent's actions are systematically and stochastically unrelated (i.e.,  $m_{12} = c_{12} = \sigma_{12} = 0$ ), it is straightforward to show that

$$\beta_i^* = \frac{(m_{ii}^2 + \psi\sigma_i^2)p_i}{m_{ii}^2 + (\varphi + \psi)\sigma_i^2 c_{ii}}. \quad (4.10)$$

Thus, when the agent's activities are unrelated, the optimal incentive for the  $i$ th task is independent of the characteristics of the  $j$ th activity. Moreover, the principal offers a higher-powered incentive to the agent when the premium goes up (i.e., when  $p_i$  is larger), when the production function is more elastic with respect to the agent's action ( $\partial\beta_i / \partial m_{ii} > 0$ ), and when the principal is risk averse (i.e.,  $\partial\beta_i / \partial \hat{\psi} > 0$ ). On the other hand, the principal offers lower powered incentives for a particular task when the agent is more risk averse (i.e.,  $\varphi$  is larger), when uncertainty is higher (i.e.,  $\sigma_i^2$  is larger), and when the cost function is more convex (i.e.,  $c_{ii}$  is larger).

### ***Related Agent Activities and Unobservable Beef Quality before Slaughter***

In reality, agent's actions to improve yield and quality of beef are not independent ( $m_{12} \neq 0$ ,  $c_{12} \neq 0$ ). For example, while the use of growth promoting implants increases yield, the rate of weight gain, and feed efficiency, it also has an apparent negative effect on beef quality (Field and Taylor, 2002; Duckett, et al., 1996). On the other hand, a common practice to increase beef quality is to feed high grain rations during the finishing



phase, which increases the percentage of fat in the carcass. As a result, marbling (intramuscular fat), and hence beef quality increases, but at the cost of yield (Fox and Black, 1984). This tradeoff is particularly important when fed cattle are priced on a grid according to actual yield and quality of beef. Another important issue for the principal is that actual quality of beef is almost unobservable and immeasurable until cattle are slaughtered. Therefore, in reality, cattle feeding contracts offering incentives for beef quality ( $\beta_2 = 0$ ) are not observed (although *ex post* grid pricing offers new possibilities).

In the case where the agent performs multiple tasks ( $m_{12} \neq 0$ ,  $c_{12} \neq 0$ ), and the quality of beef is immeasurable by the principal upon delivery of the fed cattle, such that  $\sigma_2^2$  is large and  $\sigma_{12}$  is zero (i.e., the agent's actions are independently distributed), the optimal incentive for yield improving activity is given by

$$\beta_1^* = \frac{[m_{11}A_1 - m_{12}A_2 + \psi\sigma_1^2|C|]p_1 + \varphi\theta^{-1}[m_{12}A_1 - m_{22}A_2]p_2}{m_{11}A_1 - m_{12}A_2 + \theta\sigma_1^2|C|}, \quad (4.11)$$

where  $A_1 = c_{22}m_{11} - c_{12}m_{12}$ ,  $A_2 = c_{12}m_{11} - c_{11}m_{12}$ , and  $\theta = \varphi + \psi$ .

The main comparative static result that follows from (4.11) is that if the agent's activities are substitutes in the production and cost functions (i.e., when  $m_{12} < 0$  and  $c_{12} > 0$ ) then a higher (lower) premium for actual yield (quality) leads to a higher (lower) powered incentive (i.e.,  $\partial\beta_1^*/\partial p_1 > 0$  and  $\partial\beta_1^*/\partial p_2 < 0$ ). With other things equal,  $\beta_1^*$  reaches its highest value when there is no premium for quality at all ( $p_2 = 0$ ), as in the case of the dressed-weight pricing method. This implies that, if the principal intends to sell fed cattle on a dressed weight basis, she would offer a high powered incentive for the yield improving activity. Thus, a cost-of-gain contract (the highest powered practical

incentive contract) for cattle feeding is more likely if the principal decides to sell fed cattle according to dressed weight.

Under the grid pricing mechanism, actual yield and quality of beef are measured after slaughter and both are rewarded accordingly. Therefore, the incentive for a yield improving activity is likely to be lower than a cost-of-gain contract if the beef quality premium is positive ( $p_2 > 0$ ). This result is consistent with the argument of Holmstrom and Milgrom (1991) that, when inputs are substitutes and one of the activities cannot be measured, then the only way to provide the incentive for the immeasurable activity is to reduce the incentive for the other (measurable or observable) activity.

Since the first term in the numerator of equation (4.11) is positive and the second term is negative, it may be optimal for the principal to set  $\beta_1$  equal to zero (negative) provided these two terms offset each other (the second term is greater than the first in absolute value). Zero incentives can also arise in a limiting case when the agent's activities are perfect substitutes in the production function such that  $m_{11} = m_{12} = m_{22}$  and yield and quality premiums are equal ( $p_1 = p_2$ ). In that case, both  $\beta_1 = 0$  and  $\beta_2 = 0$ . This result may explain why a majority of cattle are fed on the basis of a yardage fee plus feed cost.

Differentiating equation (4.11) with respect to the risk aversion parameters of the principal yields

$$\frac{\partial \beta_1^*}{\partial \psi} = \frac{\theta \sigma_1^2 |C| p_1 - \theta^{-1} (m_{12} A_1 - m_{22} A_2) [\psi (m_{11} A_1 - m_{12} A_2) + \phi \sigma_1^2 |C|] p_2}{m_{11} A_1 - m_{12} A_2 + \theta \sigma_1^2 |C|}. \quad (4.12)$$

The sign of the right hand side of (4.12) is positive when  $m_{12} < 0$  and  $c_{12} > 0$ , and ambiguous when  $m_{12} > 0$  and  $c_{12} < 0$ . Thus, when the agent's actions are net substitutes, the incentive for the yield improving activity increases with the level of the principal's

risk aversion. When the actions are net complements, the effect of the principal's risk aversion level on  $\beta_1$  depends on the sign of the second term in the numerator. In particular, if  $m_{12} > 0$  and  $c_{12} < 0$ , then  $\partial\beta_1^* / \partial\psi > 0$  if the first term in the numerator is absolutely larger than the second term. However, the magnitude of the effect of the principal's risk aversion on the incentive scheme also depends on  $p_1$  and  $p_2$ . If the principal is risk averse but the agent is risk neutral, then  $\partial\beta_1^* / \partial\psi = 0$  as  $\beta_1^* = p_1$ . Thus, when the agent is risk neutral but the principal is risk averse, a high-powered incentive contract is optimal.

The effect of the agent's risk aversion level on the optimal incentive scheme is negative when actions are net substitutes and ambiguous when the actions are net complements,

$$\frac{\partial\beta_1^*}{\partial\varphi} = -\frac{\sigma_1^2|C|(m_{11}A_1 - m_{12}A_2 + \psi\sigma_1^2|C|)p_1 - (m_{12}A_1 - m_{22}A_2)[\psi\theta^{-1}(m_{11}A_1 - m_{12}A_2) - (\varphi + \psi\theta^{-1})\sigma_1^2|C|]p_2}{m_{11}A_1 - m_{12}A_2 + \theta\sigma_1^2|C|} \quad (4.13)$$

For  $m_{12} < 0$  and  $c_{12} > 0$ , the first term in the numerator of (4.13) is positive and  $m_{12}A_1 - m_{22}A_2$  is negative. So  $\partial\beta_1^* / \partial\varphi < 0$  if  $\psi\theta^{-1}(m_{11}A_1 - m_{12}A_2) - (\varphi + \psi\theta^{-1})\sigma_1^2|C| > 0$ . When the agent is risk averse but the principal is risk neutral (i.e., when  $\varphi > 0$  and  $\psi = 0$ ) and the agent's actions are net substitutes, then  $\partial\beta_1^* / \partial\varphi < 0$  if  $(m_{11}A_1 - m_{12}A_2)p_1 < (m_{12}A_1 - m_{22}A_2)p_2$ . If this condition does not hold, then  $\partial\beta_1^* / \partial\varphi$  could be positive or zero. Thus, higher powered incentive contracts may be observed even when the agent is highly risk averse.

Finally, the effect of the degree of substitutability of the agent's actions in the production and cost functions (i.e., the effects of  $m_{12}$  and  $c_{12}$ ) on the optimal incentive contract is ambiguous in general. However, if  $m_{12} > 0$  and  $c_{12} < 0$  then

$$\frac{\partial \beta_1^*}{\partial m_{12}} \underset{(>)}{<} 0 \quad \text{if} \quad c_{11} m_{12}^2 \underset{(<)}{>} c_{22} m_{11}^2 + \theta \sigma_1^2 |C|.$$

In other words, the effect of substitutability in the production function can be determined under certain conditions.

### 4.3 Conclusion

The multitask principal-agent model presented in this chapter yields several testable hypotheses about the incentive structure of cattle feeding contracts. The main comparative static results of the model are that, given that carcass yield and quality improving activities of the cattle feeder are net substitutes, the power of the incentive scheme for cattle feeding is lower under the value-based grid pricing of fed cattle than under traditional pricing methods, and the power of the incentive increases with the level of the cattle owner's risk aversion and decreases with the level of the feeder's risk aversion. While other comparative static results are ambiguous, the main hypotheses are also conditional on the substitutability (or complementarity) between the cattle feeder's actions. Therefore, even qualitative relationships cannot be resolved without estimation of the production, cost, and contract coefficients.

Comparing the performance of alternative contract arrangements likely requires even more precise estimation than is necessary to determine many of these qualitative relationships. Such estimation requires ranch-to-rail data on cattle fed under various contract arrangements along with actual costs and revenues. Such data, however, are

proprietary in nature and therefore not available publicly. Further, even where such data are compiled by direct survey methods, the data are typically lacking on specifics of the array of feeder actions that can affect yield and quality, which are essential in discovering the motivation and potential for contracting. Moreover, given the complicated nature of the beef production process, linear-quadratic functional forms of the production and cost functions appear to be too simplistic.

The unique approach adopted in this study to overcome these obstacles is to use a detailed dynamic biophysical model for beef cattle growth developed in the animal science literature. This model is employed to simulate the outcomes of alternative production technologies. The growth model implicitly includes the relationships that reflect production and cost relationships and allows evaluating cattle feeding outcomes with observed input and output price data to determine the optimal incentive schemes under alternative fed cattle pricing and risk aversion scenarios. The next chapter provides a detailed description of the biophysical growth model for beef cattle.

## CHAPTER 5

### A DYNAMIC BIOPHYSICAL MODEL FOR BEEF CATTLE GROWTH

#### 5.1 Introduction

Since the late 19<sup>th</sup> century, animal scientists have been exerting a great amount of effort to understand and model the beef cattle production process. The major goal has been either to predict animal performance given a fixed feed resource or to predict feed requirements that support a fixed level of production. However, biological growth and composition of gain also depend on other factors such as the animal's biological type (e.g., genotype, sex, body type, condition, etc.), use of growth promoting implants, and environmental conditions. Therefore, where predictive accuracy is concerned, an integrated biophysical model must account for all the factors that influence an animal's biological growth and its composition. With significant advances in understanding complex biophysical relationships and rapid progress in computational technology in recent years, several mathematical models have been developed to simulate beef cattle production.

Alternative beef cattle growth simulation models mainly differ in the systems used to determine the energy content of the feedstuffs. The two most common methods used in measuring energy content of feed are total digestible nutrients (hereafter, TDN) and net energy (hereafter, NE) systems. While the TDN system works well in balancing rations for cows, the NE system has been widely adopted for simulating growth of feedlot cattle because it is more precise in measuring the energy value of feeds than the TDN system. The NE system partitions the energy content of feed into net energy for

maintenance (*NE<sub>m</sub>*) and net energy for growth (*NE<sub>g</sub>*). Lofgreen and Garrett (1968) first published a simple growth simulation model based on the NE system to compute feed requirements when performance is fixed. Fox and Black (1977a-c, 1984) altered the Lofgreen and Garrett model to predict performance when voluntary feed intake and energy content of feeds are known. They also generalized the model to account for the differences in breed, mature size, growth promoting implants, and feed additives.

Since introduction of the Fox and Black model, continuous evaluations and modifications have been made to improve its accuracy under alternative management practices and production situations (Fox et al., 1988, 1992; Tylutki et al., 1994; Perry and Fox, 1997; Fox and Tylutki, 1998). Successive Subcommittees on Beef Cattle Nutrition (hereafter, Subcommittee) of the National Research Council (NRC, 1981, 1984, 1996, 2000) have fully adopted the revised model after further evaluation with experimental data. The latest version of the model is described and documented by Fox et al. (2003).

Using the procedures and equations as described by the Subcommittee (NRC, 1996, 2000) and Fox et al. (2003), researchers in the department of Animal Science at Cornell University have developed a dynamic and mechanistic growth model with daily time steps that can be applied in feedlots to predict growth rate, accumulated weight, days required to reach target body composition, and carcass weight and composition of individual animals (Tedeschi et al., 2004). The dynamic model is able to predict either average daily gain (*ADG*) when daily dry matter intake (*DMI*) is known or dry matter required (*DMR*) when *ADG* is known (Tedeschi et al., 2004). In either case, the model requires information about length of the feeding period, energy and protein content of the diet, animal characteristics (age, gender, breed, initial body weight, frame and body

condition scores, hair depth, and adjusted final body weight at a target empty body fat percentage), and environmental conditions (temperature, humidity, hours of sunlight, wind speed, mud, and hair coat).

Tedeschi et al. (2004) evaluated their dynamic growth model with feed intake and performance data on 362 steers fed in individual pens. When dry matter intake was known, their model accounted for 89 percent of the variation with a bias of -2.6 percent in predicting individual animal *ADG* and explained 83 percent of the variation with a bias of -1 percent in estimating the observed body weights at the actual total days on feed. When *ADG* was known, their growth model predicted the dry matter required for that *ADG* with only 2 percent bias and an  $R^2$  of 74 percent. Thus, Tedeschi et al. claim that their dynamic growth model is able to predict animal performance and body composition with an acceptable degree of accuracy. This dynamic growth model is available for application in a computer program called the Cornell Value Discovery System (CVDS) developed to predict performance and costs of feeding individual animals in group pens.

The CVDS model is useful in predicting cost of gain and carcass performance during and at the end of the feeding phase. However, a major drawback of the CVDS model is that it is applicable only when either *ADG* or *DMI* is observed, while both of these variables remain unknown to the cattle feeder and/or the cattle owner before feeding the cattle. At the time of placing the cattle in feedlots, feedlot operators and feeder cattle owners typically make agreements on either the length of the feeding period or the target harvest body weight. At this point, they predict either harvest body weight when the length of the feeding period is known or days to finish when harvest body



weight is known. For this purpose, a dynamic growth model is required that can predict voluntary *DMI* by each individual animal and the resulting gain and composition.

Another limitation of the CVDS model is that it is unable to simultaneously predict cattle performance under alternative feeding strategies. While energy and protein contents of the rations significantly alter gain and its composition, a wide spectrum of rations can be formulated using various combinations of available feed ingredients (NRC, 1996, 2000). Also, there are several growth promoting implants, the effect of which are significantly different (Duckett et al., 1997). Comparison of the outcomes of alternative feed-implant strategies is required in order to make important economic decisions. For example, cattle feeders may be interested in formulating a ration that is both biologically and economically efficient. Thus, there is a need for an integrated growth model that is capable of simultaneously predicting the outcomes of alternative feeding strategies.

This chapter delineates a deterministic and dynamic biophysical growth model for beef cattle. The model is developed by adapting the CVDS model as described in Tedeschi et al. (2004) with complementary sub-models published in the reports of the Subcommittee (NRC, 1996, 2000) on beef cattle nutrition requirements and other relevant animal science research. For a wide range of alternative feed-implant strategies, the model can predict dry matter intake by each individual animal on each day on feed, resulting daily weight gain and composition, final weight and yield and quality grades of the carcass, and days required to reach a target harvest body weight or final body weight and composition for a given feeding period.

The model is deterministic in the sense that it does not include any stochastic component and the parameters in the equations are fixed. Fixed parameter values are used

mainly for two reasons. First, statistical descriptors of most of the parameters are not available. The Subcommittee reports on beef cattle nutrition (NRC, 1984, 1996, 2000) and other published animal science research (Tedeschi et al, 2004; Lofgreen and Garrett, 1968; Garrett et al., 1978; Fox and Black, 1984; and Fox et al., 1992), from which the parameter values are obtained, but do not report the underlying distributions. Second, Christian (1981) suggests that using variables other than weather to provide stochastic elements in models is unlikely to lead to marked improvements and that the use of stochastic variables increases the chance of confusion instead of clarification (Forbes and Oltjen, 1984). The basic growth model, however, does not account for the probability distributions of the independent variables including weather. Given fixed parameter values and data on independent variables, the model makes definite predictions about the values of the dependent variables without any associated probability distribution. The following sections of this chapter define the dependent and independent variables used in the model, and describe the equations for predicting cattle feeding outcomes.

## **5.2 Variables in the Biophysical Growth Model**

Major dependent variables of the growth model are daily dry matter intake, weight gain, composition of gain, carcass weight, and yield and quality grades. Independent variables in the model include an animal's biological characteristics (e.g., age, sex, initial shrunk body weight, breed, frame and body condition scores, and hair depth), metabolizable and net energy and protein content of the feed, and attributes of weather (temperature, humidity, hours of sunlight, wind speed, mud, and hair coat).<sup>18</sup>

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<sup>18</sup> Effects of growth promoting implants and feed additives on feed intake, gain, and fat content of gain are incorporated through published parameter values.

The model also requires either a user input value for expected final shrunk body weight at a target body fat (when the goal is to feed the cattle until they reach a target harvest body weight) or the length of the feeding period (when cattle are fed for a predetermined length of period). Definitions of the dependent and independent variables used in this growth model are presented in Table 5.1 in alphabetical order.

The growth model crucially depends on user input values for final shrunk body weight adjusted for the use of growth promoting implants (*AFSBW*), equivalent shrunk body weight at a target body fat percentage (*EqSBW*), and net energy and protein content of the ration. Accordingly, the first step in the cattle growth simulation model is to establish these values.

### **5.3 Determining Adjusted Final Body Weight and Composition**

The critical first decision point in beef cattle feeding is to determine the harvest body weight at a target body fat percentage. Shrunk body weights of the fed cattle sold in the US markets range from 850 to 1450 lbs.<sup>19</sup> However, making cattle as fat as possible may not be efficient from either biological and/or economic points of view. Like all other animals, growth of beef cattle is constrained by biochemical factors. Feed efficiency and average daily gain decline as an animal approaches maturity (NRC, 2000). Feed intake also declines as maturity is reached, further reducing average daily gain.<sup>20</sup> Feeding cattle

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<sup>19</sup> When calculating the actual body weight of beef cattle, a 4 percent shrink is typically assumed to account for gut fill and mud coat.

<sup>20</sup> Some feedlot operators use this reduction in ADG and intake as an indicator of "finish".

**Table 5.1: Glossary of the variables used in the growth model**

<b>Variables</b>	<b>Description</b>	<b>Unit</b>
$a_1$	Fasting heat production coefficient (0.072 for beef cattle)	Mcal/kg <sup>-0.75</sup> /day
$a_2$	Maintenance adjustment for previous temperature	Mcal/kg <sup>-0.75</sup> /day
<i>AdjDMI</i>	<i>DMI</i> adjusted for breed, body fat, and weather condition	kg/day
<i>AdjREM</i>	<i>REM</i> adjusted for cold or heat stress	Mcal/day
<i>AFSBW</i>	Adjusted final shrunk body weight (at 28% bbody fat)	kg
<i>BCS</i>	Body condition score (1=emaciated, ..., 9=obese)	
<i>BE</i>	Breed effect for maintenance	
<i>CETI</i>	Current month's effective temperature index	°C
<i>CFP</i>	Carcass fat percentage	%
<i>CW</i>	Carcass weight	kg
<i>DMFM</i>	Dry matter available for maintenance	kg/day
<i>DMFG</i>	Dry matter available for gain	kg/day
<i>DMI</i>	Predicted dry matter intake	kg/day
<i>DMIB</i>	<i>DMI</i> adjustment factor for breed	
<i>DMIBF</i>	<i>DMI</i> adjustment factor for body fat content	
<i>DMIIMP</i>	<i>DMI</i> adjustment factor for the use of implant	
<i>DMIM</i>	<i>DMI</i> adjustment factor for mud depth in the feedlot	
<i>DMIT</i>	<i>DMI</i> adjustment factor for temperature	
<i>DMITNC</i>	<i>DMI</i> adjustment factor for temperature with night cooling	
<i>EBF</i>	Empty body fat	kg
<i>EBFP</i>	Empty body fat percentage	%
<i>EBW</i>	Empty body weight	kg
<i>EI</i>	External insulation	°C/Mcal/m <sup>2</sup> /day
<i>EqSBW</i>	Equivalent shrunk body weight	kg
<i>EWG</i>	Empty weight gain	kg/day
<i>FIG</i>	Fat in gain	
<i>HCCode</i>	Hair coat code (1=dry and clean, 2=some mud on lower body, 3=wet and matted, 4=covered with wet snow or mud)	
<i>HD</i>	Hair depth	cm
<i>HE</i>	Heat production	Mcal/day
<i>HideCode</i>	Hide depth code (1=thin, 2=average, and 3=thick)	
<i>HideME</i>	Hide depth adjustment for external insulation	
<i>HRSc</i>	Hours of sunshine in the current month	Hours
<i>HRSp</i>	Hours of sunshine in previous month	Hours
<i>IF</i>	Ionophore adjustment factor	
<i>IN</i>	Total insulation	°C/Mcal/m <sup>2</sup> /day
<i>LCT</i>	Lower critical temperature	°C

**Table 5.1(continued)**

<b>Variables</b>	<b>Description</b>	<b>Unit</b>
<i>MCP</i>	Microbial crude protein	
<i>ME</i>	Dietary content of metabolizable energy	Mcal/kg
<i>MEcs</i>	Animal requirement for <i>ME</i> adjusted for cold stress	Mcal/day
<i>MP</i>	Dietary content of metabolizable protein	g/day
<i>MPb</i>	Digestible microbial protein	
<i>MPf</i>	Digestible undegraded feed protein	
<i>MPg</i>	Metabolizable protein required for gain	g/day
<i>Mud</i>	Mud depth in the feedlot	Cm
<i>MudME</i>	Mud adjustment factor for external insulation	
<i>NEg</i>	Dietary content of net energy for growth	Mcal/kg
<i>NEm</i>	Dietary content of net energy for maintenance	Mcal/kg
<i>NEmcs</i>	Cold stress adjustment factor for <i>REM</i>	
<i>NEmhs</i>	Heat stress adjustment factor for <i>REM</i>	
<i>NEFG</i>	Net energy available for growth after maintenance	Mcal/day
<i>NPg</i>	Net protein required for gain	g/day
<i>PEg</i>	Protein efficiency for gain	
<i>PETI</i>	Previous month's effective temperature index	
<i>PIG</i>	Protein in gain	
<i>PN</i>	<i>NEm</i> adjustment for previous nutrition	
<i>QG</i>	Numerical quality grade	
<i>RE</i>	Retained energy	Mcal/day
<i>REM</i>	Required energy for maintenance	Mcal/day
<i>RHc</i>	Current relative humidity	%
<i>RHp</i>	Previous relative humidity	%
<i>RMP</i>	Total metabolizable protein required for maintenance	g/day
<i>SA</i>	Surface area	m <sup>2</sup>
<i>SBW</i>	Shrunk body weight	kg
<i>SRW</i>	Shrunk reference weight (478 kg at 28% body fat)	kg
<i>SWG</i>	Shrunk weight gain	kg/day
<i>Tc</i>	Current average temperature	°C
<i>Tp</i>	Previous month's average temperature	°C
<i>TI</i>	Tissue (internal) insulation	°C/Mcal/m <sup>2</sup> /day
<i>UCT</i>	Upper critical temperature	°C
<i>UIP</i>	Undegraded feed protein	
<i>WSc</i>	Current wind speed	km/hour
<i>WSp</i>	Previous wind speed	km/hour
<i>YG</i>	Numerical yield grade	

beyond the point of biochemical maturity may improve the quality grade and generate higher revenue given the price spread, but the cost of gain is likely be higher as feed efficiency goes down. On the other hand, it may not be profitable to feed cattle until they reach biochemical maturity because palatability of beef at full maturity may not be desirable to consumers. While body fat in finished cattle varies from 21 percent to 33 percent in the world market, consumers in the US rather prefer beef with at the least USDA low Choice quality, which corresponds to approximately 28 percent empty body fat (Fox et al., 2002; NRC, 1996, 2000). Therefore, shrunk body weight at 28 percent empty body fat is typically considered to determine the target harvest body weight (Perry and Fox, 1997; NRC, 2000; Tedeschi et al., 2004).

The weight at which cattle reach 28 percent empty body fat differs depending on genotype and sex (Fox and Black, 1984; NRC, 2000). For the same reason, chemical composition of the empty body is different among cattle types even when weight is the same. Based on steer composition and heifer mature weight, steers are assumed to have 28 percent empty body fat at the mature breeding female weight of a particular frame size (Smith et al., 1976; Cundiff et al., 1981; Jenkins and Ferrell, 1984; Harpster, 1978). At the same degree of maturity, bulls are assumed to be 20 percent heavier and heifers 20 percent lighter than steers of the same frame score (Klosterman and Parker, 1976; Harpster et al., 1978; Fortin et al., 1980). Fox et al. (1992) developed a relationship between frame size and shrunk body weight of beef and dairy cattle at 28 percent empty body fat, which has been adopted by the Subcommittee (NRC, 1996). Table 5.2 presents expected shrunk body weights of beef cattle of different frame sizes at 28 percent body

fat. Thus, if frame scores are known, shrunk body weight of beef cattle can be determined from Table 5.2.

**Table 5.2: Frame scores and expected shrunk body weights of feeder cattle at 28% body fat.**

Frame Score	Weight of feeder cattle at 28% body fat		
	Bulls	Steers	Heifers
1	480	400	320
2	520	433	346
3	560	467	374
4	600	500	400
5	640	533	426
6	680	567	454
7	720	600	480
8	760	633	506
9	800	667	534

Source: Fox et al. (1992).

Expected final shrunk body weight (*EFSBW*) at 28 percent empty body fat, as predicted by the above method, can be used to estimate animal nutrient requirements for maintenance and growth and days required to finish. However, the expected finished weights for different frame sizes in Table 5.2 were estimated using data from cattle that received an estrogenic implant and were fed in a two-phase feeding program, first backgrounded on high quality forage based rations containing approximately 50 percent grain for approximately 90-120 days, and then finished on typical high-grain feedlot rations. Based on observed effects of growth promoting implants on feed intake, daily gain, feed efficiency, and weights at similar composition, Fox et al. (1992) suggest that

the *EFSBW* should be adjusted to one frame size smaller if no implant is used or one frame size larger for an estrogen and Trenbolone Acetate (TBA) combination implant.

Evaluating the results of relevant studies, the Subcommittee (NRC, 1996) provides a guideline to adjust the *EFSBW* for alternative implant and ration strategies:

No implant:  $AFSBW = EFSBW - (25 \text{ to } 45 \text{ kg.})$ ;

Estrogen only:  $AFSBW = EFSBW$ ;

Estrogen plus TBA:  $AFSBW = EFSBW + (25 \text{ to } 45 \text{ kg.})$ ;

Extended backgrounding:  $AFSBW = EFSBW + (25 \text{ to } 45 \text{ kg.})$ ;

Typical ration:  $AFSBW = EFSBW$ ;

High energy ration from weaning:  $AFSBW = EFSBW - (25 \text{ to } 45 \text{ kg.})$ .

Tedeschi et al. (2004), however, suggest reducing *EFSBW* by 5 percent for calves fed high energy rations from weaning to harvest, and increasing it by 5 percent for calves placed in backgrounding programs at a slow rate of gain for an extended period of time before finishing on a high energy ration.

#### **5.4 Determining Equivalent Shrunken Body Weight**

Based on energy intake, rate of gain, and body composition data obtained from 72 comparative slaughter experiments with 3,491 cattle, Garrett (1980) developed equations to predict energy and protein requirements for medium-frame-size steers, which were later adopted by the Subcommittee (NRC, 1984). These medium-frame steer equations can be used as the standard reference base to compute energy requirements for gain for any given rate of gain, and shrunken weight gain for any available energy for gain.

However, adjustments in body weight are needed to predict energy requirements and



gains at various stages of growth for all cattle types. Tylutki et al. (1994) describes a procedure to adjust the body weights of cattle with various body sizes and sexes to a weight at which they are equivalent in body composition to the steers in the Garrett (1980) data base. The weight equivalent ( $EqSBW$ ) to the medium-frame-size steer (NRC, 1984) is calculated as

$$EqSBW_i = SBW_i \times (SRW / AFSBW) . \quad (5.1)$$

Using the energy and protein retained validation data (Harpster, 1978; Danner et al. 1980; Lomas et al. 1982; Woody et al. 1983), the Subcommittee (NRC, 1996) estimated shrunk reference weights for three marbling categories: traces, slight, and small. The estimated empty body fat percentages within all cattle in each of the three marbling categories were 25.2 ( $\pm 2.91$ ), 26.8 ( $\pm 3.0$ ), and 27.8 ( $\pm 3.4$ ), respectively, and the corresponding  $SBW$ s of the animals were found to be 435, 462, and 478 kg (NRC, 1996). The Subcommittee (NRC, 1996) recommends using these values of  $SBW$  as the standard  $SRW$ s for the corresponding target empty body composition. Thus, in order to predict the energy requirement and gain,  $SBW$  in the Subcommittee's (NRC, 1984) equations is replaced by  $EqSBW$ , which is calculated by multiplying the ratio of 478 to adjusted final shrunk body weight at 28 percent empty body fat ( $AFSBW$ ) by the actual shrunk body weight of the animal.

## 5.5 Ration Energy and Protein Values

Dry matter intake ( $DMI$ ) and shrunk weight gain ( $SWG$ ) crucially depends on net energy values of the ration. Moreover, energy allowable growth must be supported by protein allowable growth (Tedeschi et al., 2004; NRC, 2000). The National Research

Council (1996, 2000) provides a feed library comprising nutrient and chemical composition of available feedstuffs. Using the Subcommittee (NRC, 2000) feed library, net energy and protein values of a ration containing several feed ingredients can be computed for each kilogram of feed and dry matter. The contents of metabolizable energy ( $ME$ ), net energy for maintenance ( $NE_m$ ), and net energy for growth ( $NE_g$ ) of each feed ingredient are directly available from the feed library. Metabolizable protein ( $MP$ ) content of the feed can be calculated from other components in the list following the Subcommittee (NRC, 2000).

Metabolizable protein is defined as the actual protein absorbed by the intestine. The total amount of  $MP$  available from the consumed feed is the sum of digested undegraded feed protein and digested microbial protein (NRC, 2000). Available undegraded feed protein ( $UIP$ ) is assumed to be 80 percent digestible. Therefore,

$$MP_f = 0.8 \times UIP. \quad (5.2)$$

The contribution of microbial protein to the total supply of  $MP$  is estimated from the microbial crude protein ( $MCP$ ) yield (NRC, 2000). For the feed ingredients with effective neutral detergent fiber ( $eNDF$ ) higher than 20 percent,

$$MCP = 0.13 \times TDN.$$

It is assumed that  $MCP$  contains 80 percent true protein, 80 percent of which is digestible. Hence, available microbial protein is

$$MP_b = 0.8 \times 0.8 \times MCP. \quad (5.3)$$

Finally, total  $MP$  supplied by the consumed feed is calculated as

$$MP = FP_f + MP_b. \quad (5.4)$$

Once harvest body weight and composition, equivalent shrunk body weight, and energy and protein values are determined, the growth model can be employed to predict dry matter intake, weight gain, and composition of gain on a daily basis. The model also accounts for the effects of the environment and different implant strategies on the net energy requirement for maintenance and growth in each production situation.

### **5.6 Prediction Equations for Dry Matter Intake by Individual Animal**

Although feed intake of ruminant animals is primarily driven by energy and protein requirements for maintenance and growth, factors that regulate feed intake are complex and not yet fully understood. Nevertheless, a considerable amount of empirical animal science research has established that dry matter intake (*DMI*) of an animal is determined by dietary energy concentration and physiological factors such as gastrointestinal fill, ruminal volatile fatty acid concentration and pH, percent of body fat, and age and frame size of the animal (NRC, 1996). In addition, numerous experiments on ruminant animals have shown that environmental management and dietary factors also influence feed intake. For example, feed intake increases (decreases) as the temperature falls below (above) 20° C (Kennedy et al., 1986; Minton, 1986; Young, 1986; Young et al., 1989). Other adverse environmental conditions such as level of precipitation and mud, and wind speed accentuate the effects of ambient temperature (NRC, 2000). Use of growth promoting implants increases feed intake, while ionophore feed additives decreases feed intake (Fox et al., 1988, 1992; Rumsey et al., 1992).

The Subcommittee (NRC, 1984) provided an equation to predict *DMI* for growing and finishing beef cattle that describes *DMI* as a function of dietary *NEm* concentration

and *SBW*. Later, the 1996 Subcommittee evaluated the parameters in the equations of the 1984 Subcommittee using data obtained from experiments conducted with growing and finishing beef cattle that were published in the *Journal of Animal Science* from 1980 to 1992. The base *DMI* equation, with revised parameter values adopted by the Subcommittee (NRC, 1996) is given by

$$DMI_t = (SBW_{t-1}^{0.75} \times (0.2435 \times NEm - 0.0466 \times NEm^2 - a_0)) / NEm \quad (5.5)$$

where  $a_0 = 0.1128$  for ages less than 12 months and  $a_0 = 0.0869$  for ages greater than 12 months. Subsequent research and field experiments suggested that equation (5.5) should be adjusted for the effects of empty body fat, genetic breed, feed additives, temperature, and mud depth on voluntary feed intake, which are recognized by the Subcommittee (NRC, 2000).

### ***Adjustment for Body Fat***

Using the relationship between equivalent shrunk body weight (*EqSBW*) and empty body fat percentage (*EBFP*) provided by Fox et al. (1992) and the Subcommittee (NRC, 2000), Tedeschi et al. (2003) allow a continuous adjustment for the effect of body fat on *DMI*. They recommend that the *DMI* equations be multiplied by a body fat adjustment factor (*DMIBF*) given by

$$DMIBF_t = \begin{cases} 1 & \text{for } EqSBW < 350 \text{ kg} \\ 0.7714 + 0.00196 \times EqSBW_t - 0.00000371 \times EqSBW_t^2 & \text{for } EqSBW \geq 350 \text{ kg.} \end{cases} \quad (5.6)$$

### ***Adjustment for Breed***

Fox et al. (1992) and the Subcommittee (NRC, 2000) also suggest that the *DMI* prediction equation be adjusted for genetic breed of the beef cattle with a factor defined by

$$DMIB_t = \begin{cases} 1.08 & \text{for Holstein cattle} \\ 1.04 & \text{for British Holstein cattle} \\ 1.00 & \text{for all other cattle.} \end{cases} \quad (5.7)$$

### ***Adjustment for the Use of Growth Promoting Implants***

Accepting the results of the research by Fox et al. (1992), the Subcommittee (NRC, 2000) suggests that predicted *DMI* be decreased by 6 percent when implants are not in use and by 4 percent if an ionophore is fed at concentrations of 27.5 to 33 mg/kg dietary dry matter. Although the Subcommittee (NRC, 2000) does not suggest different adjustment factors for different growth promoting implants, Duckett et al. (1996) found that use of continuous estrogenic implants increased feed intake by 6 percent over non-implanted controls, while the effect was larger (7 percent to 10 percent) for the use of estrogen plus TBA. Therefore, the *DMI* adjustment factor for the use of growth promoting implants (*DMIMP*) adopted in this study is defined as

$$DMIMP = \begin{cases} 0.94 & \text{for no anabolic implant} \\ 1.00 & \text{for any estrogenic implant} \\ 1.03 & \text{for any combination of estrogen and TBA.} \end{cases} \quad (5.8)$$

### ***Adjustment for Environmental Conditions***

Fox and Tylutki (1998) examined the effects of temperature ( $T_c$ ), relative humidity ( $RH_c$ ), wind speed ( $WS$ ), and hours of sunlight ( $HRS$ ) on feed intake of dairy cattle. They found that dairy 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. According to the Subcommittee (NRC, 2000), the *DMI* adjustment factors provided by Fox and Tylutki are equally applicable to beef cattle. The *DMI* adjustment factor (*DMIT*) for different levels of temperature is defined as

$$DMIT_i = \begin{cases} 1.16 & \text{for } T_{c_i} \leq -20^\circ C \\ 1.0433 - 0.0044 \times T_{c_i} + 0.0001 \times T_{c_i}^2 & \text{for } -20^\circ C < T_{c_i} \leq 20^\circ C \\ (119.62 - 0.9708 \times CETI) / 100 & \text{for } T_{c_i} > 20^\circ C \end{cases} \quad (5.9)$$

where *CETI* represents the current month's effective temperature index, which is computed using the current month's average temperature ( $T_c$ ), relative humidity ( $RH_c$ ), wind speed ( $WSc$ ), and hours of sunlight ( $HRS_c$ ) as (Baeta et al., 1987)

$$\begin{aligned} CETI = & 27.88 - (0.456 \times T_c) + (0.010754 \times T_c^2) - (0.4905 \times RH_c) \\ & + (0.00088 \times RH_c^2) + (1.1507 \times (1000/3600) \times WSc) \\ & - (0.126447 \times ((1000/3600) \times WSc)^2) + (0.019876 \times T_c \times RH_c) \\ & - (0.046313 \times T_c \times ((1000/3600) \times WSc)) + (0.4167 \times HRS_c). \end{aligned} \quad (5.10)$$

Fox and Tylutki (1998) also examined the effects of night cooling on feed intake as temperatures fall considerably during the night in some regions of the U.S. The *DMI* adjustment factor for the effect of weather conditions with night cooling is given by

$$DMITNC_t = \begin{cases} 1.16 & \text{for } Tc_t \leq -20^\circ C \\ 1.0433 - 0.0044 \times Tc_t + 0.0001 \times Tc_t^2 & \text{for } -20^\circ C < Tc_t \leq 20^\circ C \\ \frac{(1 - DMIT_t) \times 0.75 + DMIT_t}{100} + 1.05 & \text{for } 20^\circ C < Tc \leq 28^\circ C \\ \frac{(1 - DMIT_t) \times 0.75 + DMIT_t}{100} + 1.00 & \text{for } Tc > 28^\circ C. \end{cases} \quad (5.11)$$

### ***Adjustment for Mud Depth in the Feedlot***

Fox et al. (1992) found that voluntary feed intake by cattle decreases with the mud depth of the feedlot, which is also recognized by the Subcommittee (NRC, 2000). Tedeschi et al. (2004) provides the following equation for continuous adjustment for mud depth on feed intake.

$$DMIM_t = 1 - 0.01 \times Mud_t. \quad (5.12)$$

Thus, with the adjustments for body fat, genetic breed, feed additive, and weather condition, the prediction equation for feed intake by feedlot cattle is

$$AdjDMI_t = DMI_t \times DMIBF_t \times DMIB_t \times DMIMP \times DMITNC_t \times DMIM_t. \quad (5.13)$$

## **5.7 Required Energy for Maintenance**

As defined by the Subcommittee (NRC, 1996), the maintenance requirement for energy is the amount of feed energy intake that results in no net loss or gain of energy from the tissues of the animal body. Processes or functions comprising maintenance energy requirements include essential metabolic processes, body temperature regulation, and physical activity (NRC, 2000). Typically, energy required for maintenance is computed by adjusting the basal metabolism energy requirement for physiological state,

breed, activity, environmental effects, and heat and cold stress. The Subcommittee (NRC, 2000) defines the base maintenance energy requirement of beef cattle in a thermoneutral environment with minimal physical activity as<sup>21</sup>

$$REM_t = SBW_t^{0.75} \times ((a_1 \times BE \times PN) + a_2), \quad (5.14)$$

where  $a_1 = 0.077$ ,  $BE$  is the breed effect multiplier as provided by the Subcommittee (NRC, 2000), and  $PN$  and  $a_2$  are adjustment factors for previous plane of nutrition and previous temperature, respectively.<sup>22</sup>

According to the Subcommittee (NRC, 1996), the body condition score ( $BCS$ ) of an animal, which follows a nine point scale where 1 is emaciated and 9 is obese, reflects the previous plane of nutrition that has an effect of the animal's fasting metabolic energy requirement. In particular, for each one point change in  $BCS$  from the mid-point ( $BCS = 5$ ) a change of 5 percent in fasting metabolism is expected. This relationship is represented by

$$PN = 0.8 + (BCS - 1) \times 0.05. \quad (5.15)$$

Reviewing the studies of Young (1975a, 1975b), the Subcommittee (NRC, 1981) recognized that the temperature to which an animal had been previously exposed had an effect on the 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

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<sup>21</sup> A temperature of  $20^\circ C$  is described as being thermoneutral since this temperature has no effect on the base metabolic rate (Fox and Tylutki, 1998).

<sup>22</sup> The parameter value for  $a_1$  in the basal maintenance energy requirement equation is adopted from the study by Lofgreen and Garrett (1968) with cattle fed in individual stalls. Assuming that the animals in the study of Lofgreen and Garrett had on average 6 position changes and 8 standing hours, Tedeschi et al. (2004) suggest that the value of  $a_1$  would be 0.072 without any physical activity and no previous nutrition effect. Tedeschi et al. (2004) also provides a list of multipliers for alternative physical activities of the cattle while on feed.



cold stress or heat stress (Fox and Tylutki, 1998). The subsequent Subcommittees have adopted the following equation to take account of previous temperature on beef cattle's maintenance requirement:

$$a_2 = 0.0007 \times (20 - T_p). \quad (5.16)$$

Analyzing the same data set used by Young (1975a), Fox and Tylutki (1998) found that  $a_2$  did not decrease above the thermoneutral temperature, and proposed an alternative equations for  $a_2$  given by

$$a_2 = \begin{cases} \frac{88.426 - (0.785 \times T_p) + (0.0116 \times T_p^2) - 77}{1000} & \text{for } T_p \leq 20^\circ \text{C} \\ \frac{88.426 - (0.785 \times PETI) + (0.0116 \times PETI^2) - 77}{1000} & \text{for } T_p > 20^\circ \text{C} \end{cases} \quad (5.17)$$

where

$$\begin{aligned} PETI = & 27.88 - (0.456 \times T_p) + (0.010754 \times T_p^2) - (0.4905 \times RHp) \\ & + (0.00088 \times RHp^2) + (1.1507 \times (1000 / 3600) \times WSp) \\ & - (0.126447 \times ((1000 / 3600) \times WSp)^2) + (0.019876 \times T_p \times RHp) \\ & - (0.046313 \times T_p \times ((1000 / 3600) \times WSp)) + (0.4167 \times HRSp). \end{aligned} \quad (5.18)$$

In addition to adjustment in the maintenance energy requirement for previous ambient temperature, the Subcommittee (NRC, 2000) also recommends adjustment for the effects of current temperature. 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. 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.

#### ***Adjustment for the Direct Effect of Cold Stress***

Factors primarily contributing to differences in animal heat loss include surface area (*SA*), external insulation (*EI*), and internal or tissue insulation (*TI*). According to the Subcommittee (NRC, 2000), surface area is a function of shrunk body weight given by the equation

$$SA_t = 0.09 \times SBW_t^{0.67} . \quad (5.19)$$

Heat production per unit of animal body surface area is given by

$$HE_t = ((ME_t \times AdjDMI_t) - RE_t) / SA_t , \quad (5.20)$$

where

$$RE_t = (AdjDMI_t - (REM_{t-1} / (NE_m \times IF))) \times NE_g . \quad (5.21)$$

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). The measure of external insulation adopted by the Subcommittee is

$$EI_t = (7.36 - (0.296 \times WS_t) + (2.55 \times HD_t)) \times MudME_t \times HideME_t \quad (5.22)$$

where

$$MudME_t = \begin{cases} 1 - (HCCode_t - 1) \times 0.2 & \text{for } HCCode_t \leq 2 \\ 0.8 - (HCCode_t - 2) \times 0.3 & \text{for } HCCode_t > 2 \end{cases} \quad (5.23)$$

$$HideME_t = 0.8 + (HideCode - 1) \times 0.2. \quad (5.24)$$

Tissue insulation ( $TI$ ) is measured as

$$TI = 5.25 + 0.75 \times BCS. \quad (5.25)$$

Thus, total insulation of an animal can be expressed as

$$IN_t = EI_t + TI. \quad (5.26)$$

Using the amount of heat production by an animal and its insulation, the lower critical temperature is calculated as

$$LCT_t = 39 - (IN_t \times HE_t \times 0.85). \quad (5.27)$$

The increase in energy required to maintain essential heat production in an environment colder than the animal's  $LCT$  is computed as

$$MEcs_t = \begin{cases} SA_t \times (LCT_t - Tc_t) / IN_t & \text{for } LCT_t > Tc_t \\ 0 & \text{for } LCT_t \leq Tc_t. \end{cases} \quad (5.28)$$

Finally, required energy for maintenance adjusted for cold stress is calculated as

$$AdjREM_t = REMcs_t = REM_t + (NEm / ME) \times MEcs_t. \quad (5.29)$$

### ***Adjustment for the Direct Effect of Heat Stress***

Predicting the  $UCT$  of an animal is difficult because of the complex interaction of environmental and physiological factors. Fox and Tylutki (1998) suggest a method to

quantify the direct effect of heat stress that uses  $CETI$  instead of  $UCT$ . The heat stress factor for the required energy for maintenance developed by Fox and Tylutki (1998) is

$$NEmhs_t = \begin{cases} 1.09857 - (0.01343 \times CETI_t) \\ \quad + (0.000457 \times CETI_t^2) & \text{for } CETI_t > 20^\circ C \\ 1 & \text{for } CETI_t \leq 20^\circ C. \end{cases} \quad (5.30)$$

Required energy for maintenance is thus computed by multiplying  $REM$  by the heat stress adjustment factor,

$$AdjREM_t = REMhs_t = REM_t \times NEmhs_t. \quad (5.31)$$

### 5.8 Available Energy for Growth and Weight Gain

Weight gain that can be expected for the metabolizable energy and protein consumed by an animal on a given day is a function of the net energy available for growth ( $NEFG$ ) after accounting for maintenance requirements, and the equivalent shrunk body weight ( $EqSBW$ ) of the animal at the beginning of that day (Tedeschi et al. 2004; Tylutki et al., 1994). Accurate prediction of weight gain depends on accurate estimation of net energy available for growth and the mature weight of the animal (Fox et al., 1992).

As described by the Subcommittee (NRC, 2000), net energy available for growth can be estimated as dry matter available for growth multiplied by dietary content of  $NEg$ . Dry matter available for growth is equal to total dry matter intake minus dry matter required for maintenance, which is required energy for maintenance (adjusted for environmental and physiological factors) divided by the dietary content of  $NEm$  adjusted for the use of ionophores,

$$DMFM_t = AdjREM_t / (NE_m \times IF); \quad (5.32)$$

$$DMFG_t = AdjDMI_t - DMFM_t; \quad (5.33)$$

$$NEFG_t = DMFG_t \times NE_g. \quad (5.34)$$

The Subcommittee (NRC, 2000) developed the following equation from the body composition data base of Garrett (1980), which predicts shrunk weight gain using estimated net energy for gain (*NEFG*) and equivalent shrunk body weight (*EqSBW*) of the animal:

$$SWG_t = 13.91 \times NEFG_t^{0.9116} \times EqSBW_{t-1}^{-0.6837}. \quad (5.35)$$

The predicted shrunk weight gain is added to the current shrunk body weight to obtain the shrunk body weight at the beginning of the next day. The process continues until a specified feeding period (in days) ends or a target final body weight is reached.

## 5.9 Protein Requirements for Maintenance and Growth

Metabolizable protein required for maintenance (*MPm*) is determined by metabolic fecal, urinary, and scurf losses. Using nitrogen balance studies that account for such protein losses, the Institute National De la Recherche Agronomique (INRA, 1988) estimated that the maintenance requirement was 3.25 g MP/kg *SBW*<sup>0.75</sup>. Based on the growth of animals' metabolic body weight, Wilkerson (1993) determined the maintenance requirements for growing cattle to be 3.8 g *MP*/kg *SBW*<sup>0.75</sup>. The Subcommittee (NRC, 2000) accepted Wilkerson's measure because the estimate was based on animal growth rather than nitrogen balance. Wilkerson's measure is also supported by recent research on nitrogen balance by Susmel et al. (1993).

Given the relationship between energy available for gain ( $NEFG$ ) and protein content of gain, net protein required for gain ( $NPg$ ) can be calculated following the Subcommittee (NRC, 2000) as

$$NPg_t = SWG_t \times (268 - (29.4 \times (NEFG_t / SWG_t))). \quad (5.36)$$

However, protein conversion efficiency of  $MP$  to  $NP$  is not constant across body weights and rates of gain (NRC, 2000). Recent research on protein efficiency of growing cattle suggests that efficiency decreases as body weight increases (Ainslie et al. 1993; Wilkerson, 1993; INRA, 1988). Using INRA data, Ainslie et al. (1993) developed an equation with a lower bound to estimate protein conversion efficiency of  $MP$  to  $NP$  which was adopted by the Subcommittee (NRC, 1996, 2000),

$$PEg_t = \begin{cases} 0.834 - (0.00114 \times EqSBW_t) & \text{for } EqSBW_t \leq 300 \text{ kg} \\ 0.492 & \text{for } EqSBW_t > 300 \text{ kg}. \end{cases} \quad (5.37)$$

Metabolizable protein required for gain ( $MPg$ ) is thus calculated by dividing  $NPg$  by  $PE$ . While  $MPm$  is calculated based on metabolic body weight ( $SBW^{0.75}$ ) of an animal,  $MPg$  is based on the  $SBW$  itself. Total protein required for maintenance and growth is the sum of  $MPm$  and  $MPg$ ,

$$RMP_t = 3.8 \times SBW_t^{0.75} + (NPg_t / (PEg_t \times SBW_t)). \quad (5.38)$$

Following Tedeschi et al. (2004), the cattle growth simulation model assumes that ruminal requirements for nitrogen are met, and tissue amino acid requirements are met by the available metabolizable protein. The model also assumes that the requirements for minerals (e.g., phosphorus, calcium, magnesium, etc.) are met by the supplied diet.

## 5.10 Composition of Gain and the Amount of Body Fat

While gain is composed of protein, fat, water, nitrogen, and ash, the net energy available for gain is retained as either protein or fat (NRC, 2000). Garrett (1980, 1987) developed equations to estimate the energy content of gain as a function of observed empty body weight and gain, and then predicted the proportions of protein and fat in gain using the estimated energy content of weight gain. The Subcommittee (NRC, 1996) adopted the equations proposed by Garrett (1980, 1987). Tedeschi et al. (2004) provide similar equations that can be used to predict protein and fat content of gain when net energy available for gain (*NEFG*) and empty weight gain (*EWG*) are known:

$$EWG_t = 0.956 \times SWG_t; \quad (5.39)$$

$$PIG_t = 0.254 - 0.0271 \times (NEFG_t / EWG_t); \quad (5.40)$$

$$FIG_t = -0.154 + 0.123 \times (NEFG_t / EWG_t). \quad (5.41)$$

Body fat accumulates over time and the amount of empty body fat (*EBF*) at the end of any day during the feeding phase can be estimated by adding the amount of fat in gain to the amount of *EBF* at the beginning of the day (Tedeschi et al., 2003; 2004),

$$EBF_t = EBF_{t-1} + 0.85 \times FIG_t \times EWG_t. \quad (5.42)$$

Accordingly, the percentage of empty body fat at the end of a day on feed can be obtained by dividing the amount of accumulated fat by the empty body weight (*EBW*),

$$EBFP_t = 100 \times (EBF_t / EBW_t). \quad (5.43)$$

This approach requires an estimate of empty body fat of the cattle at the beginning of the feeding phase. Simpfendorfer (1974) and Owens et al. (1995) presented the following quadratic equations, respectively, to predict initial empty body fat.

$$EBF_0^S = 0.00054 \times EBW_0^2 + 0.037 \times EBW_0 - 0.61; \quad (5.44)$$

$$EBF_0^O = 0.000494 \times EBW_0^2 + 0.0991 \times EBW_0 - 11.34. \quad (5.45)$$

Tedeschi et al. (2003) evaluated the above equations using slaughter data from five studies (Crickenberger, 1977; Danner, 1978; Harpster, 1978; Lomas, 1979; Woody, 1978). They found that, while both of the equations accounted for a similar proportion of variation, the Owens et al. (1995) equation predicts lower values for *EBF* when *EBW* was below 200 kg and the Simpfendorfer (1974) equation overpredicts *EBF* for higher *EBW*. Tedeschi et al. (2003) suggest that the systematic bias could be eliminated by multiplying the right hand side of the Simpfendorfer (1974) equation by 0.85. Thus, the initial empty body fat can be predicted following Tedeschi et al. (2004) as

$$EBF_0 = (0.00054 \times EBW_0^2 + 0.037 \times EBW_0 - 0.61) \times 0.85. \quad (5.46)$$

### 5.11 Prediction Equations for Carcass Weight

Based on animal science laboratory research, several equations have been published in the *Journal of Animal Science* establishing a positive relationship between empty body weight and carcass weight of beef cattle (Lofgreen et al., 1962; Garrett and Hinman, 1969; Holzer and Levy, 1969; Fox et al., 1972; Fox et al., 1976; Garrett et al., 1978). The empty body weight of cattle can be predicted from shrunk body weight as (Garrett, 1980; NRC, 1996, 2000)

$$EBW_t = 0.891 \times SBW_t. \quad (5.47)$$

Carcass weight can then be calculated using any of the following equations:

$$\text{Lofgreen et al. (1962):} \quad CW_t = -21.86 + 0.69 \times EBW_t;$$



Garrett and Hinman (1969):  $CW_t = -22.22 + 0.73 \times EBW_t$ ;

Fox et al. (1976):  $CW_t = -28.71 + 0.71 \times EBW_t$ ;

Garrett et al. (1978):  $CW_t = -24.54 + 0.76 \times EBW_t$ . (5.48)

Fox et al. (1976) suggest that the above equations are mutually consistent in predicting carcass and empty body weights given alternative conditions and types of cattle tested, and compatible with live sale weights adjusted for the rumen-reticulum contents. However, parameter values in the above equations differ because the procedures used to determine carcass and empty body weight of the cattle in the corresponding research were not similar. Fox et al. (1976) argue that if all the research had determined empty body weight as live weight minus all digestive tract content, parameter values in all the equations would likely be similar.

Using actual empty body weight and carcass weight data, Tedeschi et al. (2004) evaluated the equations published by Garrett and Hinman (1969), Fox et al. (1976), and Garrett et al. (1978). They found that all three equations accounted for at least 89 percent of the variation, but for cattle with various frame sizes the Garrett and Hinman (1969) equation had the best combination of low mean bias, mean squared error (MSE), and root mean squared prediction error (RMSPE).

## 5.12 Prediction Equations for Carcass Yield and Quality Grades

The primary factor in determining yield grade is the amount of carcass fat. On the other hand, quality grade is a function of marbling score, which is directly related to the amount of carcass fat, but is subject to variation in the distribution of fat within the

carcass. Fox and Black (1984) developed two equations that can be used to predict yield grade and quality grade from the percentage of carcass fat,

$$YG_t = -1.7 + 0.15 \times CFP_t \quad \text{for } 25 \leq CFP_t \leq 40; \quad (5.49)$$

$$QG_t = 2.5 + 0.23 \times CFP_t \quad \text{for } 15 \leq CFP_t \leq 38. \quad (5.50)$$

Fox and Black (1984) argue that, although various other factors may influence yield and quality grades, their prediction equation works reasonably well under typical feedlot conditions.

Percentage of carcass fat can be estimated from empty body fat percentage following the relationship provided by Garrett and Hinman (1969),

$$CFP_t = 0.70 + 1.0815 \times EBF_t. \quad (5.51)$$

Estimated carcass fat percentage can then be used in the above equations to predict yield and quality grades. The resulting yield grade value is equivalent to the numerical yield grade standards set by the USDA. However, the numerical quality grade obtained from the prediction equation needs to be converted to represent USDA standards. Fox and Black proposed the following rule to convert numerical quality grade to the categories recognized by the USDA:

Standard = 8, Select = 9, Low Choice = 10, Mid Choice = 11,

High Choice = 12, Low Prime = 13, and Mid Prime = 14.

Using independent data from six studies (Crickenberger, 1977; Danner, 1978; Harpster, 1978; Lomas, 1979; Perry et al., 1991; Woody, 1978), which included pen- and individually-fed steers and heifers of different breeds, Tedeschi et al. (2004) evaluated the yield grade prediction equation proposed by Fox and Black. They found that the equation provided satisfactory predictions of yield grade in the range of 2.5 and 3.5, but

tended to under- and over-predict yield grade below and above that range, respectively.<sup>23</sup> Tedeschi et al. (2004) also developed an equation to predict yield grade directly from empty body fat percentage, which gives very similar results to the one developed by Fox and Black,

$$YG_t = -0.604 + 0.127 \times EBF P_t. \quad (5.52)$$

Employing carcass data of 1,355 beef cattle, Guiroy et al. (2001) estimated the relationship between carcass and empty body fat percentage to each USDA quality grade. Results from their study show that mean empty body fat percentages that correspond to USDA standard, select, low choice, mid-choice, high choice, low prime, and mid-prime are 21.13, 26.15, 28.61, 29.88, 31.00, 31.94, and 32.45, respectively. Thus, the difference in empty body fat percentage units decreases as quality grade improves, while the incremental change is fixed (4 percentage points) in the measure proposed by Fox and Black (1984). In order to predict quality grade, this model uses mean empty body fat percentages with associated standard errors as reported by Guiroy et al, while equation (5.49) is adopted to predict yield grade of the carcass.

### 5.13 Conclusion

This chapter presents a dynamic biophysical growth model for beef cattle that can simultaneously predict the outcomes of alternative feeding strategies for given animal characteristics and the production environment. In particular, for a wide range of alternative feed-implant strategies, the model is able to predict dry matter intake by each individual animal for each day on feed, resulting daily weight gain and composition, final

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<sup>23</sup> Actual yield grade is determined from accurate measures of hot carcass weight, fat thickness at the 12<sup>th</sup>-13<sup>th</sup> rib, percentage of kidney, heart, and pelvic fat, and the area of ribeye muscle (Field and Taylor, 2002).

weight and yield and quality grades of the carcass, and days required to reach a target harvest body weight or final body weight and composition for a given feeding period.

The model is developed by adapting the CVDS model as described in Tedeschi et al. (2004) with complementary sub-models published in NRC reports (1996, 2000) of the Subcommittee on beef cattle nutrition requirements and other relevant animal science research. All of the basic equations, i.e., equations (5.1)-(5.38), and associated parameter values for predicting feed intake and weight gain are well recognized and accepted by the Subcommittee (NRC, 1996, 2000) after many critical evaluations. The equations for predicting the composition of gain, carcass weight, and resulting yield and quality grades, i.e., equations (5.39)-(5.52), were also evaluated and recommended by a respected panel of animal scientists. Since this growth model can predict feed intake, growth performance, carcass yield, and beef quality with an acceptable degree of accuracy, the remainder of this dissertation considers its usefulness for examining economic decision making by cow-calf producers, cattle feeders, and beef packers including explanation of the predominance of various contract forms and the potential for new grid pricing possibilities. The next chapter employs the biophysical model to predict feedlot and carcass performance of a large set of feeder steers and evaluates the predictive efficiency of the model with actual data.

## CHAPTER 6

### APPLICATION AND EVALUATION OF THE BIOPHYSICAL GROWTH SIMULATION MODEL FOR BEEF CATTLE

#### 6.1 Introduction

The biophysical growth model for beef cattle presented in the previous chapter can be used to predict feedlot and carcass performance of individual cattle for a given input and production environment. The model may also be useful for economic decision making by cow-calf producers, cattle feeders, and beef packers. For example, given input and output price data, producers can determine the optimal time or final body weight for marketing fed cattle. This study employs the model in determining optimal actions of cattle feeders and cow-calf producers who work under alternative cattle feeding contracts. Before using the model beyond its primary purpose, it is important to test how it performs in predicting cattle feeding outcomes. This chapter presents an evaluation of the predictive efficiency of the growth model.

The biophysical growth model for beef cattle is applied to simulate feedlot and carcass performance of a large sample of steers actually fed in feedlots located in southwestern Iowa through the Tri-County Steer Carcass Futurity Cooperative (TCSCF). Simulated outcomes are then compared with the actual outcomes. The following section provides a detailed description of the data used in the simulation. The step-by-step simulation procedure is presented next. Results from the simulation are then presented and analyzed. Finally, the biophysical growth model for beef cattle is evaluated by comparing predicted outcomes with actual observations.

## **6.2 Description of Input Data**

Data used in the cattle growth simulation process were obtained from three sources. First, feedlot and carcass performance data on 1147 steers actually fed in feedlots located in Red Oak, Iowa, under the TCSCF program during 1995-99, were obtained from the Iowa Beef Center (IBC) of Iowa State University. This data set contains individual cow and calf information provided by the cow-calf producers, feedlot performance data recorded by the feeders, and carcass data collected from the packers. Second, energy and protein values of typical feed ingredients were obtained from the report on beef cattle nutrition published by the Subcommittee (NRC, 2000). Finally, daily and weekly averages of major weather variables such as temperature, relative humidity, hours of sunshine, and wind speed in Red Oak, Iowa, were obtained from the WeatherBank Incorporation, a meteorological consulting company providing weather data and products. All of these three data sets are described in detail below.

### ***The TCSCF Data***

For more than 25 years the TCSCF has been helping beef producers better manage and market their products by providing ranch to rail information. Cow-calf producers who are interested in sharing cow-calf information in exchange for feedlot and carcass performance data can feed their cattle through the TCSCF by retaining ownership and providing detailed cow and calf information. The TCSCF places the cattle from the interested cow-calf producers in participating feedlots and records information on individual animal performance during the feeding phase, and carcass data after slaughter. By obtaining feedlot and carcass data, cow-calf owners are able to learn more about how

their cattle perform on the feedlot and on the rails. On the other hand, by obtaining cow-calf information, cattle feeders and packers also learn more about the type of the cattle that are likely to perform better in the feedlot and on the rail. While this voluntary method of sample selection may self-select, say, cow-calf owners who are more interested in marketing efficiency, this selectivity should not bias the test of the biophysical growth model which is conditioned on the relevant factors (e.g., genetic stock and production practices) that could otherwise cause this bias.

The TCSCF provided data on 1147 steers to IBC researchers. The steers were placed on feed in the feedlots of Red Oak, Iowa, during October-December of 1995-98 and slaughtered during April-June of the following year. Upon receiving the cattle from the ranchers, the TCSCF obtained cow-calf information for each individual steer. Cow-calf information include birth date and weight of the steer calves, cow and sire breed, cow age and weight, cow calving interval, and cow body condition score at weaning. Individual steer's age, weight, and frame score were recorded immediately after the cattle were delivered to the participating feedlots. Upon completion of the feeding phase, TCSCF collected feedlot performance of the animals. Feedlot information include days on feed (*DOF*), total amount of feed consumed, and total weight gain. Finally, carcass data were recorded upon slaughter. Carcass data include hot carcass weight (*HCW*), dressing percentage (*DP*), fat cover (*FC*), rib-eye area (*REA*), percentage of kidney, pelvic, and heart fat (*KPH*), yield grade (*YG*), marbling score (*MS*), and quality grade (*QG*).

These detailed TCSCF data were obtained from the IBC. After careful review of the data, 22 observations were omitted from the data set because the data were not

plausible.<sup>24</sup> Table 6.1 presents the summary statistics of major variables in the retained data set of 1125 observations. The first section of Table 6.1 describes the common statistics of the sample. Some 78 percent of these feeder cattle were from Angus or Angus-crossbred cows, and 90 percent were British or British-crossbreds. More than 80 percent of these cattle were medium frame steers. The mean and median age of these cattle at the time of feedlot placement were 217 and 216 days, respectively, with a minimum age of 122 days and a maximum age of 337 days (Table 6.1). Initial body weights of these feeder steers varied from 272 to 838 lbs, with a mean placement weight of 548.6 lbs (Table 6.1). On average, the cattle were fed for 201 days, with minimum and maximum numbers of days on feed of 148 and 239, respectively (Table 6.1). Final shrunk body weight of the cattle ranged from 896 to 1530 lbs, with a mean slaughter weight of 1154.1 lbs. Dressing percentage upon slaughter varied from 57.14 percent to 61.31 percent, while the mean was 60.94 percent. More than 87 percent of the carcasses were graded as USDA yield grade three or better and around 59 percent of the carcasses were graded as USDA Choice or better.

Most of the steers in the data set were born in February, March, and April, and weaned at ages ranging from 5 to 10 months. The weaned calves were placed on feed in October, November, and December. Therefore, the data set is disaggregated according to the month of placement of the steers in the feedlots. Summary statistics of the feeder steers placed on feed in October, November, and December are presented in second, third, and fourth sections of Table 6.1, respectively. Of the 1125 steers, 521 were placed

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<sup>24</sup> Either average daily gain or feed efficiency (feed per pound of gain) of these cattle are out of the range of sensibility. Also, these cattle failed a preliminary run of the growth simulation model. Even with a high-energy ration and an aggressive implant, all of these omitted cattle required more than 300 days to reach the body weights reported by TCSCF, whereas the maximum number of reported days was 239.



**Table 6.1: Summary statistics of the TCSCF cattle.**

	Mean	Standard Deviation	Minimum	Median	Maximum
<b>All cattle:</b> 1125 observations					
Age (days)	217	29	122	216	337
Initial body weight (lb.)	548.59	83.14	272	542	838
Frame score <sup>1</sup>	4.71	1.09	0.75	4.75	7.93
Days on Feed	201	21	148	202	239
Final body weight (lb.)	1154.15	87.48	896	1150	1530
Hot carcass weight (lb.)	703.37	59.06	512	701	938
Numerical yield grade <sup>2</sup>	2.61	0.58	0.64	2.62	4.51
Numerical quality grade <sup>3</sup>	3.41	0.66	1	3	5
<b>October cattle:</b> 521 observations					
Age (days)	202	25	134	199	288
Initial body weight (lb.)	525.52	78.41	272	522	820
Frame score <sup>1</sup>	4.40	1.07	0.75	4.51	7.24
Days on Feed	209	21	148	223	239
Final body weight (lb.)	1144.16	82.34	896	1142	1530
Hot carcass weight (lb.)	696.60	55.28	527	696	938
Numerical yield grade <sup>2</sup>	2.76	0.55	1.10	2.76	4.22
Numerical quality grade <sup>3</sup>	3.32	0.63	1	3	5
<b>November cattle:</b> 257 observations					
Age (days)	216	21	122	216	276
Initial body weight (lb.)	553.49	78.25	360	552	776
Frame score <sup>1</sup>	4.86	0.98	2.01	4.88	7.45
Days on Feed	202	16	169	204	232
Final body weight (lb.)	1151.03	86.81	956	1150	1400
Hot carcass weight (lb.)	689.97	55.48	535	689	865
Numerical yield grade <sup>2</sup>	2.37	0.53	0.98	2.33	4.00
Numerical quality grade <sup>3</sup>	3.37	0.69	1	3	5
<b>December cattle:</b> 347 observations					
Age (days)	241	24	153	242	337
Initial body weight (lb.)	579.61	83.07	392	574	838
Frame score <sup>1</sup>	5.04	1.06	2.34	4.93	7.93
Days on Feed	188	17	160	199	203
Final body weight (lb.)	1171.45	92.95	920	1168	1460
Hot carcass weight (lb.)	723.48	62.08	512	724	902
Numerical yield grade <sup>2</sup>	2.57	0.58	0.64	2.59	4.51
Numerical quality grade <sup>3</sup>	3.57	0.64	1	4	5

<sup>1</sup> Frame score: 1 to 3 = small, 4 to 6 = medium, and 7 to 9 = large.

<sup>2</sup> Numerical yield grade: 1 = high, ..., 5 = low.

<sup>3</sup> Numerical quality grade: 1 = Prime, 2 = CAB, 3 = Choice, 4 = Select, 5 = Standard.

Source: Tri-County Steer Carcass Futurity Cooperative (TCSCF).

on feed during October, 257 in November, and 347 in December. From Table 6.1, the cattle placed on feed later had higher mean ages and initial and final body weights.

The relatively wide variation in most observed factors suggests this is a useful dataset for testing performance of the biophysical growth model. In order to determine whether any particular characteristic of the feeder cattle placed on feed in different months represent some underlying distribution, two-sample Kolmogorov-Smirnov (K-S) tests were performed. For each of the variables listed in Table 6.1, statistical distributions of each pair of observations categorized by feedlot placement months are compared against each other (e.g., October vs. November, November vs. December, and October vs. December). The K-S test statistics indicate that the null hypothesis of the same underlying distribution can be rejected at the 5 percent significance level for most of the variables except for final body weight, carcass weight, and quality grade of the October and November cattle.

The TCSCF data, however, do not provide any information about the production technology, inputs, and management practices adopted by the feedlots for feeding the cattle. In particular, information about the composition and energy and protein values of feed, daily dry matter intake by the animals, and the use of implants and/or feed additives were not reported. However, some information about the feed is available in the TCSCF Rules and Regulations, which states that cattle are fed a warm-up ration for 28 days before placing them on approximately an 80 percent concentrate ration.<sup>25</sup> The TCSCF Rules and Regulations also suggest that the cattle are weighed individually at the time of re-implant, which implies that a continuous implant strategy was adopted for these steers.

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<sup>25</sup> The TCSCF Rules and Regulations are listed at <http://www.ag.iastate.edu/centers/tscsf/rules.htm>.

Therefore, a set of typical feedlot rations with implants are assumed following the reports of several Southwestern Iowa feedlots and guidelines published in various beef cattle research reports and bulletins.

### ***Net Energy and Protein Values of Feedlot Rations***

Feedlot rations are typically formulated using concentrate, silage, hay, and protein, vitamin, and mineral supplements. Concentrates are high energy feeds (mostly feed grains and their by-products) that contain less than 20 percent protein and less than 18 percent fiber. Corn and sorghum are the most common feed grains in cattle rations, with barley, oats, wheat, and other grains used to a lesser extent. Silage is produced from green forage crops that are compressed and stored under anaerobic conditions. The most common crops used for silage are corn, sorghum, grasses, legumes, and some small grains. In general, grain and silage account for a large part (approximately 60 to 80 percent) of feedlot rations. Sometimes grass or alfalfa hay are substituted for a small portion of silage. While grass hays are lower in energy content than silage, they add extra fiber in the diet. On the other hand, alfalfa hay is richer in protein content than silage. Protein supplements are dry or liquid feedstuffs that contain 20 percent or more protein. Soybean meal, cottonseed meal, and corn gluten meal are the most common protein supplements used in feedlot rations. The only vitamin supplement of general practical importance to beef cattle is vitamin A. Vitamin A is usually included in all commercial protein supplements for feedlot cattle. For maintenance and growth, cattle also require minerals such as calcium, magnesium, and phosphorus. Requirements for such minerals are usually met by the mineral content of the other ingredients of the ration.

Feeding programs utilized by cattle feeders can be categorized into two major groups: simple and complex. Simple feeding programs involve feeding a relatively constant proportion of concentrate (e.g., grain) and roughage (e.g., silage) with an added protein supplement for the entire feeding period. In complex feeding programs, the grain-silage ratio is altered with every fifty or hundred pounds of weight gain. While numerous combinations are possible as the grain-silage ratio can vary from all grain to all silage, the range varies from 60 percent grain-40 percent silage to 90 percent grain-10 percent silage in typical feedlot rations (Field and Taylor, 2002). A recent survey on the feeding and marketing practices of cow-calf producers and feedlot operators in Nebraska by Feuz and Umberger (2001) found that corn grain and silage together accounted for 57 to 80 percent of feedlot rations, and that this percentage was increasing with placement weight. Feuz and Umberger also reported that the corn-silage ratio increased with placement weights, ranging from 55 percent corn-45 percent silage to 92 percent corn-8 percent silage.

Based on this survey and information obtained from three commercial feedlots in Iowa, 9 warm-up rations and 9 finishing rations are formulated for model validation purpose.<sup>26</sup> A separate set of 6 strategic rations are also formulated to take account of simple feeding programs. Beef cattle requirements for minerals, nitrogen, and amino acids are met by each of these rations (NRC, 2000).<sup>27</sup> Composition of the rations (per kg dry matter) and corresponding net energy and protein values are presented in Table 6.2. Each of the rations is comprised of four ingredients: corn grain, corn silage, alfalfa hay,

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<sup>26</sup> The three commercial feedlots are Cody Feedlot ([www.codyfeedlot.com](http://www.codyfeedlot.com)), CRI Feeders Inc. ([www.cri-feeders.com](http://www.cri-feeders.com)), and Silver Creek Feeders ([www.silvercreekfeeders.com](http://www.silvercreekfeeders.com)).

<sup>27</sup> Although numerous rations could be formulated by changing the grain-silage ratio in smaller increments, only a few combinations are selected following typical feeding practices of feedlots. In most cases, feedlot operators vary the ratio in a discrete manner as suggested by Table 6.2.

**Table 6.2: Energy and protein values of the rations (per kg dry matter).**

	<b>Composition</b>	<b>NE<sub>m</sub></b>	<b>NE<sub>g</sub></b>	<b>ME</b>	<b>MP</b>
	C:Si:A:So <sup>1</sup>	Mcal.	Mcal.	Mcal.	gm.
Warm-up Ration 1	30:50:05:15	1.804	1.171	2.732	99.52
Warm-up Ration 2	30:50:10:10	1.841	1.204	2.775	105.42
Warm-up Ration 3	30:50:15:05	1.879	1.237	2.819	111.32
Warm-up Ration 4	40:40:05:15	1.852	1.213	2.790	103.11
Warm-up Ration 5	40:40:10:10	1.889	1.246	2.833	109.01
Warm-up Ration 6	40:40:15:05	1.927	1.279	2.877	114.91
Warm-up Ration 7	50:30:05:15	1.900	1.255	2.848	106.70
Warm-up Ration 8	50:30:10:10	1.937	1.288	2.891	112.60
Warm-up Ration 9	50:30:15:30	1.975	1.321	2.935	118.51
Finishing Ration 1	60:20:05:15	1.948	1.297	2.906	110.29
Finishing Ration 2	60:20:10:10	1.985	1.330	2.949	116.19
Finishing Ration 3	60:20:15:05	2.023	1.363	2.993	122.10
Finishing Ration 4	70:10:05:15	1.996	1.339	2.964	113.88
Finishing Ration 5	70:10:10:10	2.033	1.372	3.007	119.79
Finishing Ration 6	70:10:15:05	2.071	1.405	3.051	125.69
Finishing Ration 7	80:0:05:15	2.044	1.381	3.022	117.47
Finishing Ration 8	80:0:10:10	2.081	1.414	3.065	123.38
Finishing Ration 9	80:0:15:05	2.119	1.447	3.109	129.28
Strategic Ration 1	30:40:10:10	1.841	1.204	2.775	105.42
Strategic Ration 2	40:40:10:10	1.889	1.246	2.833	109.01
Strategic Ration 3	50:30:10:10	1.937	1.288	2.891	112.60
Strategic Ration 4	60:20:10:10	1.985	1.330	2.949	116.19
Strategic Ration 5	70:10:10:10	2.033	1.372	3.007	119.79
Strategic Ration 6	80:0:10:10	2.081	1.414	3.065	123.38

<sup>1</sup> Denotes ration percentages ordered as corn:silage:soybean meal:alfalfa hay

Note: *NE<sub>m</sub>* = net energy for maintenance; *NE<sub>g</sub>* = net energy for gain; *ME* = metabolizable energy; *MP* = metabolizable protein.

Source: National Research Council (2000).

and soybean meal. The second column of Table 6.2 shows the proportion of these ingredients in the rations. Alfalfa hay and soybean meal each account for 20 percent of

the rations. The other 80 percent of the rations are corn grain and silage. Columns 3,4,5, and 6 of Table 6.2 depict net energy for maintenance (*NE<sub>m</sub>*) and growth (*NE<sub>g</sub>*), metabolizable energy (*ME*), and metabolizable protein (*MP*) available from the rations. As the table shows, energy and protein values of the rations increase with the proportions of grain and protein supplement. Dry matter, energy, and protein contents of the feed ingredients are listed in Table 6.3.

**Table 6.3: Nutrient values of feed ingredients used to formulate the rations.**

<b>Ration</b>	<b><i>DM</i></b>	<b><i>NE<sub>m</sub></i></b>	<b><i>NE<sub>g</sub></i></b>	<b><i>ME</i></b>	<b><i>TDN</i></b>	<b><i>CP</i></b>	<b><i>UIP</i></b>
<b>Ingredients</b>	%	Mcal/kg	Mcal/kg	Mcal/kg	% DM	% DM	%CP
Corn	88	2.18	1.50	3.18	88.00	9.80	55.30
Corn silage (45%)	34	1.70	1.08	2.60	72.00	8.65	30.00
Alfalfa hay	91	1.31	0.74	2.17	60.00	18.60	28.00
Soybean Meal	89	2.06	1.40	3.04	84.00	49.90	35.00

Note: *DM* = dry matter content; *NE<sub>m</sub>* = net energy for maintenance; *NE<sub>g</sub>* = net energy for gain; *ME* = metabolizable energy; *TDN* = total dry matter nutrient; *CP* = crude protein; and *UIP* = undegraded feed protein.

Source: NRC (2000).

Along with the rations listed in Table 6.2, three alternative implant strategies are considered: no implant, moderate implant (estrogen only), and aggressive implant (estrogen plus Trenbolone Acetate).<sup>28</sup> This yields 243 (9x9x3) complex ration-implant strategies and 18 (6x3) simple strategies. Following Tedeschi et al. (2004), it is assumed that requirements for minerals, nitrogen, and amino acids are met by the supplied diet.

<sup>28</sup> Following implant use guidelines suggested by Field and Taylor (2002) and Duckett et al. (1996), a continuous implant strategy is adopted throughout the finishing phase, i.e., implanting at the time of placement in the feedlot and re-implanting after 90 days.

### ***Weather Data***

Empirical studies have shown that feedlot performance of cattle depends crucially on particular environmental attributes, especially temperature, humidity, sunshine, and mud depth. Accordingly, all of the major beef cattle growth models account for the effects of such variables. The growth model presented in the previous chapter calculates dry matter intake and weight gain by the animals in a day-step fashion using average daily weather information.<sup>29</sup> However, the TCSCF dataset does not include any information about the weather conditions under which the cattle were fed. In order to simulate the production situation, daily and weekly averages of major weather variables such as temperature, relative humidity, hours of sunshine, and wind speed in Red Oak, Iowa, over the period of 1995-1999, are obtained from the WeatherBank Incorporation, a meteorological consulting company providing weather data and products.

The TCSCF cattle were placed in the feedlots during the months of October-December of 1995-1998, and slaughtered no later than June the following year. Table 6.4 presents average monthly temperature, relative humidity, wind speed, and hours of sunshine during September-June of 1995-1996, 1996-1997, 1997-1998, and 1998-1999.

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<sup>29</sup> Since temperatures move slowly from one season to the next but can fluctuate widely from day to day, Fox and Tylutki (1998) recommend using the average mean daily temperature over the previous month to represent previous exposure ( $T_p$ ), and the average mean daily temperature during the current week to represent current exposure ( $T_c$ ).

**Table 6.4: Average monthly weather information, 1995-1999.**

	Temperature (°C)	Rel. Humidity (%)	Wind Speed (kmph)	Sunshine (hours)
<b>1995-96</b>				
September	13.17	63.10	14.12	4.74
October	1.98	71.50	14.27	3.86
November	-1.90	76.81	12.30	1.94
December	-7.06	74.10	15.42	3.40
January	-2.91	62.55	14.54	5.07
February	1.85	58.45	17.44	2.09
March	10.69	58.53	17.81	3.62
April	16.24	77.61	15.16	1.81
May	22.89	73.70	11.69	4.79
June	17.13	74.70	9.55	7.09
<b>1996-97</b>				
September	12.83	65.10	15.67	5.85
October	1.28	74.67	15.02	2.91
November	-4.07	75.35	14.33	3.69
December	-6.52	70.06	16.71	4.27
January	-0.99	76.46	12.70	3.64
February	6.18	64.10	17.23	7.00
March	8.76	60.33	14.70	5.22
April	15.23	54.61	16.56	7.89
May	23.94	59.60	11.16	9.68
June	17.61	70.00	9.92	7.61
<b>1997-98</b>				
September	11.54	65.26	13.60	5.92
October	5.59	65.90	13.03	4.04
November	-1.76	72.26	12.20	2.52
December	-2.83	70.35	10.90	2.82
January	3.12	69.57	13.22	2.80
February	1.00	67.87	17.49	3.40
March	11.87	65.73	17.97	6.29
April	20.68	78.00	14.01	8.41
May	22.06	79.67	15.39	7.89
June	23.89	77.50	9.92	7.57
<b>1998-99</b>				
September	14.84	84.19	11.89	5.39
October	7.70	85.73	14.86	4.43
November	0.43	79.90	11.63	5.47
December	-3.67	86.42	14.27	3.57
January	4.11	84.29	15.52	4.87
February	5.82	71.65	15.47	6.83
March	13.06	78.50	19.63	4.19
April	17.76	64.52	16.14	6.51
May	22.81	67.87	13.35	6.88
June	18.17	63.33	8.74	8.20

Source: Weatherbank Inc.



### **6.3 Simulation Procedures and Results**

Employing the dynamic and deterministic biological growth model and using the cattle, nutrient, and weather data as described above, outcomes of feeding the TCSCF steers are simulated. Two separate simulations are performed for two alternative terminal conditions: one feeds the cattle until a target finish weight is reached and the other feeds the cattle for a predetermined length of feeding period. In the first simulation model, final shrunk body weight is an exogenous variable, while in the second total days on feed is given. Other common independent variables in the growth simulation models are age, initial shrunk body weight, breed, frame score, body condition score, hair depth, hide thickness, hair coat of the cattle, net and metabolizable energy and protein content of the ration, implant factors, and environmental attributes. However, TCSCF did not provide information about the body condition score, hair depth, hide thickness, and hair coat of the cattle. Therefore, typical values are assumed for these variables. Specifically, following the approach of the Subcommittee on Beef Cattle Nutrition (NRC, 2000), all feeder steers are assumed to have a moderate body condition score of 5, hair depth of 0.5 inches, average hide thickness with hide code 2, and a hair coat code of 2 (some mud on the lower body).

The primary objective of both of the simulations is to predict the outcomes of alternative ration-implant strategies as accurately as possible. Therefore, biological growth of each individual animal is simulated for the use of each of the ration-implant strategies under each of the terminal conditions. Daily dry matter intake, energy required for maintenance, energy available for growth, weight gain, and composition (protein and fat) of the gain are computed step by step for each individual animal for each of the 18

strategic ration-implant strategies. In the first model, daily feed intake, growth, and body composition of each of the steers are computed until they reach final weights as reported by the TCSCF. In the second simulation model, daily outcomes are calculated up to the corresponding feedlot days as reported by the TCSCF. Steps of the simulation procedure are described in Appendix 6.1.

At the end of feeding, total dry matter intake (*TDMI*), days on feed (*DOF*) for simulation model 1, total shrunk weight gain (*TSWG*) for simulation model 2, final carcass weight (*FCW*) or yield, final empty body fat percentage (*EBFP*), and the resulting yield and quality grades (*YG* and *QG*) are computed. Average daily gain (*ADG*), feed efficiency (*FE*) in terms of pounds of feed consumed per pound of gain, and dressing percentages (*DP*) measured by carcass yield as a percentage of live body weight are also calculated from the simulation outcomes. A brief summary of the simulation outcomes is presented in Tables 6.5 and 6.6. Only the means (across all cattle) of the major dependent variables are presented in the tables. Table 6.5 displays the results of simulation model 1 with a fixed terminal weight while Table 6.6 shows the results of simulation model 2 with a fixed terminal time.

According to the biophysical growth model, daily dry matter intake increases with the body weights of the cattle and potency of the growth promoting implants, but decreases with the net maintenance energy content of feed. Thus, for a given target weight gain, total dry matter intake should decrease with the maintenance energy of feed and potency of implants. Feed efficiency (pounds of feed consumed per pound of gain) and average daily gain should improve (as a result, required days on feed declines) with

the energy content of feed and potency of the implant. These predictions are confirmed by the values in columns 4, 5, 6, and 7 of Table 6.5.

**Table 6.5: Results from simulation model 1 (fixed terminal state) - means across all cattle.**

	<i>FSBW</i>	<i>DOF</i>	<i>TSWG</i>	<i>TDMI</i>	<i>ADG</i>	<i>FE</i>	<i>CW</i>	<i>DP</i>	<i>EBFP</i>	<i>YG</i>	<i>QG</i>
	(lbs.)	(days)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	%	(%)		
<b>No Implant</b>											
Ration 1	1155.5	272	607.6	4822.4	2.27	7.93	706.7	61.14	28.57	3.04	3.19
Ration 2	1155.5	263	607.6	4618.2	2.34	7.60	706.7	61.14	28.66	3.05	3.16
Ration 3	1155.6	255	607.7	4433.6	2.41	7.29	706.7	61.14	28.74	3.07	3.12
Ration 4	1155.6	248	607.7	4265.1	2.48	7.02	706.7	61.14	28.82	3.08	3.08
Ration 5	1155.6	242	607.8	4110.6	2.54	6.76	706.8	61.14	28.88	3.09	3.06
Ration 6	1155.6	236	607.7	3967.8	2.60	6.53	706.8	61.14	28.95	3.10	3.02
<b>Estrogen Only</b>											
Ration 1	1155.9	221	608.0	4248.5	2.77	6.99	706.9	61.14	27.18	2.81	3.80
Ration 2	1155.8	214	608.0	4079.1	2.85	6.71	706.9	61.14	27.26	2.83	3.78
Ration 3	1155.9	208	608.1	3923.7	2.94	6.45	707.0	61.14	27.33	2.84	3.74
Ration 4	1156.0	203	608.1	3780.2	3.01	6.22	707.0	61.14	27.40	2.85	3.70
Ration 5	1155.9	198	608.1	3646.9	3.09	6.00	707.0	61.14	27.47	2.86	3.69
Ration 6	1156.0	193	608.1	3523.7	3.16	5.79	707.0	61.14	27.53	2.87	3.67
<b>Estrogen plus Trenbolone Acetate</b>											
Ration 1	1156.1	195	608.2	3911.9	3.12	6.43	707.1	61.14	25.79	2.59	4.32
Ration 2	1156.2	190	608.3	3755.7	3.22	6.17	707.1	61.14	25.87	2.60	4.29
Ration 3	1156.2	184	608.3	3611.3	3.31	5.94	707.1	61.14	25.94	2.61	4.28
Ration 4	1156.2	179	608.4	3478.1	3.40	5.72	707.2	61.14	26.01	2.62	4.26
Ration 5	1156.2	175	608.4	3354.4	3.49	5.51	707.2	61.14	26.07	2.63	4.24
Ration 6	1156.2	171	608.4	3240.1	3.57	5.32	707.2	61.14	26.13	2.64	4.23

Note: *FSBW* = final shrunk body weight, *DOF* = days on feed, *TSWG* = total shrunk weight gain, *TDMI* = total dry matter intake, *ADG* = average daily gain, *FE* = feed efficiency, *CW* = carcass weight, *DP* = dressing percentage, *EBFP* = empty body fat percentage, *YG* = yield grade, and *QG* = quality grade.

**Table 6.6: Results from simulation model 2 (fixed terminal time) - means across all cattle.**

	<i>FSBW</i>	<i>DOF</i>	<i>TSWG</i>	<i>TDMI</i>	<i>ADG</i>	<i>FE</i>	<i>CW</i>	<i>DP</i>	<i>EBFP</i>	<i>YG</i>	<i>QG</i>
	(lbs.)	(days)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	%	(%)		
<b>No Implant</b>											
Ration 1	1018.7	203	470.8	3443.6	2.32	7.34	617.2	60.56	25.16	2.49	4.57
Ration 2	1034.0	203	486.2	3431.9	2.40	7.08	627.2	60.63	25.62	2.56	4.41
Ration 3	1048.2	203	500.4	3415.6	2.47	6.85	636.5	60.70	26.05	2.63	4.26
Ration 4	1061.3	203	513.5	3395.0	2.54	6.63	645.1	60.76	26.45	2.70	4.12
Ration 5	1073.4	203	525.6	3370.6	2.60	6.43	653.0	60.81	26.82	2.76	3.98
Ration 6	1084.5	203	536.7	3342.6	2.65	6.25	660.3	60.86	27.16	2.81	3.83
<b>Estrogen Only</b>											
Ration 1	1109.8	203	562.0	3836.8	2.77	6.84	676.8	60.96	26.09	2.64	4.23
Ration 2	1127.2	203	579.4	3826.3	2.86	6.62	688.2	61.03	26.57	2.72	4.07
Ration 3	1143.4	203	595.5	3810.3	2.94	6.41	698.8	61.09	27.02	2.79	3.89
Ration 4	1158.3	203	610.5	3789.4	3.02	6.22	708.5	61.15	27.43	2.86	3.73
Ration 5	1172.1	203	624.2	3763.9	3.08	6.04	717.6	61.20	27.82	2.92	3.57
Ration 6	1184.8	203	636.9	3734.2	3.15	5.87	725.8	61.24	28.17	2.97	3.41
<b>Estrogen plus Trenbolone Acetate</b>											
Ration 1	1179.3	203	631.4	4097.2	3.12	6.50	722.3	61.22	26.27	2.67	4.17
Ration 2	1198.8	203	650.9	4089.7	3.21	6.29	735.0	61.29	26.77	2.75	3.99
Ration 3	1216.9	203	669.0	4076.1	3.30	6.10	746.8	61.35	27.24	2.82	3.80
Ration 4	1233.6	203	685.8	4056.9	3.39	5.92	757.8	61.41	27.67	2.89	3.62
Ration 5	1249.1	203	701.2	4032.5	3.46	5.76	767.9	61.46	28.06	2.96	3.46
Ration 6	1263.4	203	715.5	4003.3	3.53	5.60	777.2	61.50	28.43	3.02	3.29

Note: *FSBW* = final shrunk body weight, *DOF* = days on feed, *TSWG* = total shrunk weight gain, *TDMI* = total dry matter intake, *ADG* = average daily gain, *FE* = feed efficiency, *CW* = carcass weight, *DP* = dressing percentage, *EBFP* = empty body fat percentage, *YG* = yield grade, and *QG* = quality grade.

The growth model also implies that empty body and carcass fat percentages increase with the net energy content of feed and decreases as more aggressive implant strategies are adopted. Column 10 of Table 6.5 shows that a 10 percent increase

(decrease) in the grain-silage ratio results in only about a 0.10 percent increase (decrease) in mean body and carcass fat, while the change is quite substantial (at least 1.31 percentage points) for a change in implant strategy. Nevertheless, in order to determine the value of the carcass, changes in body and carcass fat percentages are translated into numerical yield and quality grades. Since yield and quality grades are directly calculated from empty body fat (Tedeschi et al., 2004) or carcass fat percentages (Fox and Black, 1984), they follow the same patterns as body fat. Recall that higher numerical yield and quality grades imply lower beef quality. In particular, carcasses with yield grade higher than 3 and quality grades higher than or equal to 4 receive discounts in the grid.<sup>30</sup> Thus, aggressive implants (e.g., estrogen plus Trenbolone Acetate) and low-grain rations are undesirable as long as carcass value is the concern. As column 8 of Table 6.5 shows, carcass weight remains nearly unchanged for alternative feeding strategies. This is because the final body weights are fixed for all the strategies while the growth model predicts carcass weight from final body weight using a linear equation with fixed parameter values developed by Garrett and Hinman (1969).

In order to test whether the outcomes of alternative ration-implant strategies are different, Wilcoxon matched-pairs signed-rank tests are performed. Total dry matter intake, weight gain, and the composition of gain by each individual animal under any two ration formulae (for a given implant strategy) are paired and tested to see if the difference between the matched pairs are from a distribution whose median is zero. Similarly, outcomes under alternative implant strategies are paired (keeping the ration formula

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<sup>30</sup> The practical measures of yield and quality grades are discrete in nature. According to Guiroy et al. (2001), carcasses with *EBFP* lower than 27 should be assigned numerical quality grade 4 (Select). The decimal points in the table resulted from averaging the discrete yield and quality grades across individual carcasses.

fixed) and tested for a zero median difference. All of the test statistics indicate rejection of the hypothesis of a zero median difference at a 5.0 percent significance level. Thus, the biological growth simulation model produces a clear shift in cattle feeding outcomes associated with cattle feeding practices. More precisely, the model shows that the energy content of the feed and implant strategy systematically alters the distribution of yield and quality of beef for a typical lot of cattle.

#### **6.4 Evaluation of the Results of the Cattle Growth Simulation Model**

The equations and parameters of the biological growth simulation model adopted in this study are well recognized and accepted by the Subcommittee (NRC, 2000) after many critical evaluations. Therefore, this study does not make any attempt to evaluate functional forms or the values of the parameters used in different equations. The objective is rather to proceed with economic analyses assuming functional forms and parameter values of the biological model as proposed by this respected panel of animal scientists. Nonetheless, it is important to know how well the model performs in predicting actual cattle feeding outcomes, especially when the results of economic analyses crucially depend on the predictive efficiency of such a model.

The predictive efficiency of a biological model is typically evaluated by comparing the simulated values of the endogenous variables with empirical data. As mentioned in Chapter 5, Tedeschi et al. (2004) have previously evaluated their dynamic growth model with feed intake and performance data on 362 steers fed in individual pens. When dry matter intake was known, their model accounted for 89 percent of the variation with a bias of -2.6 percent in predicting individual animal *ADG* and explained 83 percent of the variation with a bias of -1 percent in estimating the observed body weights at the

actual days on feed. When *ADG* was known, the growth model predicted the dry matter required for that *ADG* with only 2 percent bias and an  $R^2$  of 74 percent. Tedeschi et al. found that all of the equations used to predict *CW* from *EBW* accounted for at least 89 percent of the variation, but the Garrett and Hinman (1969) equation had the best prediction when no size scaling was done. Estimating equations (5.49) and (5.52) they found that both equations had similar and satisfactory predictions of *YG* in the range of 2.5 and 3.5. Thus, the dynamic growth model presented by Tedeschi et al. is able to predict animal performance and body composition with an acceptable degree of accuracy.

As mentioned earlier, the TCSCF did not record the composition and amount of feed provided to the cattle.<sup>31</sup> Therefore, it is not possible to match the feeding strategies and compare the simulated and actual outcomes as precisely as did the study by Tedeschi et al. (2004). Thus, for the purposes of this study, further verification is needed for the case where feeding and implant strategies must be approximated with available information. In the absence of information about the nutrient contents of feed and implants actually provided to the cattle in TCSCF feedlots, a plausible range of ration-implant strategies that reflect TCSCF guideline are considered for model verification purpose. In particular, feedlot and carcass performance of each individual steer are simulated using the warm-up and finishing rations listed in Table 6.2 along with three alternative implant strategies.<sup>32</sup> The simulated outcomes are then compared with the TCSCF data following three standard statistical procedures: first, by examining the

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<sup>31</sup> The TCSCF data reports total amount of feed consumed by the cattle, but not the proportions of the feed ingredients or the energy content. Upon contacting the responsible personnel in the IBC, I learned that the amount of feed consumption by individual animals was calculated following the Cornell Net Carbohydrate and Protein Systems (CNCPS).

<sup>32</sup> Following TCSCF guidelines, no implant is considered during the warm-up ration phase and a continuous implant strategy is adopted throughout the finishing ration phase.

frequency distribution of the actual observations with respect to the plausible range of simulated outcomes; second, by testing whether the simulated and actual samples come from the same distribution; and finally, by comparing the estimated probability densities of the simulated and actual observations.

The first step in evaluating the predictive efficiency of the biophysical growth simulation model involved determining whether the actual feedlot days, final carcass weights, and yield and quality grades are within the plausible ranges constructed by the simulation of 243 (9×9×3) warm-up and finishing ration-implant strategies. The lower bounds of the range for each relevant variable is determined by warm-up ration 1 and finishing ration 1 with no implant, while the upper bound of the range is determined by warm-up ration 9 and finishing ration 9 with an aggressive implant strategy.

The two-way contingency tables reflected in Tables 6.7 and 6.8 show how many of the actual observations of days on feed, carcass weight, yield grade, and quality grade are within the plausible range simulated by model 1 (fixed terminal weight) and model 2 (fixed terminal time), respectively. From Table 6.7, approximately 92 and 69 percent of the actual days on feed and quality grades, respectively, are in the ranges of simulated outcomes by model 1. However, actual yield grades of 77 percent of the carcasses are out of the predicted range. Since no carcass weight variation occurs under model 1, two-way contingency tables for carcass weight are not presented in Table 6.7.<sup>33</sup>

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<sup>33</sup> According to the growth model, dressing percentage remains the same for alternative ration-implant strategies with a fixed terminal weight (Table 6.5). Thus, for alternative strategies, final carcass weight simulated by model 1 is the same although yield and quality grades vary. A very narrow range of carcass weights can be result from alternative ration-implant strategies because of the discrete day-step nature of the simulation model (e.g., Table 6.5).



**Table 6.7: Two-way contingency tables showing how many of the actual outcomes are within the constructed ranges simulated by growth model 1 (fixed terminal weight).**

By Feedlot Placement Year				By Feedlot Placement Month			
<b>Days on Feed</b>							
	Within Range	Out of Range	Total		Within Range	Out of Range	Total
1995	241	26	267				
1996	182	5	187	October	486	35	521
1997	219	12	231	November	238	19	257
1998	389	51	440	December	307	40	347
Total	1031	94	1125	Total	1031	94	1125
$\chi^2$ -Statistic <sup>1</sup>	17.57	<i>p</i> -value	0.001	$\chi^2$ -Statistic <sup>1</sup>	6.69	<i>p</i> -value	0.035
<b>Yield Grade</b>							
	Within Range	Out of Range	Total		Within Range	Out of Range	Total
1995	50	217	267				
1996	53	134	187	October	142	379	521
1997	44	187	231	November	48	209	257
1998	111	329	440	December	68	279	347
Total	258	867	1125	Total	258	867	1125
$\chi^2$ -Statistic <sup>1</sup>	9.05	<i>p</i> -value	0.029	$\chi^2$ -Statistic <sup>1</sup>	10.32	<i>p</i> -value	0.006
<b>Quality Grade</b>							
	Within Range	Out of Range	Total		Within the Range	Out of the Range	Total
1995	173	94	267				
1996	133	54	187	October	351	170	521
1997	151	80	231	November	173	84	257
1998	316	124	440	December	249	98	347
Total	773	352	1125	Total	773	352	1125
$\chi^2$ -Statistic <sup>1</sup>	5.59	<i>p</i> -value	0.13	$\chi^2$ -Statistic <sup>1</sup>	2.16	<i>p</i> -value	0.338

<sup>1</sup> The  $\chi^2$ -Statistic tests whether the classification between within range and out of range is random.

**Table 6.8: Contingency tables showing how many of the of the actual outcomes are within the constructed ranges simulated by growth model 2 (fixed terminal time).**

By Feedlot Placement Weight				By Frame Score			
Final Body Weight							
	Within the Range	Out of the Range	Total		Within the Range	Out of the Range	Total
1995	240	27	267	October	482	39	521
1996	181	6	187	November	235	22	257
1997	218	13	231	December	302	45	347
1998	380	60	440	Total	1019	106	1125
Total	1019	106	1125	$\chi^2$ -Statistic <sup>1</sup>	6.89	<i>p</i> -value	0.032
$\chi^2$ -Statistic <sup>1</sup>	21.66	<i>p</i> -value	< 0.001				
Final Carcass Weight							
	Within the Range	Out of the Range	Total		Within the Range	Out of the Range	Total
1995	229	38	267	October	454	67	521
1996	172	15	187	November	224	33	257
1997	206	25	231	December	252	95	347
1998	323	117	440	Total	930	195	1125
Total	930	195	1125	$\chi^2$ -Statistic <sup>1</sup>	35.32	<i>p</i> -value	< 0.001
$\chi^2$ -Statistic <sup>1</sup>	46.25	<i>p</i> -value	< 0.001				
Yield Grade							
	Within the Range	Out of the Range	Total		Within the Range	Out of the Range	Total
1995	50	217	267	October	123	398	521
1996	45	142	187	November	40	217	257
1997	40	191	231	December	52	295	347
1998	80	360	440	Total	215	910	1125
Total	215	910	1125	$\chi^2$ -Statistic <sup>1</sup>	12.72	<i>p</i> -value	0.002
$\chi^2$ -Statistic <sup>1</sup>	3.72	<i>p</i> -value	0.29				
Quality Grade							
	Within the Range	Out of the Range	Total		Within the Range	Out of the Range	Total
1995	191	76	267	October	342	179	521
1996	110	77	187	November	163	94	257
1997	156	75	231	December	236	111	347
1998	284	156	440	Total	741	384	1125
Total	741	384	1125	$\chi^2$ -Statistic <sup>1</sup>	1.4	<i>p</i> -value	0.496
$\chi^2$ -Statistic <sup>1</sup>	8.57	<i>p</i> -value	0.036				

<sup>1</sup> The  $\chi^2$ -Statistic tests whether the classification between within range and out of range is random.

For model 2 (fixed terminal time), approximately 91, 82, and 66 percent of actual body weights, carcass weights, and quality grades are within the constructed ranges, respectively (Table 6.8). Actual yield grades of only 19 percent of the carcasses are within the predicted range. Thus, a simple count of the actual observations within the constructed range indicates that, with a plausible set of ration-implant strategies, the growth model is able to reasonably well approximate the actual live weight, dressed weight, and carcass quality grade. For yield grade, either the outcomes are less accurate or yield grade is sensitive to the feed-implant strategy.

A second step is to determine whether the predictive efficiency of the growth model varies systematically with respect to the initial physical condition of an animal (e.g., feedlot placement weight, age, and frame score) or weather conditions. Table 6.1 indicates that average age and weight of the animals were significantly different across feedlot placement months. Table 6.4 shows that overall weather condition varied across the years cattle were placed on feed. The frequencies of actual observations that fall within and outside the plausible range are therefore categorized according to the feedlot placement years (1995, 1996, 1997, and 1998) and months (October, November, and December). The left panel of Tables 6.7 and 6.8 display the two-way contingency tables of frequencies for the cattle categorized according to placement years, while the two-way tables in the right panel are for the cattle categorized by placement months.

The significance of plausible classifications in Tables 6.7 and 6.8 can be tested using Pearson's chi-squared test. In the context of these tables, the null hypothesis of statistical independence of rows and columns for Pearson's chi-squared test corresponds to random classification of simulated outcomes to within- and out-of-range categories.

The chi-squared tests and their  $p$ -values are reported for each of the contingency tables in Tables 6.7 and 6.8.<sup>34</sup> For data grouped by year in Table 6.7, each of the statistics except for quality grade implies rejection of random classification at the 5 percent significance level with very small  $p$ -values in the cases of days on feed and final yield grade. However, the significance for yield grade is not meaningful because a majority of simulated results fall outside of observed outcomes.

For the data grouped by month placed on feed, the results are similar with significance for all simulated outcomes other than quality grade (with the same qualification on the results for yield grade), although the extent of significance is somewhat less for days on feed. For data categorized by year in Table 6.8, each of the statistics except for yield grade implies rejection of random classification at the 5 percent significance level with very small  $p$ -values (again with the same qualification on the results for yield grade). For the data grouped by month, the results are similar for simulated outcomes other than quality grade. These results verify that the relative frequencies of actual days on feed, final carcass weight, and yield grade differ with respect to feedlot placement year and month, while the relative frequency of predicted quality grades within the observed range does not depend on such categories.<sup>35</sup>

These results show that the biophysical growth model does not have systematic bias towards feedlot placement year or month for predicting animal performance, or towards initial physical conditions of animals and weather conditions that differ by

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<sup>34</sup> A  $p$ -value less than 0.05 suggests that the null hypothesis of no difference should be rejected at the 5 percent significance level.

<sup>35</sup> To test for systematic variation by year or month, each cell's contribution to the chi-squared value was also examined. The test statistics indicated no systematic variation for feedlot placement year or month. Each cell's individual contribution to the chi-squared value and associated tests are not reported to economize on space.

placement year and month. Notably, however, these types of chi-squared tests require selecting categories in a suitable and unbiased fashion. Information is clearly lost by combining data into categories. Thus, more precise measures for testing the goodness of fit of simulated outcomes to actual observations can further validate performance of the growth model.

A common way to test the goodness of fit of simulated observations to actual observations is to treat the two samples as independent and compare the statistical properties of their underlying distributions. The usual parametric technique is to apply a *t*-test of equal means conditioned on equal variances and then apply an *F*-test of equal variances, assuming that the simulated and actual observations are from normally distributed populations. These tests treat individual observations separately and, unlike the chi-squared tests above, do not lose information through combining data into discrete categories. However, both *t*- and *F*-tests assume that the samples in consideration are normally distributed. In order to avoid such a rigid assumption and provide conclusions with greater generality, several nonparametric tests are also used. The most widely used nonparametric techniques are the Mann-Whitney-Wilcoxon rank-sum (hereafter R-S) and Kolmogorov-Smirnov (hereafter K-S) tests. The R-S and K-S tests are both designed to test for the equality of two distributions. To test the goodness of fit of simulated data to actual data the nonparametric R-S and K-S tests are also performed in addition to the parametric *t*- and *F*-tests.

For alternative ration-implant strategies, simulation model 1 generates different days on feed required to reach a target final body weight, while model 2 generates different final shrunk body weights for a given feeding period. For each individual

animal, the ration-implant strategy that corresponds to the nearest neighbor of the actual days on feed for model 1, or the final body weight for model 2, is sorted from the plausible alternatives employing a simple search algorithm. Other relevant outcomes (e.g., final carcass weights, yield grades, and quality grades) from that particular feeding strategy are then separated and saved as the elements of a row vector of a two-dimensional matrix. This procedure is repeated for all cattle in the sample, thus generating a matrix with vectors containing simulated feedlot and carcass data. Simulated days on feed (model 1), final body weights (model 2), carcass weights, and yield grades are then compared with the actual data using the parametric  $t$ - and  $F$ -tests and the nonparametric R-S and K-S tests.<sup>36</sup> The tests are performed with full samples as well as with subsamples categorized by the months of placement of animals in feedlots. Results of the tests for model 1 and model 2 are presented in Tables 6.9 and 6.10, respectively.

For the full and grouped samples of days on feed (model 1) and final body weights (model 2), the reported  $p$ -values of  $t$ -tests in Table 6.9 and 6.10 indicate that, assuming normality and identical variances, the null hypothesis of identical means of actual and simulated outcomes cannot be rejected at the 5.0 percent significance level. The  $p$ -values of  $F$ -tests for the full and grouped samples yield no evidence of dissimilarity of variances of actual and simulated days on feed (model 1) or final body weights (model 2). The reported  $p$ -values of the nonparametric tests (R-S and K-S tests) indicate that, for the full sample as well as for each of the subsamples of days on feed

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<sup>36</sup> The parametric  $t$ - and  $F$ -test and nonparametric R-S and K-S tests assume that the comparable distributions are both continuous distributions. Since quality grade data are ordinal in nature, these tests are not applicable to comparing the distributions of actual and simulated quality grades.

**Table 6.9: Results of statistical tests to compare actual observations and simulated observations from model 1 (fixed terminal weight).**

	<i>t-t</i> est <sup>1</sup>	<i>F- test</i> <sup>2</sup>	<i>R-S test</i> <sup>3</sup>	<i>K-S test</i> <sup>3</sup>
<b>All cattle</b> (1125 observations)				
Days on Feed	Cannot reject $H_0$ $p = 0.74$	Cannot reject $H_0$ $p = 0.11$	Cannot reject $H_0$ $p = 0.78$	Cannot reject $H_0$ $p = 0.09$
Carcass Weight	Cannot reject $H_0$ $p = 0.16$	Cannot reject $H_0$ $p = 0.29$	Cannot reject $H_0$ $p = 0.27$	Cannot reject $H_0$ $p = 0.44$
Yield Grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$
<b>October cattle</b> (521 observations)				
Days on Feed	Cannot reject $H_0$ $p = 0.88$	Cannot reject $H_0$ $p = 0.20$	Cannot reject $H_0$ $p = 0.89$	Cannot reject $H_0$ $p = 0.08$
Carcass weight	Cannot reject $H_0$ $p = 0.29$	Cannot reject $H_0$ $p = 0.54$	Cannot reject $H_0$ $p = 0.37$	Cannot reject $H_0$ $p = 0.68$
Yield grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$
<b>November cattle</b> (257 observations)				
Days on Feed	Cannot reject $H_0$ $p = 1.00$	Cannot reject $H_0$ $p = 0.34$	Cannot reject $H_0$ $p = 0.93$	Cannot reject $H_0$ $p = 0.12$
Carcass weight	Reject $H_0$ $p = 0.003$	Cannot reject $H_0$ $p = 0.70$	Reject $H_0$ $p = 0.004$	Reject $H_0$ $p = 0.04$
Yield grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$
<b>December cattle</b> (347 observations)				
Days on Feed	Cannot reject $H_0$ $p = 1.00$	Cannot reject $H_0$ $p = 0.11$	Cannot reject $H_0$ $p = 0.34$	Cannot reject $H_0$ $p = 0.06$
Carcass weight	Cannot reject $H_0$ $p = 0.26$	Cannot reject $H_0$ $p = 0.70$	Cannot reject $H_0$ $p = 0.14$	Cannot reject $H_0$ $p = 0.14$
Yield grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$

<sup>1</sup> The two-sample t-test verifies whether the actual and simulated observations are independent random samples from normal distributions with equal means given equal but unknown variances

<sup>2</sup> The two-sample F-test verifies whether the actual and simulated observations come from normal distributions with the same variance regardless of equality of means.

<sup>3</sup> Both the R-S test and K-S nonparametric tests verify whether the distributions of actual and simulated observations are the same.

Note:  $H_0$  represent the null hypothesis of equality of distributions and corresponding  $p$ -values are the probabilities of a more extreme result. Rejection corresponds to 5.0 percent significance.

**Table 6.10: Results of the statistical tests to compare actual observations and simulated observations from model 2 (fixed terminal time).**

	<i>t-t</i> test <sup>1</sup>	<i>F</i> -test <sup>2</sup>	R-S test <sup>3</sup>	K-S test <sup>3</sup>
<b>All cattle</b> (1125 observations)				
Body Weight	Cannot reject $H_0$ $p = 0.81$	Cannot reject $H_0$ $p = 0.69$	Cannot reject $H_0$ $p = 0.83$	Cannot reject $H_0$ $p = 0.97$
Carcass Weight	Cannot reject $H_0$ $p = 0.45$	Cannot reject $H_0$ $p = 0.14$	Cannot reject $H_0$ $p = 0.61$	Cannot reject $H_0$ $p = 0.57$
Yield Grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$
<b>October cattle</b> (521 observations)				
Body Weight	Cannot reject $H_0$ $p = 0.93$	Cannot reject $H_0$ $p = 0.80$	Cannot reject $H_0$ $p = 0.99$	Cannot reject $H_0$ $p = 0.96$
Carcass weight	Cannot reject $H_0$ $p = 0.47$	Cannot reject $H_0$ $p = 0.39$	Cannot reject $H_0$ $p = 0.54$	Cannot reject $H_0$ $p = 0.58$
Yield grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$
<b>November cattle</b> (257 observations)				
Body Weight	Cannot reject $H_0$ $p = 0.96$	Cannot reject $H_0$ $p = 0.84$	Cannot reject $H_0$ $p = 0.999$	Cannot reject $H_0$ $p = 0.99$
Carcass weight	Reject $H_0$ $p = 0.005$	Cannot reject $H_0$ $p = 0.57$	Reject $H_0$ $p = 0.009$	Reject $H_0$ $p = 0.03$
Yield grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$
<b>December cattle</b> (347 observations)				
Body Weight	Cannot reject $H_0$ $p = 0.71$	Cannot reject $H_0$ $p = 0.65$	Cannot reject $H_0$ $p = 0.71$	Cannot reject $H_0$ $p = 0.94$
Carcass weight	Cannot reject $H_0$ $p = 0.08$	Cannot reject $H_0$ $p = 0.40$	Cannot reject $H_0$ $p = 0.10$	Cannot reject $H_0$ $p = 0.09$
Yield grade	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$	Reject $H_0$ $p < 0.001$

<sup>1</sup> The two-sample t-test verifies whether the actual and simulated observations are independent random samples from normal distributions with equal means given equal but unknown variances

<sup>2</sup> The two-sample F-test verifies whether the actual and simulated observations come from normal distributions with the same variance regardless of equality of means.

<sup>3</sup> Both the R-S test and K-S nonparametric tests verify whether the distributions of actual and simulated observations are the same.

Note:  $H_0$  represent the null hypothesis of equality of distributions and corresponding  $p$ -values are the probabilities of a more extreme result. Rejection corresponds to 5.0 percent significance.



(model 1) or final body weights (model 2), the null hypothesis that actual and simulated distributions are identical cannot be rejected at the 5.0 percent significance level (Tables 6.9 and 6.10).

The test results for the actual and simulated carcass weights and yield grades obtained under both models are similar because, with matched body weight and feedlot days for each animal in the sample, the ranking of carcass performance turns out to be the same by the two methods even though the quantitative outcomes are slightly different. As implied by the reported  $p$ -values of  $t$ -tests in Table 6.9 and 6.10, assuming normality, the null hypothesis of identical means and variances of actual and simulated carcass weights cannot be rejected at the 5.0 percent significance level for the full sample nor for the October and December subsamples. The  $p$ -value of the  $t$ -test for carcass weights of cattle placed in feedlots in November implies rejection of the hypothesis of identical means at the 5.0 percent significance level. On the other hand, the  $p$ -values of  $F$ -tests for the November subsample yield no more evidence of dissimilarity of variances of carcass weights than for the full sample or the other subsamples. However, for the full and grouped samples of actual and simulated yield grades, the  $p$ -values of  $t$ - and  $F$ -tests imply rejection of the null hypotheses at any acceptable level of significance.

The reported  $p$ -values of the nonparametric tests (R-S and K-S tests) indicate that, for the full sample as well as for the October and December subsamples of actual and simulated carcass weights, the null hypothesis that actual and simulated distributions are identical cannot be rejected at the 5.0 percent significance level (Tables 6.9 and 6.10). However, for the November subsample of carcass weights, the hypothesis of identical distributions is rejected at the 5.0 percent level of significance, although the K-S test is

not rejected at 1.0 percent level. The R-S and K-S test results further indicate that the null hypotheses that actual and simulated yield grade distributions are identical can be rejected for all cases at reasonable significance levels.

In summary, the parametric and nonparametric tests confirm that the biophysical growth simulation model is able to approximate actual days on feed (for given final body weight), final body weights (for given days on feed), and carcass weights well with a plausible set of ration-implant strategies. But, the model fails to predict yield grade at a reasonable level of acceptance.

While the above tests involve cumulative frequency distributions of the simulated and actual data, the probability densities can be estimated for further comparison. Several parametric, semiparametric, and nonparametric techniques are available for probability density estimation. Kernel density estimation is the most popular technique among the nonparametric methods. Probability densities of the actual and simulated days on feed (model 1), carcass weight, yield grade, and quality grade data are estimated using a Gaussian kernel function. Actual and estimated densities for each of these are graphically presented in Figure 6.1.

The solid and dashed lines in Figure 6.1A represent the probability density curves for actual and simulated days on feed, respectively. Figure 6.1B presents the corresponding quantile-quantile (q-q) plot, showing whether the actual and simulated days on feed come from the same distribution.<sup>37</sup> The probability density and q-q plots

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<sup>37</sup> The quantile-quantile (q-q) plot is a graphical technique for determining if two data sets come from populations with a common distribution (i.e., a graphical alternative for the various two-sample tests). A q-q plot is a plot of the quantiles of the first data set against the quantiles of the second data set. If the data falls near the 45° line, then the evidence suggests the two samples come from the same distribution. The method is robust with respect to changes in the location and scale of either distribution.

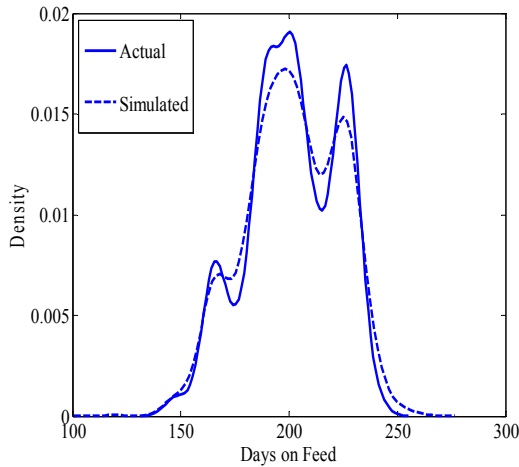


Figure 6.1A: Estimated kernel densities of actual and simulated days on feed (all cattle).

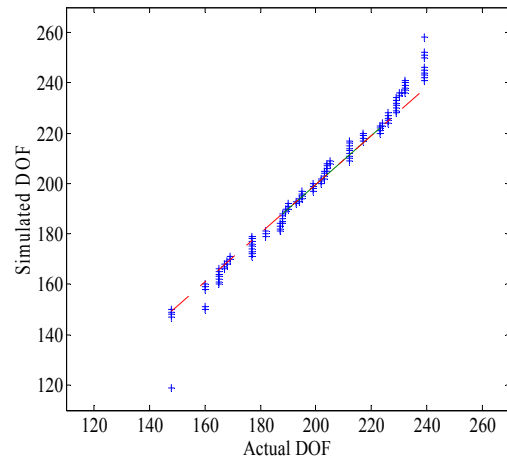


Figure 6.1B: Quantile-quantile plot of actual and simulated days on feed (all cattle).

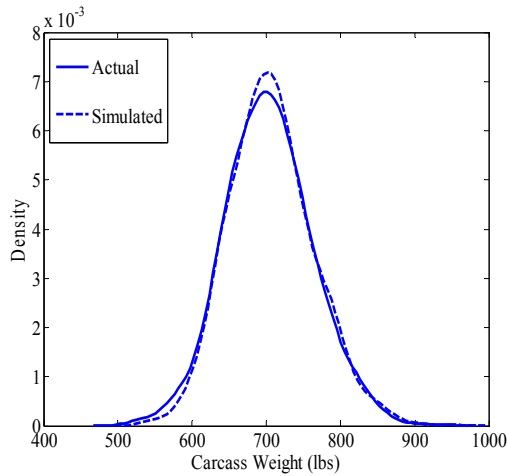


Figure 6.1C: Estimated kernel densities of actual and simulated carcass weights (all cattle).

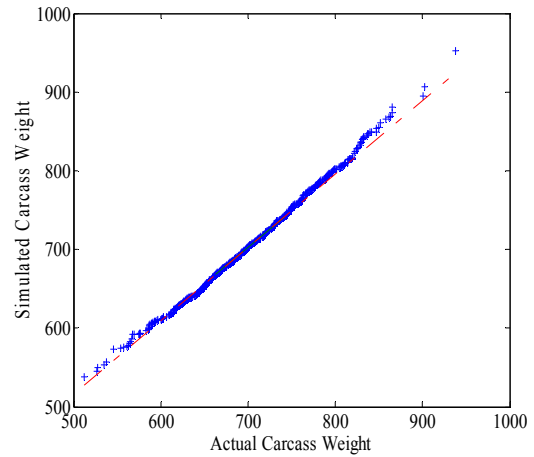


Figure 6.1D: Quantile-quantile plot of actual and simulated carcass weights (all cattle).

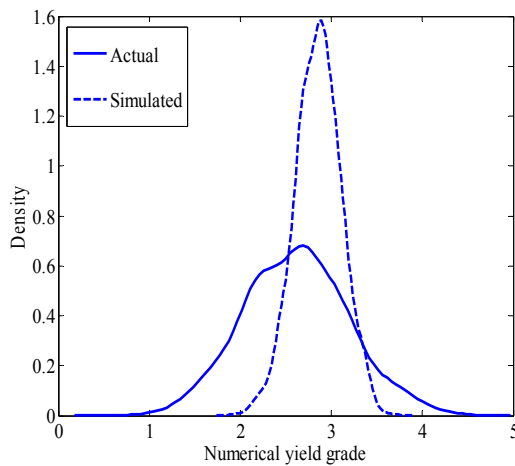


Figure 6.1E: Estimated kernel densities of actual and simulated yield grades (all cattle).

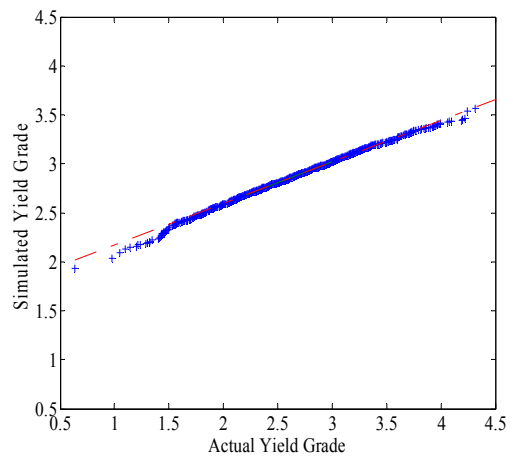


Figure 6.1F: Quantile-quantile plot of actual and simulated yield grades (all cattle).

indicate that the actual and simulated days on feed have similar distributions. In a similar fashion, probability density curves of actual and simulated carcass weights and corresponding q-q plot are represented by Figures 6.1C and 6.1D, respectively. These figures show that the actual and simulated carcass weights have virtually the same distribution.

Figures 6.1E and 6.1F show the probability density curves and the corresponding q-q plots for actual and simulated yield grade observations. While estimated densities appear to be quite different for simulated and actual yield grades, the q-q plot shows that the predictions are ranked quite accurately. In accordance with the findings of Tedeschi et al. (2004), the probability density curves and the q-q plot indicate that the growth model tends to over-predict (under-predict) numerical yield grade when actual yield grade is below 2.5 (above 3.5). While the simulation model over-predicts numerical yield grades of 66.1 percent of the observations, the means of actual and simulated yield grades are 2.61 and 2.85, respectively. Compared to the actual discrete variation in qualitative yield grades (which are whole numbers), this quantitative bias at the mean level seems of limited consequence. More importantly, the relatively accurate qualitative ranking suggested by Figure 6.1F suggests that the simulated qualitative yield grades appear to be useful for examining the implications of alternative fed cattle pricing, although the under-representation of quantitative yield grade variability must be considered in evaluating variability of grid pricing with respect to yield grade.

Figure 6.1G represents the probability density curves for the actual and simulated quality grades.<sup>38</sup> The estimated density of simulated quality grades is similar to that of actual quality grades except for a slight location shift to the right, thus slightly over-predicting actual numerical quality grade. This bias in the prediction of quality grades is much smaller than the actual discrete variation in quality grades, which are whole-numbered grades. This persistent but small discrepancy is viewed as minimal and is thus ignored.

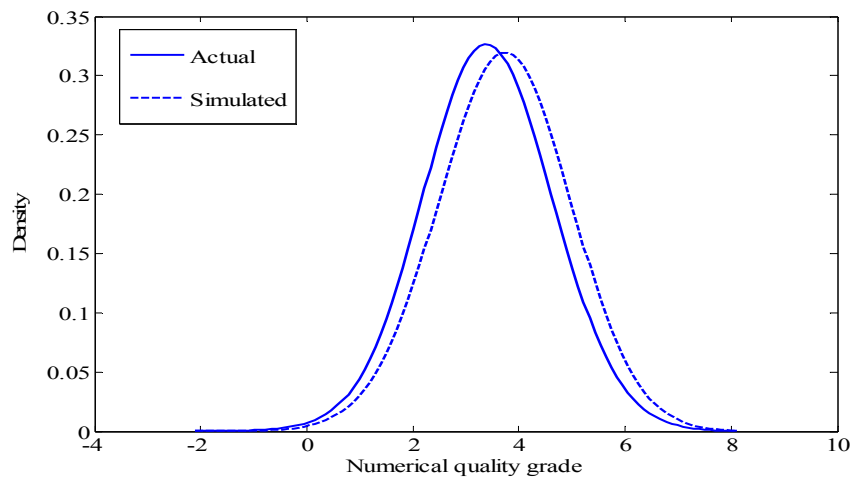


Figure 6.1G: Estimated kernel densities of actual and simulated quality grades (all cattle).

Finally, probability densities of actual and simulated observations categorized by the feedlot placement months (October, November, and December) are also estimated following the same procedure. Estimated densities and q-q plots of actual and simulated days on feed, carcass weight, yield grade, and quality grade data for the cattle placed in the feedlot in October, November, and December are shown in Figures 6.2, 6.3, and 6.4, respectively. From these figures it is evident that, while the corresponding densities of the

<sup>38</sup> Each observation of a numerical quality grade assumes an integer value in the range of 1 and 5. Quantile-quantile plots for actual and simulated quality grade data thus display only five discrete points, and therefore are not reported.

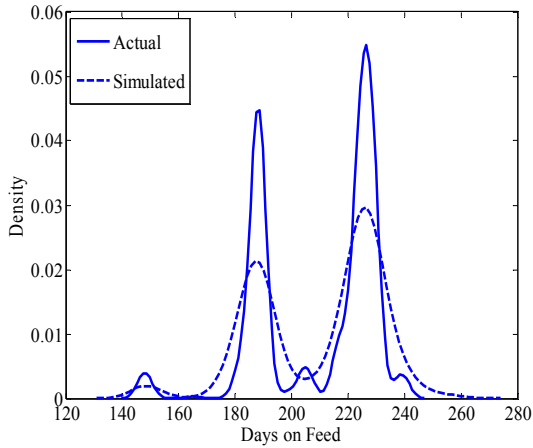


Figure 6.2A: Estimated kernel densities of actual and simulated days on feed (October cattle).

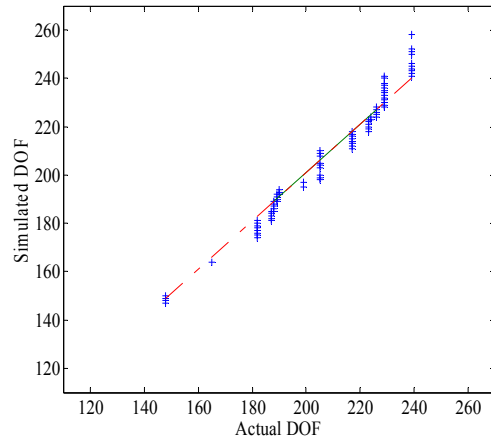


Figure 6.2B: Quantile-quantile plot of actual and simulated days on feed (October Cattle).

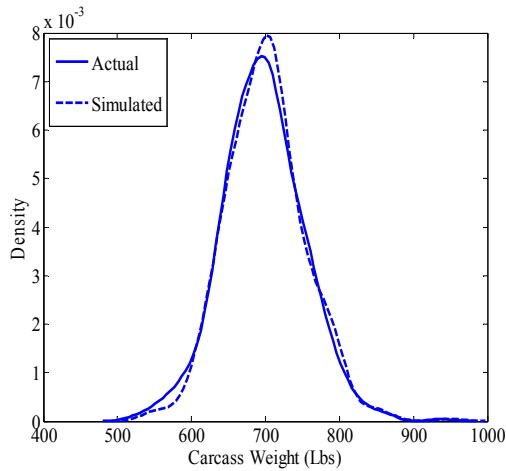


Figure 6.2C: Estimated kernel densities of actual and simulated carcass weights (October cattle).

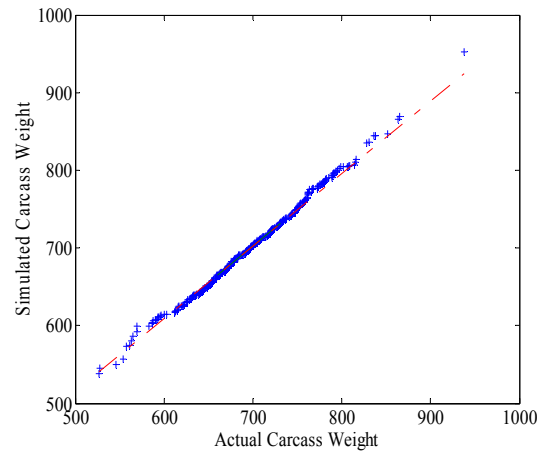


Figure 6.2D: Quantile-quantile plot of actual simulated carcass weights (October Cattle).

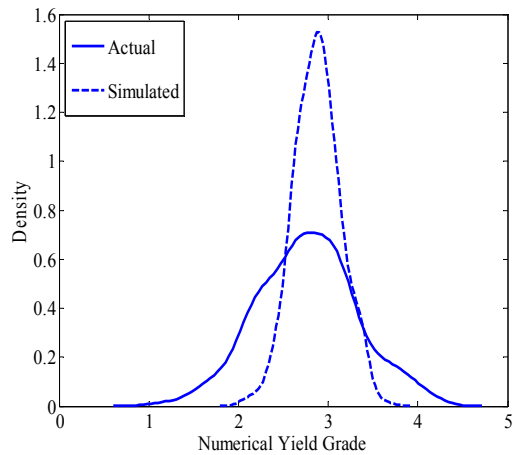


Figure 6.2E: Estimated kernel densities of actual and simulated yield grades (October cattle).

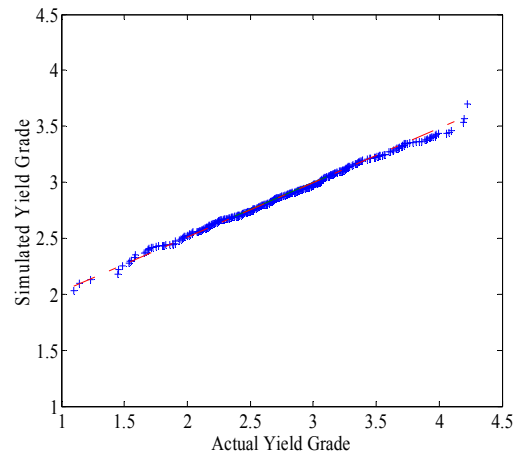


Figure 6.2F: Quantile-quantile plot of actual and simulated yield grades (October Cattle).

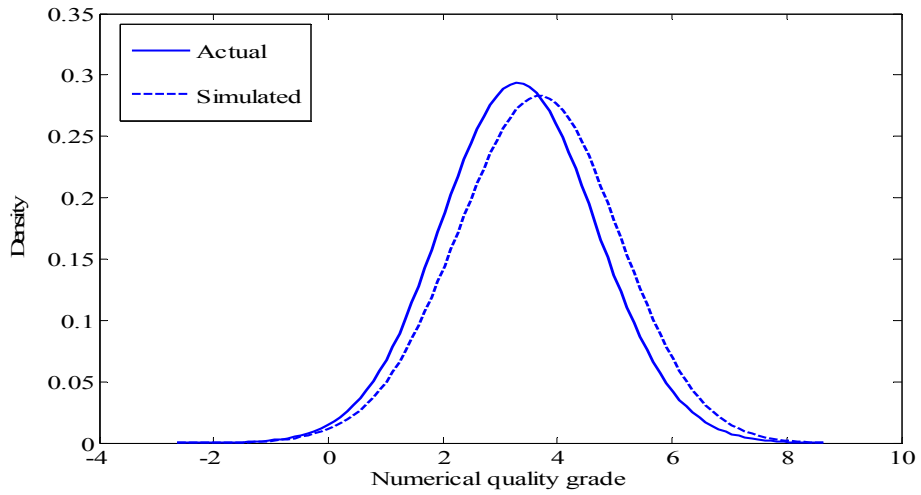


Figure 6.2G: Estimated kernel densities of actual and simulated quality grades (October cattle).

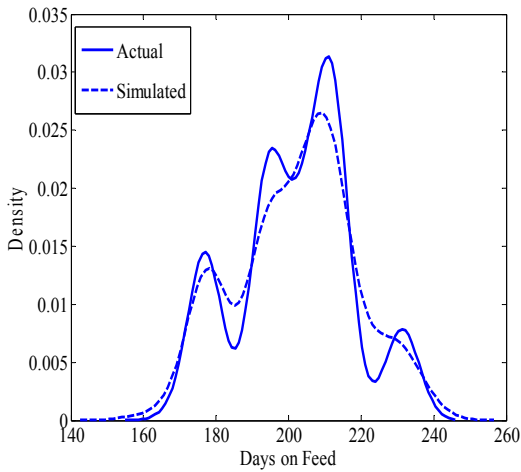


Figure 6.3A: Estimated kernel densities of actual and simulated days on feed (November cattle).

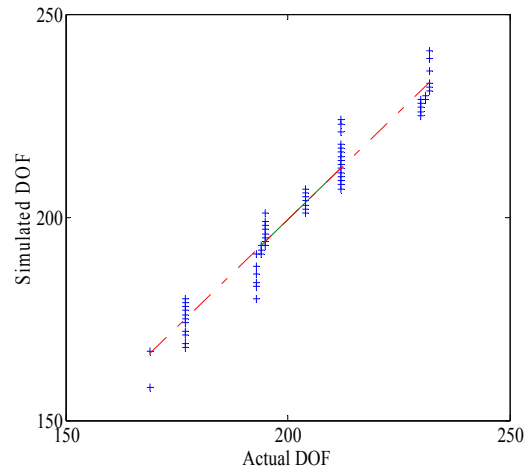


Figure 6.3B: Quantile-quantile plot of actual and simulated days on feed (November Cattle).

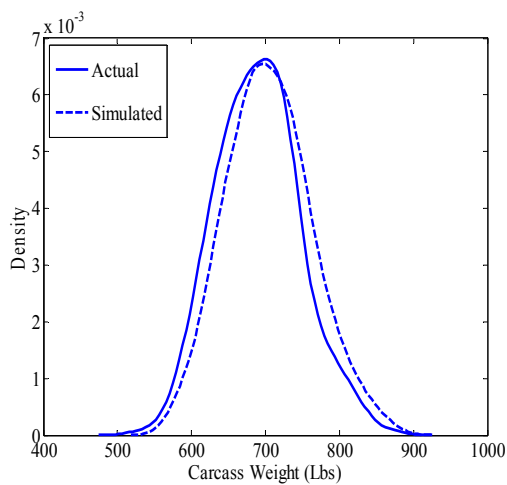


Figure 6.3C: Estimated kernel densities of actual and simulated carcass weights (November cattle).

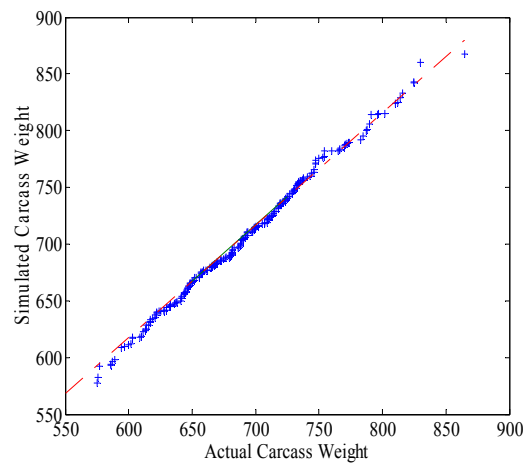


Figure 6.3D: Quantile-quantile plot of actual and simulated carcass weights (Nov. Cattle).

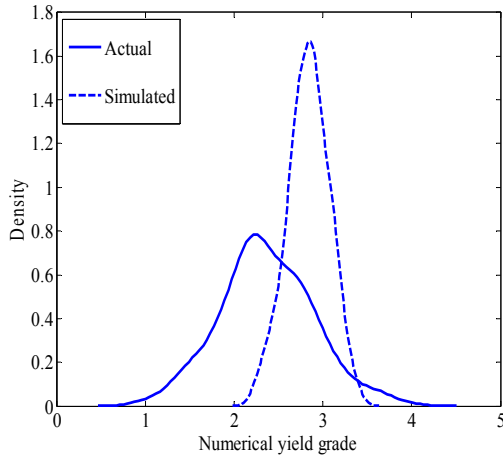


Figure 6.3E: Estimated kernel densities of actual and simulated yield grades (November cattle).

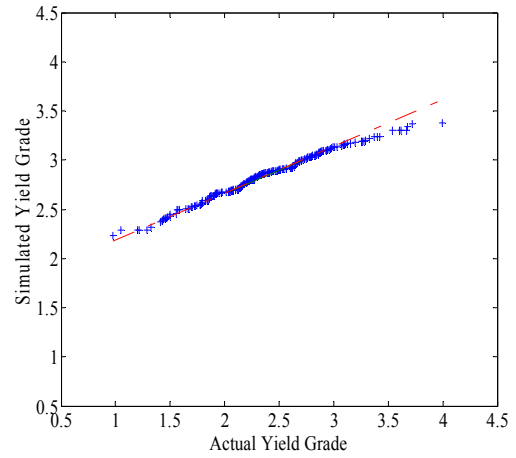


Figure 6.3F: Quantile-quantile plot of actual and simulated yield grades (November Cattle).

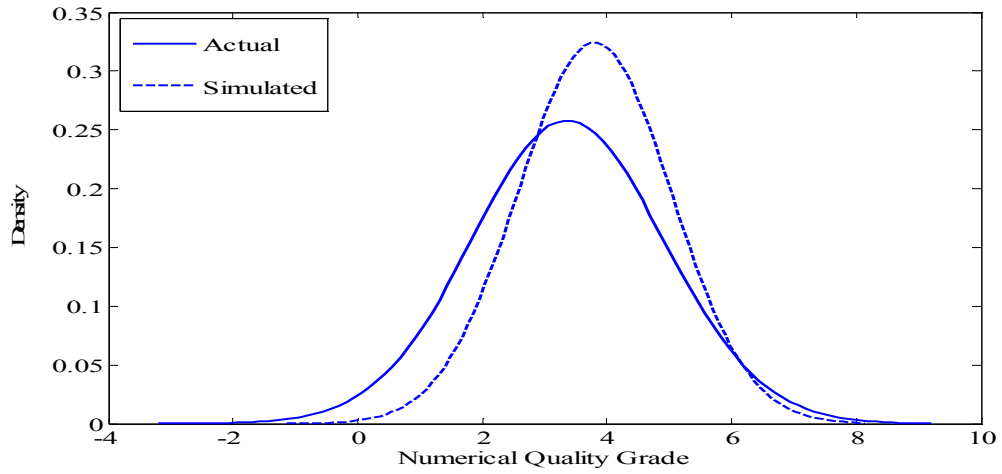


Figure 6.3G: Estimated kernel densities of actual and simulated quality grades (November cattle).

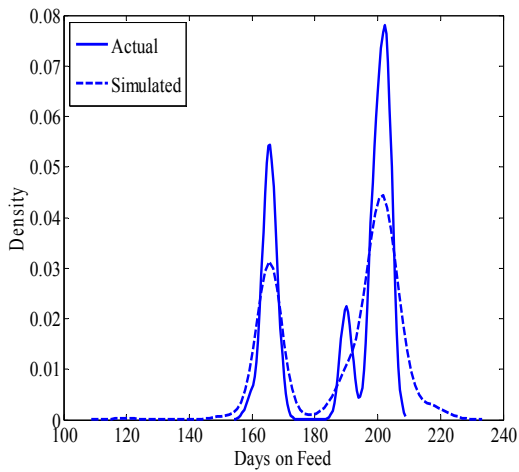


Figure 6.4A: Estimated kernel densities of actual and simulated days on feed (December cattle).

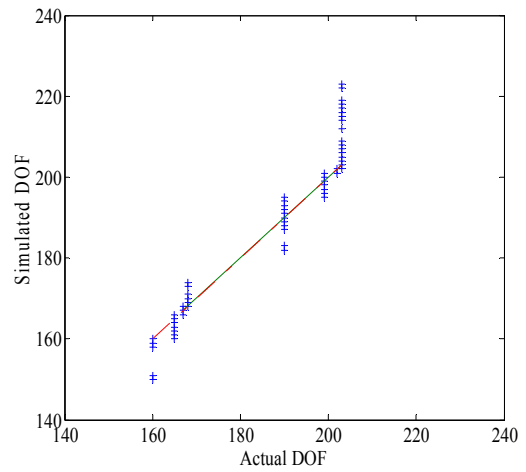


Figure 6.4B: Quantile-quantile plot of actual and simulated days on feed (December Cattle).



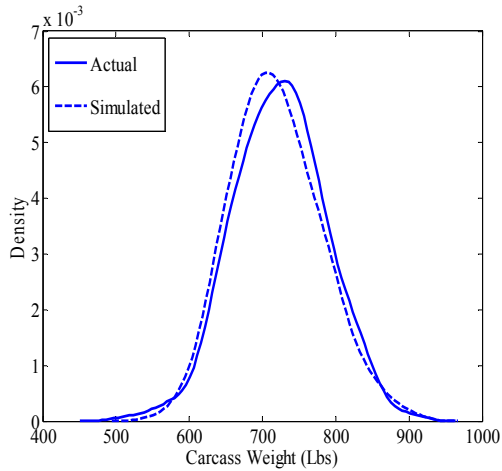


Figure 6.4C: Estimated kernel densities of actual and simulated carcass weights (December cattle).

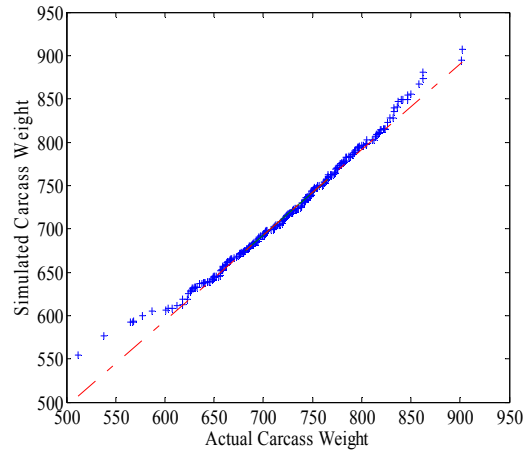


Figure 6.4D: Quantile-quantile plot of actual and simulated carcass weights (December Cattle).

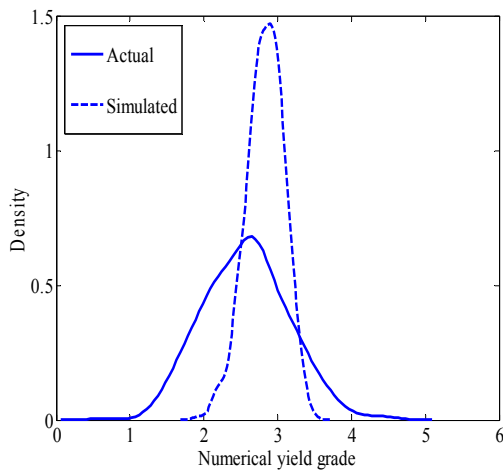


Figure 6.4E: Estimated kernel densities of actual and simulated yield grades (December cattle).

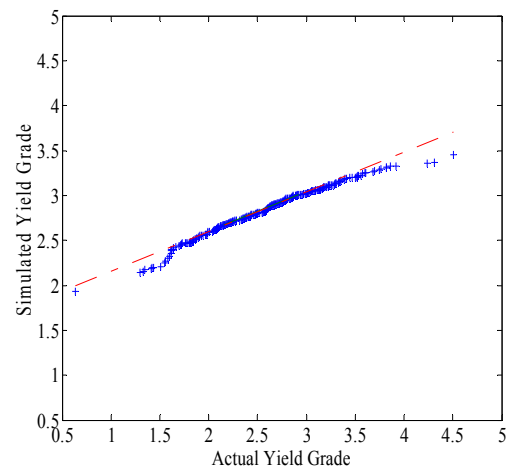


Figure 6.4F: Quantile-quantile plot of actual and simulated yield grades (December Cattle).

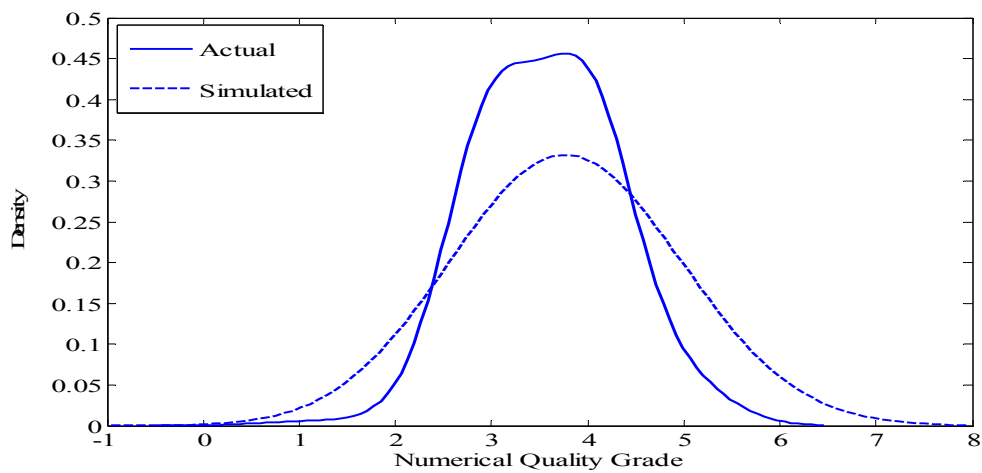


Figure 6.4G: Estimated kernel densities of actual and simulated quality grades (December cattle).

disaggregated sample follow patterns similar to the densities of the full sample, the predictive efficiency of the biophysical growth model is higher for the cattle placed on feed in October than for those placed on feed in November and December. However, no particular pattern is observed for the progression of the feedlot placement months. Furthermore, the high degree of similarity between actual and simulated distributions in these plots reveals that the nonparametric tests reject identical distributions only because of quantitatively inconsequential differences. Estimated densities of feedlot and carcass performance data simulated by model 2 are almost identical to those of model 1 and, therefore, are presented graphically in Appendix 6.2.

Both the statistical and graphical results provide considerable justification for using the simulated carcass weights of the growth model. The statistical and graphical results also indicate that the biophysical growth simulation model provides useful predictions of other actual feedlot and carcass performance outcomes except for yield grade. While the model tends to predict qualitative variation in yield grade correctly, it understates the quantitative variation. Animal science research (e.g., Tedeschi et al., 2004) also recognizes this inadequacy of the model. Thus, in terms of comparing the benefits of a given grid pricing system to the traditional fed cattle pricing methods, this result suggests that the estimated benefits of grid pricing would be biased downward because the effective incentive for yield grade would be understated by the growth model. However, as long as the growth model provides satisfactory predictions about carcass weight and quality grade outcomes and ranks yield grade predictions with an acceptable degree of accuracy, the model appears to permit determination of the structure

of optimal contracts for cattle feeding with grid pricing possibilities aside from biasing the optimal premium incentive for yield grade.

For example, Figure 6.1C suggests that the average quantitative yield grade predicted by the growth model is higher than the actual average. If this bias in quantitative yield grade prediction shifts qualitative yield grade predictions upward (e.g., predicted qualitative yield grade is 3 while the actual yield grade is 2), the predicted yield grade premium from a given grid pricing system would be lower implying less incentive for overall beef quality improvement than the actual incentive in effect. In this case, the effective incentive in an optimal contract with grid pricing would be understated if based on analysis with the growth model. Thus, with appropriate interpretation of the results, the growth model appears to be useful for the purpose of determining optimal cattle feeding contracts with alternative fed cattle pricing systems.

## **6.5 Conclusion**

The biophysical growth simulation model for beef cattle presented in Chapter 5 is employed in this chapter to predict feedlot and carcass performance of a large set of feeder steers that were actually fed in different feedlots located in Red Oak, Iowa. The simulated outcomes under alternative ration-implant strategies are then compared with actual feedlot and carcass performance data. Statistical analyses suggest that the growth model is able to predict required days on feed to reach a target final body weight, accumulated weight for a given feeding period, carcass weight, and quality grade with an acceptable degree of accuracy. In particular, the model is able to predict carcass weight (yield) almost accurately, while it slightly over-predicts the actual quality grade of

carcasses. The bias in quality grade prediction appears to be minimal. While the model also provides satisfactory predictions of quantitative yield grade within a certain range and predicted yield grades are accurately ranked, it tends to understate the variation in quantitative yield grade. Since the ability of the model to predict all other aspects of beef cattle feeding performance with quite satisfactory results, further use of the model for the purpose of investigating optimal contracts with grid pricing appears acceptable with appropriate qualifications regarding yield grade predictions.

Employing this biophysical growth model for beef cattle, the next chapter determines the optimal incentive structures for cattle feeding contracts under alternative fed cattle pricing schemes. In particular, feedlot and carcass performance under alternative feeding strategies are combined with historical price data to evaluate the predictions of the multitask principal-agent model presented in Chapter 4.

## CHAPTER 7

### OPTIMAL INCENTIVE STRUCTURE FOR CATTLE FEEDING CONTRACTS

#### 7.1 Introduction

The dynamic biophysical model for beef cattle growth presented in Chapter 5, which is validated in Chapter 6, provides a unique opportunity to evaluate the theoretical predictions of the multitask model presented in Chapter 4. That is, using the biophysical model to represent the technology of feedlots, the economic model of Chapter 4 can be used to examine feeder behavior under alternative contract provisions, and the implications for contract choice by cattle owners. As indicated by the results of the growth simulation model, with a target harvest body weight as the terminal condition for feeding, average daily gain (*ADG*) increases and days required to reach the target body weight (*DOF*) and pounds of feed required per pound of gain (*FE*) decrease with the nutrient content of the ration and the potency of the growth promoting implant. On the other hand, the quality of beef increases with the energy content of feed and decreases with the potency of the implant. Energy content of feed and the potency of the growth promoting implant are thus substitutes in affecting the quality of beef. As in the multitask model, the substitution effect of these two inputs in determining beef quality has similar implications for the incentive structure of cattle feeding contracts, especially when beef quality is not measurable or verifiable before slaughter.

Defining the profit equations and utility functions of a contract cattle feeder and an owner who retains ownership of the cattle until slaughter, the next section discusses the implications of the beef cattle growth simulation results for the incentive structure of

cattle feeding contracts. The cattle performance data generated by the biophysical growth simulation model with expected shrunk body weight as the terminal condition are then combined with historical price data to determine the optimal incentive schemes for cattle feeding under alternative fed cattle pricing methods and risk aversion scenarios. Section 7.3 provides a description of the historical price series and plausible ranges of constant absolute risk aversion coefficients for the feeder and owner. Section 7.4 presents a generalized search method, which is used to determine the optimal (expected profit/utility maximizing) incentive schemes for cattle feeding. Optimal incentive schemes for cattle feeding and corresponding production technologies under alternative fed cattle pricing methods and risk aversion scenarios obtained from the search are presented and implications of the results are analyzed in Section 7.5. The last section summarizes and concludes the chapter.

## **7.2 Profit and Utility Functions of the Cattle Feeder and Owner**

Following conventional wisdom and the model in Chapter 4, both cattle owners and feeders are assumed to maximize profits or the expected utility of profits. For an owner, the number of animals is predetermined by prior breeding decisions. For a feedlot operator, the number of animals in a feeding season is determined by prior investment in feedlot facilities. Feeding seasons are determined by the breeding practices and biological cycle of bovine animals. Traditionally, cow-calf producers in the U.S. breed their cows in late winter and early spring. Thus, the majority of calves are born in February, March, and April, and placed in feedlots during the following October, November, or December. Calves placed in the feedlots during the fall gain market weight in the following April,

May, or June. Some producers breed their cows in late summer or early fall, primarily to reduce losses from calf scours and to complement their forage production program (Field and Taylor, 2002). The fall born calves are placed in the feedlots in the following summer, which become ready for slaughter in the following fall and winter.

Commercial feedlots acquire feeder cattle from cow-calf producers or stocker operators by direct purchase or custom-feeding arrangements. When a feedlot operator supplies custom feeding services on a contractual basis, his decisions depend on the incentive structure of the payment scheme. When feeding the cattle on the basis of a typical yardage-fee-plus-feed-cost contract, his short-run profit is maximized by maximizing the number of days required to reach a target harvest weight. In this case, the feedlot operator has an incentive to keep the animals in the facility for a longer period. This incentive is higher as the fixed fee per animal per day is higher (i.e., for higher yardage charges). On the other hand, the cost-of-gain contract provides incentives for the reduction of feed cost and the number of days required to reach a target harvest weight. Thus, the objective of a commercial feeder differs with the incentive scheme of cattle feeding contracts.

The criteria of cattle feeders' alternative objectives with existing cattle feeding contracts can be combined in a general profit equation. Suppose a commercial feedlot has a one-time capacity to feed  $n$  cattle. The feeder's net profit from feeding each individual animal under any of the existing contract forms can be described by the following equation, which nests the incomes under alternative payment schemes

$$\pi_i^F = [\alpha + \beta \times ADG_i + (\gamma - 1) \times ADG_i \times FE_i \times P_R - C_{nf}] \times DOF_i \text{ for } i = 1, \dots, n;$$

subject to  $0 \leq \alpha \leq \bar{\alpha}$ ,  $0 \leq \beta \leq \bar{\beta}$ , and  $0 \leq \gamma \leq \bar{\gamma}$  (7.1)

where  $\pi_i^F$  represents the feeder's profit from feeding animal  $i$ ,  $\alpha$  is the yardage charge per animal per day,  $\beta$  is the payment per pound of gain,  $\gamma$  is the owner's share of feed cost,  $P_R$  denotes price per pound of feed,  $C_{nf}$  represents non-feed cost per animal per day, and  $ADG_i$ ,  $FE_i$ , and  $DOF_i$  denote average daily gain, feed efficiency, and days on feed, respectively. Given that the yardage charge, payment per pound of gain, and the owner's share of feed cost never take negative values in reality, the lower limits of individual contract parameters are set to zero. The upper limits of the contract parameters given by  $\bar{\alpha}$ ,  $\bar{\beta}$ , and  $\bar{\gamma}$  represent the maximum feasible yardage fee per day, payment per pound of gain, and the owner's share of feed cost. These are determined by the maximum attainable profit from the fed cattle and the participation constraints of the feeder and owner. When  $\alpha = 0$  and  $\gamma = 0$ , equation (7.1) represents the feeder's profit from feeding animal  $i$  under the typical cost-of-gain contract. Alternatively, when  $\beta = 0$  and  $\gamma = 1$ , the above equation represents the feeder's profit under the yardage-fee-plus-feed-cost contract. The payment scheme takes the form of a yardage-fee-plus-feed-markup (on feed cost) contract when  $\beta = 0$  and  $\gamma > 1$ .

The cattle feeder's revenue per pound of added weight, i.e., the payment scheme, associated with equation (7.1) is

$$\alpha \times \frac{DOF_i}{TSWG_i} + \beta + (\gamma - 1) \times FE_i \times P_R = \frac{\alpha}{ADG_i} + \beta + (\gamma - 1) \times FE_i \times P_R \text{ for } i = 1, \dots, n$$

where  $TSWG_i$  is total shrunk weight gain by animal  $i$ . For a target weight gain (i.e., fixed  $TSWG_i$ ),  $DOF_i$  increases (i.e.,  $ADG_i$  decreases) with  $\alpha$  and  $FE_i$  increases with  $\gamma$ . Since  $DOF_i$  and  $FE_i$  decrease with the energy content of feed and the potency of the implant, the feeder's cost saving incentive is lower for higher  $\alpha$  and  $\gamma$ . The incentive for cost



saving is the highest when  $\alpha = 0$  and  $\gamma = 0$ , and the lowest when  $\alpha = \bar{\alpha}$  and  $\gamma = \bar{\gamma}$ . The payment per pound of gain is the highest ( $\beta = \bar{\beta}$ ) when  $\alpha = 0$  and  $\gamma = 0$  and the lowest when  $\alpha = \bar{\alpha}$  and  $\gamma = \bar{\gamma}$ . Thus, the power of the incentive scheme (i.e., the incentive for using a high energy ration and an aggressive implant) increases with  $\beta$  and decreases with  $\alpha$  and  $\gamma$ . In some cases, a feeder might find beneficial cost savings by using an aggressive (moderate) implant strategy with a low (high) energy ration. However, the feeder's substitution between the energy content of the ration and the potency of the implant depends on the marginal rate of substitution and relative marginal costs of these inputs.

The feeder's total profit from feeding  $n$  cattle is the sum of  $\pi_i^F$  over  $i = 1, \dots, n$ .

Thus, the feeder's average profit per head can be represented by

$$\begin{aligned}\bar{\pi}^F &= \frac{1}{n} \left( \sum_{i=1}^n \pi_i^F \right) \\ &= [\alpha + \beta \times ADG + (\gamma - 1) \times ADG \times FE \times P_R - C_{nf}] \times DOF\end{aligned}\quad (7.2)$$

where the variables without subscripts represent averages over the  $n$  cattle in the lot. The feedlot operator's profit per animal per day is given by

$$\begin{aligned}\frac{\pi^F}{DOF} &= \frac{1}{n \times DOF} \left( \sum_{i=1}^n \pi_i^F \right) \\ &= [\alpha + \beta \times ADG + (\gamma - 1) \times ADG \times FE \times P_R - C_{nf}].\end{aligned}\quad (7.3)$$

Total shrunk weight gain by an animal can be expressed as a product of average daily gain and the number of days on feed. Therefore, the feeder's average profit per hundred pounds of weight gain can be represented by

$$\hat{\pi}^F = \frac{100}{\sum_{i=1}^n ADG_i \times DOF_i} \times \left( \sum_{i=1}^n \pi_i^F \right) = \frac{1}{k} \times \left( \sum_{i=1}^n \pi_i^F \right) \quad (7.4)$$

where  $k$  is the total number of one hundred pound increments in weight added to  $n$  cattle. Thus,  $k$  represents the size of the feedlot operation in terms of weight gain, while  $n$  represents the feedlot's size in terms of number of cattle.

Beef cattle production is usually one of many on-farm activities of cow-calf producers.<sup>39</sup> Cow-calf producers who retain the ownership of their cattle through slaughter while having them fed in commercial feedlots can reasonably be assumed to maximize profit per animal unless risk aversion is a concern. Suppose a cow-calf producer intends to retain the ownership of  $n^*$  feeder cattle. The cattle owner's profit from feeding the cattle in a commercial feedlot on a contractual basis and selling each individual fed animal on a grid that uses cash live-weight prices for establishing the base price of the grid can be expressed as

$$\begin{aligned} \pi_j^O = & \left[ P_L + (DP_j - DP_E) \times P_L + (P_Y \times \Delta Y + P_Q \times \Delta Q) \times DP_j \right] \times \frac{TSWG_j + ISBW_j}{100} \\ & - \left[ \alpha + \beta \times ADG_j + \gamma \times ADG_j \times FE_j \times P_R \right] \times DOF_j - \frac{ISBW_j}{100} \times P_F \text{ for } j = 1, \dots, n^* ; \\ & \text{subject to } 0 \leq \alpha \leq \bar{\alpha}, 0 \leq \beta \leq \bar{\beta}, \text{ and } 0 \leq \gamma \leq \bar{\gamma}, \end{aligned} \quad (7.5)$$

where  $ISBW$  stands for initial shrunk body weight of the feeder cattle,  $P_L$  and  $P_F$  denote prices of fed and feeder cattle per hundred pounds of live weight, respectively,  $DP_j$  and  $DP_E$  are actual and expected dressing percentages, respectively,  $P_Y$  and  $P_Q$  represent yield and quality grade premiums, respectively, and  $\Delta Y$  and  $\Delta Q$  are incremental yield and quality grades, respectively. Equation (7.5) nests the owner's profits from live- and

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<sup>39</sup> A large number of cow-calf producers do not depend primarily or substantially on beef cattle for their annual income. A 1997 NAHMS survey showed that only 380 out of 2,713 cow-calf operations have their primary source of income from the beef herd. Producers with 100 or fewer cattle have other, more important sources of agricultural income or off-farm jobs.

dressed-weight pricing of the cattle. In particular, when there are no yield and quality grade premiums (i.e.,  $P_Y = 0$  and  $P_Q = 0$ ), equation (7.5) represents the owner's profit from dressed-weight pricing. Yield premium is just the difference between the actual and expected dressing percentages multiplied by the live price. When there is no premium for yield (i.e.,  $DP_j - DP_E = 0$ ), then the equation represents profit under live-weight pricing.

For a target weight gain (i.e., fixed  $TSWG_i$ ), the cattle owner's revenue increases with  $P_L, P_Y, P_Q, DP_j, \Delta Y$  and  $\Delta Q$ , and decreases with  $DP_E$ .<sup>40</sup> According to the growth model,  $\Delta Q$  decreases with the potency of the growth promoting implant. Therefore, as long as  $P_Q$  is positive (i.e., the owner sells fed cattle through the grid pricing method), the cattle owner offers a low powered incentive for cost saving by choosing a payment scheme with a low  $\beta$ . On the other hand, if  $P_Q = 0$  (i.e., the owner sells fed cattle through the live- or dressed-weight pricing methods), the owner offers a high incentive for cost saving by choosing a payment scheme with high  $\beta$ . The cattle owner's tradeoff between  $\alpha$  and  $\gamma$  for a given  $\beta$  depends on their relative net marginal benefits for the owner. The cattle owner's average profit per head, per head per day, and per hundred pounds of weight gain are given by the following equations, respectively,

$$\bar{\pi}^O = \frac{1}{n^*} \left( \sum_{j=1}^{n^*} \pi_j^O \right) \quad (7.6)$$

$$\dot{\bar{\pi}}^O = \frac{1}{n \times DOF} \left( \sum_{j=1}^n \pi_j^O \right) \quad (7.7)$$

$$\hat{\pi}^O = \frac{100}{\sum_{j=1}^{n^*} ADG_j \times DOF_j} \times \left( \sum_{j=1}^{n^*} \pi_j^O \right) = \frac{1}{k^*} \times \left( \sum_{j=1}^{n^*} \pi_j^O \right) \quad (7.8)$$

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<sup>40</sup> According to the growth model  $DP_j$  is a linear function of body weight and therefore remains the same for a target weight gain. Yield grade outcomes of the model should be ignored as the predictive efficiency of the sub-model is low.

where  $k^*$  and  $n^*$  are the cattle owner's size of operation in terms of weight gain and number of cattle, respectively.

The cattle owner's choice of a particular payment scheme and the feeder's choice of a production technology under that scheme also depend on their respective risk preferences. Following expected utility theory, preferences of the risk-averse cattle feeder and the risk-averse owner are represented by expected utility functions with constant absolute risk aversion. As suggested by the derivation in Chapter 4, the choices of both the cattle owner and feeder are modeled with constant absolute risk aversion for the typical per animal problem. While normality may not hold in the simulation as under assumptions in the theoretical model of Chapter 4, the absolute risk aversion from the aggregate model is applied to the choice model for the per animal problem. That is, suppose the feeder's short-run profit  $\pi_i^F$  for  $i = 1, \dots, n$  on each animal represents a random draw from the same (unknown) distribution. Then, under the conditions of the Central Limit Theorem and assuming the size  $n$  of the feeders operation is limited by fixed investments, the average incremental gain can be treated as approximate normally distributed. If  $\Pi^F = \sum_{i=1}^n \pi_i^F$  denotes the total net profits of the feeder from feeding  $n$  cattle and his utility follows  $U^F(\Pi^F) = -\exp(-\phi\Pi^F)$ , then his expected utility is

$$E(U^F(\Pi^F)) = -E[\exp(-\phi\sum_{i=1}^n \pi_i^F)] = -\prod_{i=1}^n E[\exp(-\phi\pi_i^F)] = -nE[\exp(-\phi\bar{\pi}^F)]$$

where  $\bar{\pi}^F$  represents the feeder's average profit per animal. Thus, the problem can be modeled as constant absolute risk aversion with respect to the typical per animal problem using the same absolute risk aversion coefficient as in the total profit problem.

A similar derivation also implies constant absolute risk aversion on the part of the cattle owner following  $U^O(\Pi^O) = -\exp(\psi\Pi^O)$  where  $\Pi^O = \sum_{i=1}^{n^*} \pi_i^O$  denotes the total net profits of the owner from retaining ownership of  $n^*$  cattle where  $n^*$  fixed by prior breeding decisions. The owner's expected utility is given by

$$E(U^O(\Pi^O)) = -E[\exp(-\psi \sum_{i=1}^{n^*} \pi_i^O)] = -\prod_{i=1}^{n^*} E[\exp(-\psi \pi_{i=1}^O)] = -n^* E[\exp(-\psi \bar{\pi}^O)],$$

where  $\bar{\pi}^O$  denotes the owner's average profit per animal. Thus, maximization of the expected utility of total profit is equivalent to maximizing the expected utility of the average profit per animal using the same absolute risk coefficient.

The cattle feeder's and owner's stochastic costs and returns under alternative production technologies and fed cattle pricing methods can be calculated according to the profit equations (7.2) and (7.6) using cattle performance and random price data. For various constant absolute risk aversion coefficients of the owner and feeder, corresponding expected utilities can then be obtained according to the exponential utility functions. Feedlot and carcass performances of the TCSCF cattle for each of the 18 strategic ration-implant strategies are generated employing the biophysical growth simulation model presented in Chapter 5. Following the procedure described in Chapter 6, daily feed intake, weight gain, and composition (protein and fat) of the gain are computed until each individual animal reaches the expected (estimated) final shrunk body weight (*EFSBW*) for the USDA "Choice" grade. The use of *EFSBW* as the terminal condition in the growth model is consistent with the objectives of beef industry participants.<sup>41</sup> The required data on total shrunk weight gain (*TSWG*), days on feed

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<sup>41</sup> Beef producers and packers strive to consistently produce "Choice" quality beef, which is desired most by the customers (Field and Taylor, 2002). In order to ensure "Choice" quality grade, feedlot operators

(*DOF*), average daily gain (*ADG*), feed efficiency (*FE*), dressing percentage (*DP*), and yield and quality grades (*YG* and *QG*) are thus obtained from the growth simulation model. The next section describes price data and plausible risk aversion coefficients for the cattle feeder and owner.

### 7.3 Price Data and Risk Aversion Coefficients

Historical weekly average prices for fed cattle, feeder cattle, feed ingredients, and grid premiums and discounts data were obtained from the Livestock and Grain Market News (LGMN) of the Agricultural Marketing Service (AMS) of the United States Department of Agriculture (USDA). These included Iowa weekly weighted average live- and dressed-weight prices for fed cattle, prices for feeder cattle of different weight groups and frame sizes, and weekly average prices for corn during January 1996 through December 1999. Iowa prices for soybean meal and alfalfa hay are not available through the USDA. Therefore, weekly average prices for soybean meal in Decatur, Central Illinois, and weekly average prices for alfalfa hay in Kansas were obtained for the same period. Weekly average yield and quality grade premiums and discounts paid in the grid under voluntary price reporting during 1996-99 and under mandatory price reporting during 1999 to 2005 were also collected. Summary statistics of the fed cattle and feed ingredient prices and quality and yield grade premiums/discounts are presented in Table 7.1.

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strive to harvest the cattle when they reach 0.3-0.4 inches of back fat (Chambers, 2005). Most beef cattle are likely to gain 0.3-0.4 inches of back fat at the corresponding *EFSBW* (Guiroy et al., 2001; Fox et al., 1992). Also, feed efficiency and average daily gain declines beyond this point. Feuz (1999) reports that the average back fat thickness of 85 pens of cattle (5,520 head) priced on three different grids in 1997 was 0.41 inches with a standard deviation of 0.11 inches. Packers also prefer live cattle between 1,000-1,400 lbs, which are most likely to produce beef carcasses between 600-900 lbs.

**Table 7.1: Summary statistics of the historical price series.**

<b>Variables</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Minimum</b>	<b>Median</b>	<b>Maximum</b>
<b>Prices for Fed Cattle (\$/lb)</b>					
Live Weight Price	0.65	0.034	0.56	0.65	0.73
Dressed Weight Price	1.03	0.057	0.89	1.04	1.19
<b>Quality Grade Premiums/Discounts (\$/lb)</b>					
Prime	0.07	0.016	0.04	0.06	0.10
Certified Angus Beef (CAB)	0.02	0.009	0.01	0.02	0.05
Select	-0.09	0.046	-0.25	-0.08	-0.03
Standard	-0.18	0.039	-0.31	-0.16	-0.12
<b>Yield Grade Premiums/Discounts (\$/lb)</b>					
YG 1 (YG < 1)	0.03	0.002	0.02	0.03	0.03
YG 2 (1 = <YG < 2)	0.02	0.002	0.01	0.02	0.02
YG 3 (2 =< YG < 3)	0.01	0.002	0.01	0.01	0.02
YG 4 (3.5 =< YG < 4)	0.00	0.001	0.00	0.00	0.00
YG 5 (4 =< YG < 5)	-0.13	0.010	-0.14	-0.13	-0.11
YG 6 (YG > 5)	-0.18	0.004	-0.19	-0.18	-0.17
<b>Prices for Feed Ingredients (\$/lb)</b>					
Corn	0.05	0.016	0.03	0.04	0.09
Soybean Meal	0.10	0.028	0.06	0.10	0.15
Alfalfa Hay	0.05	0.005	0.04	0.05	0.06

Note: Live and dressed weight prices for fed cattle and corn are Iowa weekly average prices during 1996-1999. Prices for soybean meal and alfalfa hay are weekly averages prices during 1996-1999 in Decatur, Central Illinois, and Kansas, respectively. Yield and quality grade premiums are weekly averages of voluntarily reported prices to the USDA during 1996-1999 and mandatorily reported prices during 1999 to 2005.

Source: Direct communication with personnel in Livestock and Grain Market News (LGMN) of the Agricultural Marketing Service (AMS), United States Department of Agriculture (USDA).

There is no widely quoted market price for corn silage because market for silage is very limited. Therefore, corn silage prices are calculated from corn prices following the

guidelines of the Iowa State University Extension Service. A value of 9 times the price of corn per bushel for each ton of usable (harvested and stored) silage is commonly used (Edwards, 2005). This value is adjusted for dry matter (34 percent) content of the corn silage used in rations formulated for the growth model.

Grid base prices are not available because beef packers are not obligated to report those even under the mandatory price reporting rules of the AMS. While a variety of methods have been used to establish base prices in carcass grids, the most popular technique has been to use a formula that uses a local cash market price reported by an independent third party (e.g., the USDA) or an adjusted packing plant average price (Schroeder et al., 2003; Ward et al., 2002). The price is usually adjusted to a standard dressing percentage (Schroeder et al., 2003). Following Schroeder et al. (2003), grid base prices for this study are calculated from USDA live-weight prices with adjustment to an estimated dressing percentage (62.30 percent) plus \$1.00 per hundred pounds of carcass. For example, using average live-weight price as the reference, the calculated grid base price according to this formula is  $((\$0.65/0.623) + 0.01 =) \$1.04/\text{lb}$ . The estimate of the dressing percentage is obtained by regressing the live-weight prices on dressed-weight prices without an intercept term.

The nonparametric Lilliefors test is performed on each of the historical price series to test whether they are drawn from populations with a normal distribution.<sup>42</sup> The test results indicate that the null hypothesis of normality should be rejected at the 5.0 percent significance level for all of the price series. Normal probability plots of the price data also confirm that approximation with a multivariate normal distribution could be

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<sup>42</sup> The Lilliefors test is a two-sided goodness-of-fit test suitable when a fully-specified null distribution is unknown and its parameters must be estimated (Lilliefors, 1967).



inappropriate. The correlation coefficient matrix of the multivariate data shows that cattle and feed ingredient prices are highly correlated. Therefore, multivariate densities of the prices are estimated using a Gaussian kernel function. Then random price vectors are drawn from the estimated multivariate distribution of the data until 10,000 observations are obtained.

Cost of each individual feeder animal is calculated from the USDA reported Iowa prices for different weight groups and frame sizes. Prices on the particular week of delivery of each feeder animal to the feedlot are used to determine the cost. Non-feed cost per animal per day during 1995-99 is obtained from historical profitability reports of three Iowa feedlots (Cody Feedlot, CRI Feeders, and Silver Creek Feeders). Labor, utility, and interest on feed (9.0 percent per annum) are reported to be 20 cents per animal per day during 1995-2000. Prices of a moderate implant (\$0.95 for Synovex S) and a high potency implant (\$3.25 for Synovex Plus) were obtained from Duckett et al. (1996), and were found to remain current according to prices at CattleStore in August 2006. Accordingly, the costs of implanting at the beginning of the feed regime plus reimplanting after approximately 90 days of feeding are calculated to be \$1.90 and \$6.50 per animal for the moderate and high potency implants, respectively. Thus, the costs of feeder cattle and implants, and non-feed cost per animal per day are not random in the model.

Because estimates of relative risk aversion generally vary relatively less than do estimates of absolute risk aversion, the coefficients of constant absolute risk aversion are chosen to match plausible values of relative risk aversion. Saha et al. (1994) report a brief survey of estimates of relative risk aversion coefficients that range from 0 to 18.8. The

feeder's and owner's constant absolute risk aversion coefficients are calibrated from these estimates according to  $\hat{\phi} = \varphi \cdot \Pi^F$  and  $\hat{\psi} = \psi \cdot \Pi^O$ , where  $\hat{\phi}$  and  $\hat{\psi}$  are the feeder's and owner's relative risk aversion coefficients at mean profit levels. A survey of cattle feeders and cow-calf producers showed that the capacity of feedlot operations ranges from 55 to 89,000 animals with an average of 5,000, and the size of cow-calf operations varies from 10 to 4,500 cattle with an average of 500 animals (Feuz and Umberger, 2001). Mark et al. (2000) reported that cattle feeders' average profit per animal was \$15 during 1980-1997, while Marsh and Feuz (2002) reported that the average return to cow-calf producers was \$93 per slaughtered animal during 1980-96. Substituting these values in  $\hat{\phi} = \varphi \cdot \Pi^F$  and  $\hat{\psi} = \psi \cdot \Pi^O$ , the upper bounds of feeder's and owner's absolute risk aversion coefficients (corresponding to relative risk aversion of 18.8) are calibrated to be 0.025 and 0.019, respectively. Accordingly, the full range of risk aversion possibilities up to these limits is investigated in model simulations.

#### **7.4 The Feasible Contract Parameter Space and the Generalized Search Procedure**

The optimal incentive schemes and corresponding production technologies under alternative fed cattle pricing methods and risk preferences of the cattle feeder and owner are determined by employing a parameter search procedure developed specifically for this study. The basic idea is to search the feasible parameter space for the combinations of the contract coefficients ( $\alpha$ ,  $\beta$ , and  $\gamma$ ) that induce the feeder to adopt the production technology that gives maximum expected utility to the cattle owner. The search is performed in a Stackelberg fashion. First, a parameter space for all feasible combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  is determined. Second, the technology space is searched for the feeder's

expected utility maximizing production technology (e.g., his expected utility maximizing ration-implant strategy) for every feasible combination of  $\alpha$ ,  $\beta$ , and  $\gamma$ . Finally, the contract parameter space is searched for the cattle owner's expected utility maximizing incentive scheme given the feeder's optimal production technology choice associated with each. The search is performed separately for each of the alternative fed cattle pricing methods: live-weight pricing, dressed-weight pricing, and grid pricing.

In order to construct the parameter space for  $\alpha$ ,  $\beta$ , and  $\gamma$ , first the lower and upper bounds of each of these contract coefficients are determined from the minimum and maximum attainable net revenues from sale of a fed animal (i.e., the revenue from sale of the fed animal minus the cost of the feeder animal). Because a negative yardage charge, negative payment per pound of gain, or negative share of feed cost for the owner are nonsensical and unrealistic, the lower limits of individual contract parameters are set to zero. On the other extreme, for the case when the cattle are fed and the owner transfers the entire net revenue to the cattle feeder, the maximum possible values of  $\alpha$ ,  $\beta$ , and  $\gamma$  (upper bounds) are found to be 0.49, 0.47, and 1.45, respectively. In other words, if the net revenue is transferred completely and exclusively through a yardage fee (i.e.,  $\beta = 0$  and  $\gamma = 0$ ), then  $\alpha = \$0.49$  per animal per day. Similarly, if the net revenue is transferred completely and exclusively through a payment per pound of gain, then  $\beta = \$0.47$  per pound while  $\alpha = 0$  and  $\gamma = 0$ . If the transfer is made completely and exclusively through a reimbursement for feed cost, then  $\gamma = 1.45$ , i.e., a 45 percent markup on feed cost is given to the feeder) while  $\alpha = 0$  and  $\beta = 0$ . From any of these extremes, the owner would never pay more to induce the cattle feeder to enter the contract because that would cause a negative net benefit for the owner.

Because the simulation model has discontinuities in some of the defining equations, the first step in optimization was to test for concavity of profits. The concavity of the cattle feeder's and owner's profit functions was also tested considering all feasible combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$ . In particular, the feeder's and owner's profits are calculated by combining biophysical growth simulation outcomes for various random draws from the historical price series. For each draw, the feeder's and owner's profits for each feasible combination of  $\alpha$ ,  $\beta$ , and  $\gamma$  were compared with various convex combinations of the profits for the nearest neighbors of the coefficients with the same average coefficients. The tests for both strong and weak concavity of the feeder's and owner's profits failed for the overall feasible parameter space. Although the failures were minor, this conclusion motivated comparison of all combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  with 0.01 accuracy to determine optimal choices.

With an increment of 0.01 within the corresponding intervals ( $0 \leq \alpha \leq 0.49$ ,  $0 \leq \beta \leq 0.47$ , and  $0 \leq \gamma \leq 1.45$ ), there are 350,400 plausible combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$ . Because the number of combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  is so large, further possibilities for limiting the sample space without loss of generality were considered. The feasible region for  $\alpha$ ,  $\beta$ , and  $\gamma$  is determined by the participation constraints of the feeder and owner and their maximum attainable net profits (i.e., net revenue minus cost of feeding). Setting the feeder's and owner's reservation net incomes equal to zero, the feasible parameter space can thus be further confined by

$$ADG \times FE \times P_R + C_{nf} \leq \alpha + \beta \times ADG + \gamma \times ADG \times FE \times P_R \leq (R - C_F) / DOF \quad (7.9)$$

where  $R$  is the cattle owner's average revenue from selling a fed animal,  $C_F$  is the cost of a feeder animal, and  $\alpha \geq 0$ ;  $\beta \geq 0$ ;  $\gamma \geq 0$ . The left hand side of the above expression

represents average feed and non-feed cost per head per day and the right hand side represents the cattle owner's average net revenue per head per day from retaining ownership of the feeder animal until slaughter. The values of the cattle performance variables and ration price in (7.9) are set to match the feeding strategy with maximum cost of gain per pound of live weight. The value of  $R$  is set to the minimum of the average revenues under alternative production technologies and fed cattle pricing methods. Setting the boundaries of the feasible parameter space in this fashion allows one to consider all ration-implant strategies and fed cattle pricing methods available to the cattle feeder and owner. Only the combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  that satisfy (7.9) are considered further. With this innocuous reduction of the parameter space, 39,829 combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  are found to be feasible. This parameter space is called the unrestricted parameter space because it contains all values not eliminated by trivial considerations.

While this parameter space considers all feasible choices for  $\alpha$ ,  $\beta$ , and  $\gamma$ , only two major types of contracts are observed in reality: a yardage-fee-plus-feed-cost contract with or without a markup ( $\alpha > 0$ ,  $\beta = 0$ , and  $\gamma \geq 1$ ) and a cost-of-gain contract ( $\alpha = 0$ ,  $\beta > 0$ , and  $\gamma = 0$ ). Therefore, to examine whether the form of typical contracts in current practice can be explained by the model, a further restricted feasible parameter space was also considered to allow only typical linear incentive contracts ( $\alpha \geq 0$ ,  $\beta \geq 0$ , and  $\gamma = 0$ ) and cost-plus contracts ( $\alpha \geq 0$ ,  $\beta = 0$ , and  $\gamma \geq 1$ ). These two sub-spaces are combined to represent a restricted parameter space corresponding to contract forms in current use. In this restricted parameter space, there are 1,085 combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  to consider.

For both the restricted and unrestricted parameter spaces, the cattle feeder's expected net returns and corresponding expected utility are computed for each

combination of  $\alpha$ ,  $\beta$ , and  $\gamma$  under each of the alternative ration-implant strategies for various values of constant absolute risk aversion coefficient in the interval  $0 \leq \varphi \leq 0.025$ . The feeder's expected profit and utility maximizing feeding strategies are thus determined for each combination of  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\varphi$ . The cattle owner's expected profit and utility per animal under a particular fed cattle pricing method given the feeder's optimal strategies for all feasible combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  are computed in the same way (for various constant absolute risk aversion coefficients in the interval  $0 \leq \psi \leq 0.019$ ). The owner's profit and utility maximizing  $\alpha$ ,  $\beta$ , and  $\gamma$  are then determined for each pair of values for the feeder's and owner's risk aversion parameters. The expected utility maximizing combination of  $\alpha$ ,  $\beta$ , and  $\gamma$  is the optimal incentive scheme for the cattle owner and the corresponding feeding strategy is the optimal production technology for the cattle feeder for a particular combination of  $\varphi$  and  $\psi$ . This procedure is repeated for live-weight, dressed-weight, and grid pricing methods for fed cattle and also for all plausible combinations of  $\varphi$  and  $\psi$  in the relevant range. A description of the search procedure is given in Appendix 7.1 in algorithmic form.

## **7.5 Optimization Results**

The optimal contract coefficients, cattle feeding strategies, and corresponding certainty equivalents under alternative fed cattle pricing methods and risk aversion scenarios are presented in Tables 7.2 and 7.3. Table 7.2 displays the results of the generalized search performed over the unrestricted parameter space ( $\alpha \geq 0, \beta \geq 0, \gamma \geq 0$ ) for the TCSCF cattle evaluated with year-round weekly average prices. Table 7.3 shows

**Table 7.2: Optimal contracts, cattle feeding strategies, and certainty equivalents (CE) of the cattle owner and feeder ( $\alpha \geq 0, \beta \geq 0, \gamma \geq 0$ ).**

Absolute Risk Aversion Coeff.		Live Weight Pricing							Dressed Weight Pricing							Grid Pricing						
Owner	Feeder	Optimal Parameter			Strat-egy <sup>2</sup>	Certainty Equivalent <sup>1</sup>			Optimal Parameter			Strat-egy <sup>2</sup>	Certainty Equivalent			Optimal Parameter			Strat-egy <sup>2</sup>	Certainty Equivalent		
		$\alpha$	$\beta$	$\gamma$		Owner	Feeder	Total	$\alpha$	$\beta$	$\gamma$		Owner	Feeder	Total	$\alpha$	$\beta$	$\gamma$		Owner	Feeder	Total
0	0	0.14	0.10	0.80	15	130.0*	10.9*	140.9*	0.14	0.10	0.80	15	116.4*	10.9*	127.3*	0.19	0.03	0.97	11	119.3*	10.4*	129.7*
0	0.000025	0.14	0.10	0.80	15	130.0*	10.9*	140.9*	0.14	0.10	0.80	15	116.4*	10.9*	127.3*	0.19	0.03	0.97	11	119.3*	10.4*	129.7*
0	0.00025	0.14	0.10	0.80	15	130.0*	10.9*	140.9*	0.14	0.10	0.80	15	116.4*	10.9*	127.3*	0.19	0.03	0.97	11	119.3*	10.4*	129.7*
0	0.0025	0.14	0.10	0.80	15	130.0*	10.8*	140.8*	0.14	0.10	0.80	15	116.4*	10.8*	127.2*	0.19	0.03	0.97	11	119.3*	10.4*	129.7*
0	0.025	0.14	0.10	0.80	13	129.7*	9.7*	139.5*	0.14	0.10	0.80	13	116.2*	9.7*	125.9*	0.19	0.03	0.97	11	119.3*	10.4*	129.6*
0.000025	0	0.14	0.10	0.80	15	129.9*	10.9*	140.8*	0.14	0.10	0.80	15	116.3*	10.9*	127.3*	0.19	0.03	0.97	11	119.2*	10.4*	129.6*
0.00025	0	0.14	0.10	0.80	15	129.2*	10.9*	140.1*	0.14	0.10	0.80	15	115.9*	10.9*	126.8*	0.19	0.03	0.97	11	118.3*	10.4*	128.8*
0.0025	0	0.14	0.10	0.80	15	122.4*	10.9	133.3*	0.14	0.10	0.80	15	111.4*	10.9	122.3*	0.13	0.08	0.87	12	110.3*	10.5	120.8*
0.019	0	0.15	0.11	0.76	13	73.3*	11.9	85.2*	0.15	0.11	0.76	13	79.5*	11.9	91.4*	0.23	0.08	0.78	10	57.0*	11.7*	68.8*
0.000025	0.000025	0.14	0.10	0.80	15	129.9*	10.9*	140.8*	0.14	0.10	0.80	15	116.3*	10.9*	127.3*	0.19	0.03	0.97	11	119.2*	10.4*	129.6*
0.000025	0.00025	0.14	0.10	0.80	15	129.9*	10.9*	140.8*	0.14	0.10	0.80	15	116.3*	10.9*	127.2*	0.19	0.03	0.97	11	119.2*	10.4*	129.6*
0.000025	0.0025	0.14	0.10	0.80	15	129.9*	10.8*	140.7*	0.14	0.10	0.80	15	116.3*	10.8*	127.1*	0.19	0.03	0.97	11	119.2*	10.4*	129.6*
0.000025	0.025	0.14	0.10	0.80	13	129.7*	9.7	139.4*	0.14	0.10	0.80	13	116.1*	9.7	125.9*	0.19	0.03	0.97	11	119.2*	10.4*	129.5*
0.00025	0.000025	0.14	0.10	0.80	15	129.2*	10.9*	140.1*	0.14	0.10	0.80	15	115.9*	10.9*	126.8*	0.19	0.03	0.97	11	118.3*	10.4*	128.8*
0.00025	0.00025	0.14	0.10	0.80	15	129.2*	10.9*	140.1*	0.14	0.10	0.80	15	115.9*	10.9*	126.8*	0.19	0.03	0.97	11	118.3*	10.4*	128.8*
0.00025	0.0025	0.14	0.10	0.80	15	129.2*	10.8*	140.0*	0.14	0.10	0.80	15	115.9*	10.8*	126.7*	0.19	0.03	0.97	11	118.3*	10.4*	128.8*
0.00025	0.025	0.14	0.10	0.80	13	129.0*	9.7	138.7*	0.14	0.10	0.80	13	115.7*	9.7	125.4*	0.19	0.03	0.97	11	118.3*	10.4*	128.7*
0.0025	0.000025	0.14	0.10	0.80	15	122.4*	10.9	133.3	0.14	0.10	0.80	15	111.4*	10.9	122.3	0.13	0.08	0.87	12	110.3*	10.5	120.8*
0.0025	0.00025	0.14	0.10	0.80	15	122.4*	10.9	133.3	0.14	0.10	0.80	15	111.4*	10.9	122.3	0.13	0.08	0.87	12	110.3*	10.5	120.8*
0.0025	0.0025	0.14	0.10	0.80	15	122.4*	10.8	133.2*	0.14	0.10	0.80	15	111.4*	10.8	122.2*	0.13	0.08	0.87	12	110.3*	10.5	120.7*
0.0025	0.025	0.14	0.10	0.80	13	122.3*	9.7*	132.1*	0.14	0.10	0.80	13	111.4*	9.7*	121.1*	0.13	0.08	0.87	12	110.3*	9.9	120.1
0.019	0.000025	0.15	0.11	0.76	13	73.3*	11.9	85.2	0.15	0.11	0.76	13	79.5*	11.9	91.4	0.23	0.08	0.78	10	57.0*	11.7*	68.8*
0.019	0.00025	0.15	0.11	0.76	13	73.3*	11.9	85.2	0.15	0.11	0.76	13	79.5*	11.9	91.4	0.23	0.08	0.78	10	57.0*	11.7*	68.7*
0.019	0.0025	0.15	0.11	0.76	13	73.3*	11.7	85.0	0.15	0.11	0.76	13	79.5*	11.7	91.3	0.23	0.08	0.78	10	57.0*	11.6*	68.6*
0.019	0.025	0.14	0.10	0.80	13	73.4*	9.7*	83.2*	0.14	0.10	0.80	13	79.7*	9.7*	89.4*	0.21	0.08	0.80	10	56.3*	10.5	66.8*

<sup>1</sup> Shaded cells highlight the highest of the cattle owner's and feeder's certainty equivalents (CE) among live weight, dressed weight, and grid pricing methods; Cells with asterisks indicate cases in which the CE with the unrestricted parameter space dominates the CE with the restricted parameter space.

<sup>2</sup> Strategy 10 is 60% corn and a moderate implant; 11 is 70% corn and a moderate implant; 12 is 80% corn and a moderate implant; 13 is 30% corn and an aggressive implant; 15 is 50% corn and an aggressive implant.

**Table 7.3: Optimal contracts, feeding strategies, and certainty equivalents (CE) of the owner and feeder ( $\alpha \geq 0, \beta \geq 0, \gamma = 0; \alpha \geq 0, \beta = 0, \gamma \geq 1$ ).**

Absolute Risk		Live Weight Pricing							Dressed Weight Pricing							Grid Pricing						
Aversion Coeff.		Optimal Parameters			Strat-	Certainty Equivalent <sup>1</sup>			Optimal Parameters			Strat-	Certainty Equivalent			Optimal Parameters			Strat-	Certainty Equivalent		
Owner	Feeder	$\alpha$	$\beta$	$\gamma$	egy <sup>2</sup>	Owner	Feeder	Total	$\alpha$	$\beta$	$\gamma$	egy <sup>2</sup>	Owner	Feeder	Total	$\alpha$	$\beta$	$\gamma$	egy <sup>2</sup>	Owner	Feeder	Total
0	0	0.05	0.00	1.19	12	111.5	10.4	121.9	0.05	0.00	1.19	12	98.0	10.4	108.3	0.05	0.00	1.19	12	119.1	10.4*	129.4
0	0.000025	0.05	0.00	1.19	12	111.5	10.3	121.9	0.05	0.00	1.19	12	98.0	10.3	108.3	0.05	0.00	1.19	12	119.1	10.3	129.4
0	0.00025	0.05	0.00	1.19	12	111.5	10.3	121.9	0.05	0.00	1.19	12	98.0	10.3	108.3	0.05	0.00	1.19	12	119.1	10.3	129.4
0	0.0025	0.05	0.00	1.19	12	111.5	10.2	121.8	0.05	0.00	1.19	12	98.0	10.2	108.2	0.05	0.00	1.19	12	119.1	10.2	129.3
0	0.025	0.05	0.00	1.19	12	111.5	9.1	120.6	0.05	0.00	1.19	12	98.0	9.1	107.1	0.05	0.00	1.19	12	119.1	9.1	128.2
0.000025	0	0.16	0.00	1.09	12	111.4	10.4	121.8	0.16	0.00	1.09	12	97.9	10.4	108.2	0.16	0.00	1.09	12	119.0	10.4*	129.3
0.00025	0	0.16	0.00	1.09	12	109.4	10.4	119.8	0.16	0.00	1.09	12	96.1	10.4	106.5	0.16	0.00	1.09	12	116.9	10.4*	127.3
0.0025	0	0.00	0.40	0.00	13	99.6	30.6*	130.2	0.00	0.40	0.00	13	88.6	30.6*	119.2	0.26	0.00	1.00	10	107.0	11.1*	118.2
0.019	0	0.00	0.40	0.00	13	27.6	30.6*	58.2	0.00	0.40	0.00	13	33.7	30.6*	64.3	0.26	0.00	1.00	10	34.5	11.1	45.6
0.000025	0.000025	0.16	0.00	1.09	12	111.4	10.4	121.8	0.16	0.00	1.09	12	97.9	10.4	108.2	0.16	0.00	1.09	12	119.0	10.4*	129.3
0.000025	0.00025	0.16	0.00	1.09	12	111.4	10.4	121.8	0.16	0.00	1.09	12	97.9	10.4	108.2	0.16	0.00	1.09	12	119.0	10.4*	129.3
0.000025	0.0025	0.16	0.00	1.09	12	111.4	10.3	121.8	0.16	0.00	1.09	12	97.9	10.3	108.2	0.16	0.00	1.09	12	119.0	10.3	129.3
0.000025	0.025	0.16	0.00	1.09	12	111.4	10.1*	121.5	0.16	0.00	1.09	12	97.9	10.1*	108.0	0.16	0.00	1.09	12	119.0	10.1	129.0
0.00025	0.000025	0.16	0.00	1.09	12	110.5	10.4	120.9	0.16	0.00	1.09	12	97.2	10.4	107.6	0.16	0.00	1.09	12	118.1	10.4*	128.4
0.00025	0.00025	0.16	0.00	1.09	12	110.5	10.4	120.9	0.16	0.00	1.09	12	97.2	10.4	107.6	0.16	0.00	1.09	12	118.1	10.4*	128.4
0.00025	0.0025	0.16	0.00	1.09	12	110.5	10.3	120.9	0.16	0.00	1.09	12	97.2	10.3	107.6	0.16	0.00	1.09	12	118.1	10.3	128.4
0.00025	0.025	0.16	0.00	1.09	12	110.5	10.1*	120.6	0.16	0.00	1.09	12	97.2	10.1*	107.3	0.16	0.00	1.09	12	118.1	10.1	128.1
0.0025	0.000025	0.00	0.40	0.00	13	103.5	30.6*	134.0*	0.00	0.40	0.00	13	92.5	30.6*	123.1*	0.26	0.00	1.00	10	109.4	11.1*	120.6
0.0025	0.00025	0.00	0.40	0.00	13	103.5	30.3*	133.8*	0.00	0.40	0.00	13	92.5	30.3*	122.9*	0.26	0.00	1.00	10	109.4	11.1*	120.6
0.0025	0.0025	0.00	0.40	0.00	13	103.5	28.0*	131.5	0.00	0.40	0.00	13	92.5	28.0*	120.6	0.26	0.00	1.00	10	109.4	11.1*	120.6
0.0025	0.025	0.00	0.40	0.00	13	103.5	5.1	108.5	0.00	0.40	0.00	13	92.5	5.1	97.6	0.26	0.00	1.00	10	109.4	11.1*	120.5*
0.019	0.000025	0.00	0.40	0.00	13	60.4	30.6*	90.9*	0.00	0.40	0.00	13	66.9	30.6*	97.5*	0.26	0.00	1.00	10	49.2	11.1	60.3
0.019	0.00025	0.00	0.40	0.00	13	60.4	30.3*	90.7*	0.00	0.40	0.00	13	66.9	30.3*	97.2*	0.26	0.00	1.00	10	49.2	11.1	60.3
0.019	0.0025	0.00	0.40	0.00	13	60.4	28.0*	88.4*	0.00	0.40	0.00	13	66.9	28.0*	94.9*	0.26	0.00	1.00	10	49.2	11.1	60.3
0.019	0.025	0.00	0.40	0.00	13	60.4	5.1	65.4	0.00	0.40	0.00	13	66.9	5.1	71.9	0.26	0.00	1.00	10	49.2	11.1*	60.3

<sup>1</sup> Shaded cells highlight the highest of the cattle owner's and feeder's certainty equivalents (CE) from live weight, dressed weight, and grid pricing methods; Cells with asterisks indicate cases in which the CE with the restricted parameter space dominates the CE with the unrestricted parameter space.

<sup>2</sup> Strategy 10 is 50% corn with a moderate implant; 12 is 80% corn with a moderate implant; 13 is 30% corn with an aggressive implant.



the results of the search over the parameter space restricted by typical contract forms ( $\alpha \geq 0, \beta \geq 0, \gamma = 0$ ; and  $\alpha \geq 0, \beta = 0, \gamma \geq 1$ ).<sup>43</sup> In general, the results indicate that the optimal choices of cattle feeding contracts vary mainly with the incentive structure of alternative fed cattle pricing methods. In particular, the power of the optimal incentive scheme for cattle feeding (i.e., the degree of incentive for cost saving) is lower under value-based grid pricing than under traditional live- and dressed-weight pricing methods.

The value-based grid pricing of fed cattle offers premiums (discounts) for higher (lower) yield, as well as for superior (inferior) quality of the carcass. Traditional live and dressed-weight pricing mechanisms do not provide any systematic incentives for carcass quality. Live-weight pricing provides an incentive for live weight gain, while dressed-weight pricing offers a premium (discount) for higher (lower) yield. For a given target harvest weight, the traditional pricing methods simply provide a cost saving incentive. The cattle owner with any of these fed cattle pricing objectives transmits the embedded incentive structure of the chosen pricing method to the feeder through a payment scheme that induces the feeder to adopt a particular ration-implant strategy that produces desired outcomes at minimum cost.

As explained in Section 7.2, the cattle feeder's incentive for cost saving (carcass quality improvement) increases (decreases) with the payment per pound of gain ( $\beta$ ) and decreases (increases) with the yardage fee per animal head per day ( $\alpha$ ) and the owner's share of feed cost ( $\gamma$ ). Since feed cost accounts for a major share (70-80 percent) of the total cost of feeding, the cattle feeder's choice for a particular feeding strategy crucially

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<sup>43</sup> The optimal contract coefficients and corresponding cattle feeding strategies remain the same when the cattle performance data are evaluated with January-June seasonal prices. The structure of the optimal incentive scheme is similar for the TCSCF cattle placed in October and December evaluated with January-April and March-June seasonal prices, respectively.

depends on his share of feed cost. The cost of feed required for a target weight gain increases with the grain content of the ration and decreases with the potency of the growth promoting implant. Thus, for a given harvest weight, total feed cost is the highest with ration-implant Strategy 12 (80 percent corn with a moderate implant) and the lowest with Strategy 13 (30 percent corn with an aggressive implant strategy).<sup>44</sup> On the other hand, for a given harvest weight, carcass quality is the highest with Strategy 12 and the lowest with Strategy 13. The results in Table 7.2 and 7.3 indicate that, the feeder chooses a relatively less costly strategy when fed cattle are to be marketed using any of the traditional pricing methods, and a relatively costly strategy yielding higher carcass quality when fed cattle are sold through the grid pricing system.<sup>45</sup> Obviously, the power of the optimal incentive scheme (i.e., the incentive for cost saving) under value-based grid pricing is lower than the power of the schemes that are optimal under traditional live- and dressed-weight pricing methods.

The optimal choice of contract and production technology also depends on the risk aversion levels of the contracting parties. In particular, the results indicate that the power of the incentive for cost saving (carcass quality improvement) increases (decreases) with the cattle owner's risk aversion level, but the effect of the feeder's risk

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<sup>44</sup> Although 30 percent corn may seem very low, a 1999 survey of feedlots in Nebraska (Feuz and Umberger, 2001) reported that grain percentage varied considerably in typical feedlot rations. While corn grain accounted for 60 percent-80 percent of feedlot rations in general, some feedlots used as low as 30 percent corn in the ration for 500-699 pound cattle. Furthermore, 30 percent corn rations are optimal in Tables 7.2 and 7.3 only when risk aversion for the feeder or owner is high.

<sup>45</sup> The results show that the feeder has a strong tendency to choose an aggressive implant strategy and/or a lower grain ration whenever his share of the feed cost is significant. However, cattle feeding without an implant is not found to be optimal in any of the cases considered in this study.

aversion on the incentive scheme is minimal.<sup>46</sup> While these results confirm the predictions of the multitask model presented in Chapter 4 and are consistent with reality, other major findings and their implications are discussed in detail below.

### ***Optimal Contracts in the Unrestricted Parameter Space***

The upper panel of Table 7.2 shows the results for cases when the cattle owner is risk neutral ( $\psi = 0$ ). Comparing the values of  $\alpha$ ,  $\beta$ , and  $\gamma$  under alternative fed cattle pricing methods, the power of the optimal incentive scheme with grid pricing ( $\alpha = 0.19$ ,  $\beta = 0.03$ ,  $\gamma = 0.97$ ) is lower than what is optimal with live- and dressed-weight pricing ( $\alpha = 0.14$ ,  $\beta = 0.10$ ,  $\gamma = 0.80$ ). This is also evident from the relatively costly ration-implant strategy adopted by the feeder under grid pricing (Strategy 11: 70 percent corn with a moderate implant), while a less costly strategy (Strategy 15: 50 percent corn with an aggressive implant) is optimal under traditional pricing methods. Incentive compatibility implies that the particular compensation scheme under grid pricing provides a lower incentive for cost saving than the one under live- or dressed-weight pricing methods. With a risk-neutral cattle owner, the values of the optimal contract coefficients do not change with the risk preference of the feeder. However, for a very highly risk-averse cattle feeder ( $\varphi = 0.025$ ), a relatively less costly feeding strategy (Strategy 13: 30 percent corn with an aggressive implant) is optimal under traditional pricing methods.

The middle panel of Table 7.2 shows the results for cases when the feeder is risk neutral ( $\varphi = 0$ ) but the owner is risk averse ( $\psi > 0$ ). In these cases, the feeder's optimal strategies (Strategies 13 and 15) for the compensation schemes with traditional pricing

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<sup>46</sup> In the remainder of this section, the power of the incentive scheme refers to the power of the cattle feeder's incentive for cost saving.

methods are less costly than the strategies (Strategies 10, 11, and 12) that are optimal for the payment schemes with grid pricing. The feeder's choice for costly feeding strategies under grid pricing implies that these cattle feeding contracts provide less incentive for cost saving in order to provide incentives for improving carcass quality.

The lower panel of Table 7.2 shows the optimal contract coefficients and corresponding cattle feeding strategies when both the feeder and owner are risk averse ( $\varphi > 0, \psi > 0$ ).

The values of  $\alpha, \beta,$  and  $\gamma$  along with the corresponding feeding strategies imply that the incentive for cost saving is lower with the contracts under grid pricing than the contracts under live and dressed pricing. For each of the risk aversion scenarios, relatively lower grain rations with an aggressive implant (Strategies 13 and 15) are found to be optimal under traditional fed cattle pricing methods, while higher grain rations with a moderate implant (Strategies 10, 11, and 12) are optimal under grid pricing.

In general, the incentive for cost saving increases with the cattle owner's and feeder's risk aversion levels. This effect, however, is not continuous and obvious only when the contracting parties are highly risk averse.<sup>47</sup> The incentive structure of the optimal cattle feeding contract is apparently insensitive to the level of the feeder's risk aversion (Table 7.2). For traditional pricing methods, a very high level of risk aversion on the cattle feeder's part (e.g.,  $\varphi = 0.025$ ) alters the optimal ration-implant strategy without changing the values of the contract coefficients. On the other hand, a high level of risk aversion on the cattle owner's part ( $0.0025 \leq \psi$ ) alters the optimal incentive scheme as well as the feeding strategy. With live- and dressed-weight pricing of fed cattle, Strategy 13 (30 percent corn with an aggressive implant) appears to be optimal if either the owner

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<sup>47</sup> Only five risk aversion levels of the feeder and owner are reported in Tables 7.2 and 7.3: no risk aversion ( $\varphi = 0, \psi = 0$ ), low risk aversion ( $\varphi = 0.000025, \psi = 0.000025$ ), moderate risk aversion ( $\varphi = 0.00025, \psi = 0.00025$ ), high risk aversion ( $\varphi = 0.0025, \psi = 0.0025$ ), and very high risk aversion ( $\varphi = 0.025, \psi = 0.019$ ).

or the feeder is highly risk averse, while Strategy 15 (50 percent corn with an aggressive implant) is optimal in all other risk aversion scenarios.

For the value-based grid pricing method, the incentive structure of optimal cattle feeding contracts does not change with the level of the feeder's risk aversion (Table 7.2). On the other hand, the effect of the cattle owner's risk aversion on the optimal incentive scheme with grid pricing is ambiguous depending on the level of the owner's risk aversion. The value of  $\beta$  increases and  $\alpha$  and  $\gamma$  decrease with the cattle owner's risk aversion level within a moderate to high range ( $0.00025 \leq \psi \leq 0.0025$ ), thus providing a higher incentive for cost saving. But a relatively more costly strategy (Strategy 12 instead of Strategy 11) becomes optimal for the feeder although the incentive for cost saving is higher. However, the value of  $\alpha$  increases and  $\gamma$  decreases, with  $\beta$  remaining the same, as the cattle owner becomes more risk averse ( $0.0025 < \psi \leq 0.019$ ). The corresponding feeding strategy (Strategy 10: 60 percent corn with a moderate implant) implies that the power of the incentive scheme is higher when the level of the owner's risk aversion is very high. Thus, with the value-based grid pricing system and the unrestricted contract parameter space, the power of the optimal incentive scheme decreases first for a certain range of the owner's risk aversion level ( $0.00025 \leq \psi \leq 0.0025$ ), and then increases ( $0.0025 \leq \psi \leq 0.019$ ). Non-concavity of the profit functions at the optimum is a plausible explanation for this inconsistency, which is not apparent with the restricted contract parameter space.

### *Optimal Contracts in the Restricted Parameter Space*

The search over the restricted parameter space  $[(\alpha \geq 0, \beta \geq 0, \gamma = 0) \text{ and } (\alpha \geq 0, \beta = 0, \gamma \geq 1)]$  corresponds to typical contracts observed in commercial cattle feeding. The optimal contract coefficients presented in Table 7.3 show that, for each combination of risk preferences of the feeder and owner, the power of the optimal incentive scheme with grid pricing is either the same or lower than those that are optimal with traditional fed cattle pricing methods. The power of the optimal incentive scheme increases with the cattle owner's risk aversion level, while risk aversion on the feeder's part does not have any effect on the optimal choice of contracts or ration-implant strategies. In particular, as long as the cattle owner is not highly risk averse, the value of the optimal contract coefficients and corresponding cattle feeding strategies are the same under each of the fed cattle pricing methods. For a highly risk-averse cattle owner, a very high powered incentive contract (e.g., a cost-of-gain contract) is optimal under live- and dressed-weight pricing methods, while a typical yardage-fee-plus-feed-cost contract with a zero incentive for cost saving is optimal under grid pricing.

The upper panel of Table 7.3 shows optimal values of the contract coefficients, corresponding ration-implant strategies, and resulting certainty equivalents when the cattle owner is risk neutral. Irrespective of the feeder's risk preference, the optimal contracts and ration-implant strategies are found to be the same under all three fed cattle pricing methods. The optimal strategy for a risk-neutral owner is to pay a yardage fee of \$0.05 per animal per day plus the total feed cost with a 19 percent markup, which induces the feeder to produce the highest quality carcass, which incurs the most costly feeding strategy (Strategy 12: 80 percent corn with a moderate implant). The middle and lower

panels of Table 7.3 show that the yardage fee ( $\alpha$ ) increases and payment for feed cost ( $\gamma$ ) decreases with the level of the cattle owner's risk aversion. A yardage fee of \$0.16 per animal per day with a 9 percent markup on the feed cost is optimal for a low to moderately risk-averse cattle owner ( $0.000025 \leq \psi \leq 0.00025$ ) under each of the fed cattle pricing methods. For a high level of risk aversion on the owner's part, the cost-of-gain contract ( $\alpha = 0, \beta = 0.40, \gamma = 0$ ) is optimal under traditional live and dressed pricing, while a contract with a higher yardage fee and full reimbursement for feed cost without a markup ( $\alpha = 0.26, \beta = 0, \gamma = 1.00$ ) is optimal under grid pricing. These payment schemes resemble the ones typically observed in reality, which implies that the model helps to explain contract variation observed in reality. Although the restricted parameter space allows for linear incentive contracts ( $\alpha > 0, \beta > 0$ ), such contracts are never found to be optimal by the model and are hardly observed in reality.

The use of an aggressive implant is optimal only when cattle are fed under a cost-of-gain contract. A moderate implant strategy is always optimal under yardage-fee-plus-feed-cost contracts. The choice of yardage fee and the markup on feed cost vary with risk preferences of the cattle owner and the fed cattle pricing methods. Only restricted contracts are observed in practice and the level of the feeder's risk aversion does not alter the optimal payment scheme or the feeding strategy. Adoption of a particular payment scheme with a particular fed cattle pricing objective reflects the level of risk aversion of the cattle owner.

### ***Comparison of the Restricted and Unrestricted Contracts***

In both the restricted and unrestricted parameter spaces, the optimal contract coefficients and corresponding production technologies (i.e., ration-implant strategies) with live- and dressed-weight pricing methods are identical for each of the risk aversion scenarios (Tables 7.2 and 7.3). This is due to the similar incentive structures of live- and dressed-weight pricing of fed cattle. As mentioned earlier, live-weight pricing provides an incentive for live weight gain and dressed-weight pricing offers an incentive for carcass weight gain. According to the biophysical growth model, carcass weight is a linear function of the live body weight of an animal. Thus, when live weight is an exogenous specification of the contract, the incentive structures of these pricing methods are similar. Although the revenues under live- and dressed-weight pricing methods vary with the difference between the actual and estimated dressing percentages, the difference in revenues under these traditional pricing systems does not alter the values of the contract coefficients at the optimum.

Comparing the values of unrestricted contract coefficients ( $\alpha$ ,  $\beta$ , and  $\gamma$ ) and corresponding feeding strategies under traditional and modern fed cattle pricing methods, the optimal compensation schemes and production technologies under grid pricing are different than those that are optimal under traditional pricing methods (Table 7.2). This is because the incentive structure of grid pricing is fundamentally different than the incentive structure of traditional pricing methods. In addition to the premium (discount) for higher (lower) yield, grid pricing also offers premiums (discounts) for higher (lower) carcass quality. This result validates the primary hypothesis of this study that the optimal incentive structure for cattle feeding contracts varies with the incentive structure of



alternative fed cattle pricing methods. With the restricted parameter space, however, optimal contracts and corresponding production technologies are the same unless the cattle owner is highly risk averse (i.e.,  $\psi \geq 0.0025$ ).

### ***Comparison of the Cattle Owner's and Feeder's Welfare with Unrestricted and Restricted Contracts***

Certainty equivalents of the feeder (hereafter FCE), the owner (hereafter OCE), and the total certainty equivalents (sum of the feeder's and owner's certainty equivalents, hereafter TCE) for each of the fed cattle pricing methods and risk preference scenarios are also reported in Tables 7.2 and 7.3. The TCEs with asterisks indicate preferable contracts for each of the pricing methods. Comparing the TCEs between restricted and unrestricted parameter spaces, the restriction on the parameter space (i.e., limiting the choice of compensation schemes) reduces TCE with each of the marketing environments under most of the risk preference scenarios. While the deadweight loss is a natural consequence of constrained optimization, the direction and magnitude of the change in TCE depend mainly on the risk preferences of the contracting parties and fed cattle pricing methods.

Under traditional fed cattle pricing methods, unrestricted contracts strictly dominate restricted ones (in terms of TCE) as long as either the owner or the feeder is risk neutral. Restricted contracts strictly dominate unrestricted ones when the cattle owner is highly risk averse (i.e.,  $\psi = 0.0025$ ) and the feeder has low to moderate level of risk aversion (e.g.,  $0.000025 \leq \varphi \leq 0.00025$ ), and also when the owner is very highly

risk-averse but the feeder is not very highly risk-averse (i.e.,  $0.000025 \leq \varphi \leq 0.0025$ ).<sup>48</sup> In such cases, TCEs under the traditional pricing methods are slightly higher with the restricted contracts than the TCEs with the unrestricted ones. Under grid pricing, unrestricted contracts strictly dominate restricted ones except for one risk aversion scenario ( $\varphi = 0.025$  and  $\psi = 0.0025$ ). Such a high level of risk aversion, however, is unlikely on the part of a typical custom cattle feeder. Thus, restricted contracts achieve higher total welfare than unrestricted contracts with traditional fed cattle pricing methods only if cattle owners tend to have high risk aversion while cattle feeders have moderate risk aversion.

Also from Tables 7.2 and 7.3, the loss (gain) of TCE due to the restriction on the contract parameter space is large (small) with traditional pricing methods, while the magnitude of loss is very small with grid pricing except when the owner is very highly risk averse ( $\psi = 0.019$ ). The magnitude of the loss (gain) in TCE increases (decreases) with the risk aversion levels of the contracting parties. However, the effect of the owner's risk aversion on TCE is much larger than that of the feeder's risk aversion.

The deadweight loss due to the restriction on the contract parameter space corresponds to the change in optimal feeding strategies. The loss is higher for a change in the optimal implant strategy than the loss due to a change in the proportion of feed ingredients in the ration. For grid pricing, optimal implant strategies under alternative risk aversion scenarios remain the same with the restricted and unrestricted contracts. The restriction on the contract parameter space alters the optimal grain content of ration only slightly. On the other hand, for traditional fed cattle pricing methods, optimal implant

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<sup>48</sup> In most optimization problems restricted maximization yields a smaller optimum than unrestricted maximization. In this case, however, the maximization is not over TCE. Rather, the owner chooses the contract parameters to maximize OCE, which is why TCE can be higher in the restricted case.

strategies remain the same under the restricted and unrestricted contracts only if the cattle owner is highly risk averse (i.e.,  $\psi \geq 0.0025$ ). If the owner has low to moderate risk aversion (i.e.,  $0 \leq \psi \leq 0.00025$ ), then an aggressive implant strategy with a relatively low-grain ration (Strategy 15) is optimal with unrestricted contracts, while a moderate implant strategy with a high-grain ration (Strategy 12) is optimal with restricted contracts. While the optimal feeding strategy with unrestricted contracts changes with a very high level of risk aversion by the feeder, the risk preference of the feeder does not alter the choice of optimal feeding strategy among restricted contracts.

The changes in FCE and OCE due to the restriction on the contract parameter space, however, do not follow the same pattern as of the change in TCE. In tables 7.2 and 7.3, the FCEs with asterisks indicate the feeder's preference and the OCEs with asterisks indicate the cattle owner's preference between the restricted and unrestricted contracts for each of the fed cattle pricing methods. For each of the risk aversion scenarios, the OCEs with the unrestricted contracts are higher than the OCEs with the restricted contracts under each of the fed cattle pricing methods. Thus, the owner always prefers the unrestricted contracts. This result is as expected because the owner chooses the contract parameters where every choice in the restricted parameter space is also available to the owner in the unrestricted case.<sup>49</sup>

The feeder's preference between the restricted and unrestricted contracts varies with the risk preferences of the contracting parties, especially the cattle owner. With traditional fed cattle pricing methods, a risk-neutral cattle feeder (i.e.,  $\varphi = 0$ ) prefers the unrestricted contracts unless the owner is highly risk averse (i.e.,  $\psi < 0.0025$ ) and a risk-

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<sup>49</sup> This is classical result where restricted maximization yields an optimum no larger than unrestricted maximization.

averse feeder (i.e.,  $\varphi > 0$ ) prefers unrestricted contracts unless either the feeder is very highly risk averse (i.e.,  $\varphi = 0.025$ ) or the owner is highly (i.e.,  $\psi \geq 0.0025$ ) risk averse. A high level of risk aversion on the cattle owner's part improves FCE significantly in the restricted case relative to the unrestricted case unless the feeder is very highly risk averse. In such cases, cost-of-gain contracts are optimal and transfer a large amount of surplus from the owner to the feeder. For a risk-neutral cattle feeder (i.e.,  $\varphi = 0$ ) and a moderately risk-averse owner (i.e.,  $\psi = 0.00025$ ), FCEs under the unrestricted and restricted contracts are similar, \$10.9 and \$10.4, respectively. In contrast, if the owner is highly risk averse (i.e.,  $\psi \geq 0.0025$ ), then the risk-neutral feeder's FCE under the unrestricted and restricted contracts are \$10.9 and \$30.6, respectively. Comparing the corresponding OCEs under these scenarios, a highly risk-averse owner pays a high risk premium, a major part of which is recouped by the feeder unless he is also very highly risk averse.

Under grid pricing, restricted and unrestricted FCEs are almost the same for low to moderate levels of risk aversion by the cattle feeder and owner (i.e.,  $\varphi, \psi \leq 0.00025$ ). Restricted FCEs are higher with grid pricing when the owner is highly risk averse (i.e.,  $\psi = 0.0025$ ). With the restricted parameter space, the yardage fee ( $\alpha$ ) increases and the owner's share of feed cost ( $\gamma$ ) decreases with the owner's risk aversion level. For a high level of risk aversion by the owner (i.e.,  $\psi = 0.0025$ ),  $\alpha$  reaches its feasible maximum with  $\gamma = 1$ . While a very high level of risk aversion by the owner tends to increase  $\alpha$  and decrease  $\gamma$  further, such cases fall outside the restrictions of sensibility on the contract parameter space. The feeder also prefers restricted contracts when both of the contracting parties are very highly risk averse (i.e.,  $\varphi = 0.025$  and  $\psi = 0.019$ ).

In the case of OCE, the restriction on the contract parameter space substantially reduces owner benefits under live and dressed-weight pricing for each of the risk preference combinations. However, the magnitude of the loss with grid pricing is much smaller. In particular, the loss of OCE due to the restriction on the contract parameter space is minor under grid pricing unless the owner is highly risk averse (i.e.,  $\psi \geq 0.0025$ ). For low to moderate levels of risk aversion by the cattle owner (e.g.,  $0.000025 \leq \varphi \leq 0.00025$ ), the loss of OCE due to the restriction is about \$18.4 under traditional pricing, while the loss under grid pricing is only \$0.02. On the other hand, for a very highly risk-averse cattle owner, the losses of OCE under traditional and grid pricing mechanisms are \$12.9 and \$7.8, respectively.

Thus, for low to moderate levels of risk aversion, the cattle owner remains nearly indifferent between the restricted and unrestricted contracts with grid pricing, while the owner strictly prefers unrestricted contracts with the traditional pricing of fed cattle. This rough equivalence for the owner is remarkable given that the unrestricted contract choice must dominate the restricted choice for the owner by construction. For the same range of risk aversion levels, the feeder also remains indifferent between the restricted and unrestricted contracts with grid pricing. For traditional pricing methods, however, the feeder slightly prefers unrestricted contracts, while he strongly prefers restricted contracts at higher levels of risk aversion. Thus, compared to traditional pricing methods, grid pricing is clearly demonstrated to better align the incentives of the feeder and owner.

### *The Cattle Owner's Preference between Traditional and Grid Pricing Systems*

The highlighted OCEs in Tables 7.2 and 7.3 indicate the fed cattle pricing method preferred by the cattle owner with unrestricted and restricted contract forms, respectively. With unrestricted contracts, the cattle owner prefers live-weight pricing of fed cattle as long as she is not very highly risk averse (i.e.,  $\psi < 0.019$ ). The cattle owner prefers dressed-weight pricing with unrestricted contracts only when she is very highly risk averse (e.g.,  $\psi = 0.019$ ). Interestingly, grid pricing with unrestricted contracts is not preferable by the owner in any of the risk preference scenarios. This is contrary to the principle that greater information should improve market efficiency under grid pricing. But this outcome is plausible because the owner does not attempt to maximize TCE.

Average revenues, costs, and total profit per animal under alternative fed cattle pricing methods and ration-implant strategies are reported in Table 7.4. The average revenue per animal from dressed-weight pricing (\$798.14) is lower than the average revenue from live-weight pricing (\$811.71) because the actual yield (dressing percentage) of the carcass is lower than the estimated yield (implied by the live and dressed-weight price series). While the estimated yield is 62.30 percent, the simulated average yield of the TCSCF cattle is found to be 61.49 percent.<sup>50</sup> Consequently, the revenue from dressed-weight pricing is lower than the revenue under live-weight pricing on average. This is reflected in the certainty equivalents of the risk-neutral feeder and owner as reported in Table 7.2. Average total profits represented by bold fonts in Table 7.4 correspond to TCEs of the risk-neutral owner and feeder in Table 7.2.

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<sup>50</sup> The actual average yield reported by TCSCF was 61.29 percent. The simulated average dressing percentage is slightly higher because, in the growth simulation for optimization purposes, expected final shrunk body weights (*EFSBW*) are used instead of actual final shrunk body weights (*FSBW*) reported by TCSCF.

**Table 7.4: Average revenues, costs, and profits per animal under alternative fed cattle pricing methods and cattle feeding strategies.**

Feeding Strategies <sup>1</sup>	Average Revenue (US\$)			Average Cost <sup>5</sup> (US\$)		Average Profit (US\$)		
	Live <sup>2</sup>	Dressed <sup>3</sup>	Grid <sup>4</sup>	Feed	Feeder Cattle	Live	Dressed	Grid
Strategy 10	811.71	798.14	819.15	271.64	417.82	122.25	108.68	129.69
<b>Strategy 11</b>	811.71	798.14	819.15	272.18	417.32	122.21	108.64	<b>129.65</b>
Strategy 12	811.71	798.14	819.15	272.92	416.88	121.92	108.35	129.36
Strategy 13	811.71	798.14	746.75	253.81	417.26	140.64	127.07	75.68
Strategy 14	811.71	798.14	746.75	254.37	416.64	140.70	127.13	75.74
<b>Strategy 15</b>	811.71	798.14	746.75	254.74	416.08	<b>140.89</b>	<b>127.32</b>	75.93
Strategy 16	811.71	798.14	746.75	255.40	415.57	140.74	127.17	75.78
Strategy 17	811.71	798.14	746.75	255.83	415.12	140.77	127.20	75.81
Strategy 18	811.71	798.14	746.75	256.50	414.71	140.50	126.93	75.54

<sup>1</sup> Strategy 10: 60% corn, moderate implant; Strategy 11: 70% corn, moderate implant; Strategy 12: 80% corn, moderate implant; Strategy 13: 30% corn, aggressive implant; Strategy 14: 40% corn, aggressive implant; Strategy 15: 50% corn, aggressive implant; Strategy 16: 60% corn, aggressive implant; Strategy 17: 70% corn, aggressive implant; Strategy 18: 80% corn, aggressive implant.

<sup>2</sup> Average revenue from live-weight pricing is the same for each of the ration-implant strategies because of the lot-average nature of the pricing method.

<sup>3</sup> Average revenue under dressed-weight pricing is lower than the average revenue under live-weight pricing because of the difference between actual dressing percentage (61.49 percent) and estimated dressing percentage (62.30 percent).

<sup>4</sup> Grid revenue for ration-implant strategies 10-12 (moderate implant) is higher than the revenue for strategies 13-18 (aggressive implant) because average quality of the carcasses is "Choice" with a moderate implant while it is "Select" with an aggressive implant.

<sup>5</sup> Feed and feeder cattle costs include 9.0 percent interest over the feeding period.

Although the formula for establishing the base price of the grid also uses the estimated dressing percentage to calculate the value of each carcass, the average revenue from the grid (\$819.15, when the average quality of the carcasses is "Choice") is higher

than the average revenue from dressed pricing.<sup>51</sup> This is mainly because of the additional dollar for each 100 pounds of carcass in the grid base formula and the beef quality premium earned on average. While the average revenue from grid pricing is higher than the average revenue earned with live-weight pricing of fed cattle, grid pricing is still not preferred by the cattle owner.

A sensible explanation for the poor overall performance of grid pricing among unrestricted contracts appears to be some combination of asymmetry of discounts versus premiums and the additional risk for owners associated with *ex post* pricing under risk aversion. Discounts in a typical grid are much larger than premiums. Quality grade premiums per 100 pounds of carcass range from \$1 to \$6, but discounts are usually \$15 to \$25 and more. Thus, one discounted animal can easily offset the premiums earned on several premium animals. With this system of premiums and discounts in grid pricing, *ex post* information about carcass yield and quality adds to price risk, which leads to lower expected prices and lower certainty equivalents of the risk-averse owner and feeder.

The results in Table 7.2 show that the OCEs with grid pricing are lower than with live-weight pricing even in the risk-neutral case. This is because the additional cost of ensuring beef quality is higher than the expected additional revenue earned from the grid.<sup>52</sup> On average, carcasses failed to earn a positive premium in the grid. With given harvest body weights, “Choice” is the highest average carcass quality attained using ration-implant Strategies 10-12, while Strategies 13-18 produced “Select” carcasses on

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<sup>51</sup> The estimated dressing percentage used in the formula to establish the grid base price is obtained by regressing historical live weight prices on dressed-weight pricing without the intercept term. Some packing plants instead use plant average dressing percentage.

<sup>52</sup> Tables 7.2 and 7.3 show that, when fed animals are to be priced on the grid, the cattle owner induces the feeder to adopt a moderate implant strategy with a high grain ration (Strategies 10-12), which produces “Choice” carcasses on average.



average. Average revenue per animal from grid pricing is \$819.15 when the average quality of carcasses is “Choice” and \$746.75 when the average quality is “Select”. Thus, the average discount per animal for a lower quality grade is substantial. In order to avoid this discount in the grid, the cattle owner not only pays extra rents to the feeder for inducing a quality-ensuring feeding strategy but also pays an extra premium to avoid increased price risk. Thus, the owner is worse off with grid pricing under risk neutrality.

With restricted contracts, the cattle owner prefers grid pricing to traditional live- and dressed-weight pricing unless she is very highly risk averse ( $\psi < 0.019$ ). With low to moderate levels of risk aversion by the cattle owner, OCEs under grid pricing with restricted contracts are significantly higher than those under traditional pricing methods. This is because the deadweight loss due to the restriction on the contract parameter space is attributed mostly to the cattle owner, while the loss is substantial under the traditional pricing methods but trivial under grid pricing. A very highly risk-averse cattle owner (i.e.,  $\psi = 0.019$ ) prefers dressed-weight pricing to live-weight and grid pricing with restricted contracts only if the feeder is not risk neutral.

Given the structure of premiums and discounts for various carcass traits, profitability under grid pricing crucially depends on the difference between the actual and estimated dressing percentage used in establishing the base price in the grid. With further investigation I have found that, even under restricted contracts, the cattle owner prefers live-weight to grid pricing if the actual yield is slightly lower (e.g., 61.00 percent) or if the estimated yield is slightly higher (e.g., 62.80 percent). On the other hand, even with unrestricted contracts, the cattle owner remains indifferent between traditional and grid pricing systems with unrestricted contracts if actual and estimated yields are

approximately the same. The owner prefers grid pricing with unrestricted contracts if the actual yield exceeds the estimated yield.

Between the two traditional pricing methods, the cattle owner prefers live-weight pricing to dressed-weight pricing with restricted contracts. This is because the average revenue from live-weight pricing is higher than the average revenue from dressed-weight pricing as actual carcass yield (61.49 percent) is lower than the estimated yield (62.30 percent). Cattle owners are likely to prefer live-weight pricing as long as their expected yield is lower than the estimated yield (implied by the historical live- and dressed-weight price series). Thus, uncertainty about carcass yield and quality might be a reason for the predominance of live-weight pricing in fed cattle marketing.

### ***The Cattle Feeder's Preference between Unrestricted and Restricted Contract Forms***

The highlighted FCEs in Tables 7.2 and 7.3 indicate the cattle feeder's preference between unrestricted and restricted parameter spaces (contract forms) given that the cattle owner then chooses her most preferred fed cattle pricing method and contract parameters given one of these forms.<sup>53</sup> If the cattle feeder chooses the contract form (can restrict the parameter space), even though the owner chooses the contract parameters, these would reflect the chosen contract forms and pricing methods for each of the risk preference scenarios. As indicated by the highlighted OCEs in Tables 7.2 and 7.3, the cattle owner prefers live-weight pricing with unrestricted contracts and grid pricing with restricted contracts as long as she is less than very highly risk averse (i.e.,  $\psi < 0.019$ ). If the cattle

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<sup>53</sup> This choice sequence seems to fit reality while reversing these choices or allowing the cattle owner to make both choices does not.

owner is very highly risk-averse (i.e.,  $\psi = 0.019$ ), she prefers dressed-weight pricing under both restricted and unrestricted contract forms unless the feeder is risk neutral.

The highlighted FCEs in the upper panel of Table 7.2 indicate that, if the cattle owner is risk-neutral (i.e.,  $\psi = 0$ ), then the feeder prefers the unrestricted form of contracts. A risk-neutral cattle owner prefers live-weight pricing with unrestricted contracts, while she prefers grid pricing with the restricted contracts. At any level of the feeder's risk aversion, the unrestricted FCEs under live-weight pricing (Table 7.2) are higher than the restricted FCEs under grid pricing (Table 7.3).

A risk-neutral cattle feeder's preference over contract forms varies with the owner's risk aversion levels (see middle panels of Tables 7.2 and 7.3). For low to moderate levels of risk aversion by the cattle owner (i.e.,  $0.000025 \leq \psi \leq 0.00025$ ), the risk-neutral feeder ( $\varphi = 0$ ) prefers the unrestricted contract form. In these cases, the owner prefers live-weight pricing with unrestricted contracts and grid pricing with restricted contracts. Again, the unrestricted FCEs under live-weight pricing are higher than the restricted FCEs under grid pricing. If the cattle owner is highly risk-averse (i.e.,  $\psi = 0.0025$ ), then the risk-neutral feeder prefers the restricted contract form. In this case, restricted FCEs are higher than unrestricted FCEs under each of the pricing methods. Although the feeder's potential gain from traditional pricing with restricted contracts are substantially higher, he is not able to realize that as the owner prefers grid pricing with restricted contracts. However, if the owner is very highly risk-averse (i.e.,  $\psi = 0.019$ ), the feeder prefers the unrestricted contract forms while the owner prefers dressed-weight pricing.

A risk-averse feeder's preferences between alternative contract forms depend on both the owner's and the feeder's risk aversion levels (see the lower panels of Tables 7.2 and 7.3). For low to moderate levels of risk aversion by the owner (i.e.,  $0.000025 \leq \psi \leq 0.00025$ ), the feeder prefers the unrestricted form as long as he is not very highly risk averse (i.e.,  $0.000025 \leq \varphi \leq 0.0025$ ). In these cases, the owner prefers live-weight pricing with unrestricted contracts and grid pricing with restricted contracts, and the feeder prefers unrestricted FCEs under live-weight pricing to restricted FCEs under grid pricing. However, if the feeder is very highly risk averse (i.e.,  $\varphi = 0.025$ ) while the owner has low to moderate levels of risk aversion, then the restricted FCEs under grid pricing are higher than the unrestricted FCEs under live-weight pricing. If the cattle owner is highly risk averse (i.e.,  $\psi = 0.0025$ ), the feeder prefers the restricted contract form as the owner chooses grid pricing. For a very high level of risk aversion (i.e.,  $\psi = 0.019$ ), the owner chooses dressed-weight pricing and the feeder prefers the restricted form as long as he is less than very highly risk averse (i.e.,  $0 < \varphi < 0.025$ ). If the feeder is also very highly risk averse (e. g.,  $\varphi = 0.025$ ), then he prefers the unrestricted contract form because the unrestricted FCE is higher than the restricted FCE. Thus, if the feeder controls the choice to restrict the parameter space, he chooses the unrestricted space if the cattle owner has a low to moderate level of risk aversion but chooses the restricted parameter space if he is not very highly risk averse and the owner is highly (or very highly) risk averse.

For alternative risk preference combinations of the cattle owner and feeder, Table 7.5 shows the preferred fed cattle pricing methods, contract parameters, corresponding cattle feeding strategies, and resulting certainty equivalents and average carcass quality when the cattle owner chooses the pricing method and the feeder chooses the contract

**Table 7.5: Preferred pricing methods, contract parameters, feeding strategies, and resulting certainty equivalents, and average carcass quality when the cattle owner chooses pricing methods and the feeder chooses contract forms (not the contract parameters).**

Risk Aversion		Pricing Method <sup>1</sup>	Contract Coefficients <sup>2</sup>			Strat-egy <sup>3</sup>	Certainty Equiv.			Carcass Quality
Owner	Feeder		$\alpha$	$\beta$	$\gamma$		Owner	Feeder	Total	
0	0	LWP	0.14	0.10	0.80	15	130.0	10.9	140.9	Select
0	0.000025	LWP	0.14	0.10	0.80	15	130.0	10.9	140.9	Select
0	0.00025	LWP	0.14	0.10	0.80	15	130.0	10.9	140.9	Select
0	0.0025	LWP	0.14	0.10	0.80	15	130.0	10.8	140.8	Select
0	0.025	LWP	0.14	0.10	0.80	13	129.7	9.7	139.5	Select
0.000025	0	LWP	0.14	0.10	0.80	15	129.9	10.9	140.8	Select
0.00025	0	LWP	0.14	0.10	0.80	15	129.2	10.9	140.1	Select
0.0025	0	GP	<b>0.26</b>	<b>0</b>	<b>1.00</b>	10	107.0	11.1	118.2	Choice
0.019	0	DWP	0.15	0.11	0.76	13	79.5	11.9	91.4	Select
0.000025	0.000025	LWP	0.14	0.10	0.80	15	129.9	10.9	140.8	Select
0.000025	0.00025	LWP	0.14	0.10	0.80	15	129.9	10.9	140.8	Select
0.000025	0.0025	LWP	0.14	0.10	0.80	15	129.9	10.8	140.7	Select
0.000025	0.025	GP	<b>0.16</b>	<b>0</b>	<b>1.09</b>	12	119.0	10.1	129.0	Choice
0.00025	0.000025	LWP	0.14	0.10	0.80	15	129.2	10.9	140.1	Select
0.00025	0.00025	LWP	0.14	0.10	0.80	15	129.2	10.9	140.1	Select
0.00025	0.0025	LWP	0.14	0.10	0.80	15	129.2	10.8	140.0	Select
0.00025	0.025	GP	<b>0.16</b>	<b>0</b>	<b>1.09</b>	12	118.1	10.1	128.1	Choice
0.0025	0.000025	GP	<b>0.26</b>	<b>0</b>	<b>1.00</b>	10	109.4	11.1	120.6	Choice
0.0025	0.00025	GP	<b>0.26</b>	<b>0</b>	<b>1.00</b>	10	109.4	11.1	120.6	Choice
0.0025	0.0025	GP	<b>0.26</b>	<b>0</b>	<b>1.00</b>	10	109.4	11.1	120.6	Choice
0.0025	0.025	GP	<b>0.26</b>	<b>0</b>	<b>1.00</b>	10	109.4	11.1	120.5	Choice
0.019	0.000025	DWP	<b>0</b>	<b>0.40</b>	<b>0</b>	13	66.9	30.6	97.5	Select
0.019	0.00025	DWP	<b>0</b>	<b>0.40</b>	<b>0</b>	13	66.9	30.3	97.2	Select
0.019	0.0025	DWP	<b>0</b>	<b>0.40</b>	<b>0</b>	13	66.9	28.0	94.9	Select
0.019	0.025	DWP	0.14	0.10	0.80	13	79.7	9.7	89.4	Select

<sup>1</sup> LWP = Live-weight pricing; DWP = Dressed-weight pricing; and GP = Grid pricing.

<sup>2</sup> Contract parameters that are observed in current practice are represented by bold-faced numbers.

<sup>3</sup> Strategy 10: 60% corn, moderate implant; Strategy 11: 70% corn, moderate implant; Strategy 12: 80% corn, moderate implant; Strategy 13: 30% corn, aggressive implant; Strategy 15: 50% corn, aggressive implant.

form (not the contract parameters). From Table 7.5, live-weight pricing is preferable whenever the owner has low to moderate level of risk aversion and the feeder has less than very high risk aversion. Dressed-weight pricing is preferable only if the owner is very highly risk-averse. In all other risk preference scenarios, grid pricing is preferable. The highlighted contract coefficients indicate the situations when restricted contract forms such as yardage-fee-plus-feed-cost contracts and cost-of-gain contracts are preferable. Thus, when the cattle owner chooses the pricing method but the feeder can choose to restrict the contract parameter space, a mix of traditional and modern fed cattle pricing methods and contract forms are likely to coexist in reality. The last column of Table 7.5 also indicates that average beef quality increases with the adoption of grid pricing.

### ***Rationalizing Results with Reality***

In current practice, only restricted contract forms such as yardage-fee-plus-feed-cost contracts (with or without a markup on feed cost) and cost-of-gain contracts are observed. Obviously, from the optimization formulation, the cattle owner never prefers restricted contracts (Tables 7.2 and 7.3), but the feeder prefers restricted contracts when the owner is highly risk-averse. Cattle owners who retain ownership of their feeder animals through slaughter face substantial price and production risks (Popp et al., 2007; Marsh and Feuz, 2002). Moreover, given the small scale of beef production herds, high levels of risk aversion by cattle owners are likely in reality.<sup>54</sup> Thus, the feeder has an incentive to restrict the contract parameter space. Moreover, it may be reasonable for the

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<sup>54</sup> In the United States, only about 10 percent of cow-calf operations have more than 100 head of breeding cows (Field and Taylor, 2002). A large number of cow herds are small, with less than 30 cows per operation (Ward, 1997).

feeder to insist on a reasonably simple contract form for administrative and decision making purposes. Given the contract form, the owner may choose contract parameters but has the prerogative to go to an alternative feedlot since she owns the cattle. As the cattle owner chooses the contract parameters, the feeder is left with only the accept or reject option. Certainly, the owner chooses the fed cattle pricing method since she owns the cattle. Thus, it is realistic to assume that feeders have control over restricting the parameter space while owners choose the contract parameters and fed cattle pricing method. With this assumption, the optimization results of this chapter can explain observed practices in contract cattle feeding and fed cattle marketing.

The results presented in Tables 7.2 and 7.3 show that, in the absence of grid pricing, the cattle owner always prefers live-weight pricing as long as she is not very highly risk-averse (e. g.,  $0 \leq \psi \leq 0.0025$ ). The cattle owner prefers dressed-weight pricing only if she is very highly risk-averse (e.g.,  $\psi = 0.019$ ). Given this preference structure, the feeder chooses unrestricted contracts if the owner has low to moderate level of risk aversion (i.e.,  $0 \leq \psi \leq 0.00025$ ), and restricted contracts if the owner is highly risk averse (e.g.,  $0.0025 \leq \psi \leq 0.019$ ) but the feeder is not very highly risk averse (i.e.,  $\varphi < 0.025$ ). In such cases, cost-of-gain contracts appear to be optimal (e.g.,  $\beta = \$0.40$  with  $\alpha = 0$  and  $\gamma = 0$ ). The feeder's welfare improves with such a restriction on the contract parameter space. For example, with a highly risk-averse owner, restricted FCEs (e.g., \$ 28.0 when  $\psi, \varphi = 0.0025$ ) are substantially higher than unrestricted FCEs (e.g., \$10.8 when  $\psi, \varphi = 0.0025$ ). However, even with the restriction on the contract parameter space, the owner prefers live-weight pricing if she is not very highly risk averse (e.g.,  $\psi = 0.0025$ ), but prefers dressed-weight pricing if she is very highly risk averse (e.g.,  $\psi = 0.019$ ). Thus, high

levels of risk aversion on the cattle owners' part explain the traditional practices for marketing fed cattle using live- and dressed-weight pricing methods assuming feeders control the choice to restrict the parameter space.

When grid pricing is introduced into these traditional practices, a highly risk-averse cattle owner (i.e.,  $\psi = 0.0025$ ) no longer prefers traditional pricing methods with restricted contract forms. While the cattle feeder still prefers restricted contract forms in these cases, the highly risk-averse cattle owner prefers grid pricing as it improves her welfare (Tables 7.2 and 7.3). Moreover, cost-of-gain contracts are replaced by yardage-fee-plus-feed-cost contracts (e.g.,  $\alpha = \$0.26$ ,  $\beta = 0$ , and  $\gamma = 1$ ) in these cases. Thus, the introduction of grid pricing decreases (increases) the scope of cost-of-gain (yardage-fee-plus-feed-cost) contracts in commercial cattle feeding.<sup>55</sup>

However, for a very highly risk-averse cattle owner (i.e.,  $\psi = 0.019$ ), dressed-weight pricing with restricted contract forms is still preferable to grid pricing as long as the feeder is not risk neutral ( $\varphi = 0$ ) or very highly risk averse ( $\varphi \neq 0.025$ ). Cost-of-gain contracts appear to be optimal only in this situation. Thus, with the introduction of grid pricing, a mix of yardage-fee-plus-feed-cost and cost-of-gain contracts and traditional and grid pricing practices are observed if cattle owners choose the pricing method and feeders can restrict the parameter space.

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<sup>55</sup> In order to obtain information about contract cattle feeding practices, more than 30 feedlot operators in Iowa were directly contacted by telephone in 2005. Several of them reported that they had switched from using cost-of-gain contracts to yardage-fee-plus-feed-cost contracts. None of them reported switching from yardage-fee-plus-feed-cost contracts to cost-of-gain contracts.



## 7.6 Summary and Conclusions

This chapter examines the behavior of cattle feeders under alternative cattle feeding contract provisions, and the implications for contract parameter choice by cattle owners. The multitask principal-agent model presented in Chapter 4 yields a variety of testable hypotheses, which are evaluated by empirically determining the optimal incentive structure for cattle feeding contracts under alternative fed cattle pricing methods and risk preferences of cattle feeders and owners. The dynamic biophysical model for beef cattle growth presented in Chapter 6 was employed to simulate feedlot and carcass performance outcomes for a large sample of feeder steers under various ration-implant strategies. Simulated feedlot and carcass performance data were then combined with historical price series to calculate stochastic costs and returns of cattle owners and feeders with various degrees of risk aversion. The optimal (profit and utility maximizing) cattle feeding contract parameters for owners and corresponding production technologies (ration-implant strategies) chosen by feeders are then determined by performing a generalized search on a feasible contract parameter space. This was done, first, with the provision of cost sharing in addition to fixed fee and performance incentives and, second, without cost sharing provisions (i.e., restricting the parameter space to typical contract forms—yardage-fee-plus-feed-cost contracts or cost-of-gain contracts).

The optimization results validate the main hypotheses of the multitask model as well as hypotheses about the benefits and implications of grid pricing. First, results demonstrate that carcass yield and quality improving inputs are substitutes in the production technology of feedlots. Second, they show that overall beef quality increases

under grid pricing with optimal owner and feeder behavior. Third, the power of the optimal incentive scheme for cattle feeding (i.e., the degree of the incentive for cost saving) is lower under value-based grid pricing than under traditional live- and dressed-weight pricing methods. Fourth, the power of the incentive scheme increases with the degree of cattle owners' risk aversion. Fifth, compared to traditional pricing methods, value-based grid pricing better aligns the incentives of cattle owners and feeders under feeding contract structures in current use (yardage-fee-plus-feed-cost contracts and cost-of-gain contracts). Sixth, asymmetry in the premium-discount structure in current grids and the additional risk associated with carcass yield and quality under grid pricing are the main reasons for the continued use of live-weight pricing and apparent slowness to adopt grid pricing. Seventh, more balanced premiums and discounts in grid pricing may be required to achieve further expansion of grid pricing and overall improvement of beef quality and consistency. Eighth, if cattle feeders can limit the contract parameter space to traditional forms of contracts and owners choose the contract parameters, then typical forms of cattle feeding contracts can be rationalized by optimal behavior under plausible levels of risk aversion.. Finally, the introduction of grid pricing decreases (increases) the tendency towards cost-of-gain (yardage-fee-plus-feed-cost) contracts in commercial cattle feeding.

## CHAPTER 8

### **General Conclusions and Reflections**

The major results of this dissertation are based on feedlot and carcass performance outcomes simulated by a widely-accepted dynamic biophysical model of beef cattle growth. This research represents a unique approach to investigation of the optimality of various feeding contract forms in livestock production. In particular, this approach has the capability of representing a much wider variety of factors that reflect animal attributes and determine both quality and yield of meat production than typical revealed preference contract data has, even when it is (rarely) available. The model validation has revealed quite plausible simulation results for most but not all of the dimensions of productivity, although the results appear to be satisfactory subject to some rescaling of interpretation. Application of the biophysical growth model under contract optimization permits examination of contract parameter sensitivity to a rich set of issues in contract form as well as the preference structures of contract participants. Observed choices in reality can be rationalized within a subset of risk preference structures on the part of owners and feeders.

With these results, future research along this line appears promising. However, model application is tedious given the need to evaluate the entire parameter space because of minor nonconcavities in the biophysical growth model. Several issues deserve further consideration. Most importantly, the model offers a valuable tool to evaluate alternative grids as pricing structures. Because this research highlights problems associated with excessive discounts in the current grid, such research could be helpful in

identifying a grid that would both be widely adopted and yet improve the quality and consistency of beef production. Further, this research could be helpful in determining optimal adjustments in grid pricing required under the actual risk aversion of contracting parties. Little information is available to determine which the various risk aversion levels examined in this dissertation are most appropriate. In particular, this research shows that aversion to risk in *ex post* pricing is a deterrent to adoption of grid pricing. Thus, some downward adjustment in pricing discounts and/or upward adjustment in premiums sensitive to common levels of risk aversion could serve to increase adoption of grid pricing, thus increasing the quality and consistency of overall meat production.

Further, this study has assumed a traditional stopping rule for feeding (a target harvest weight), but this model can be further applied to determine the optimal stopping rule, which might involve a combination of traits. From a broader social perspective, these last few issues can be further developed in a model including consumers where a sound measure of the marginal benefits to consumers of beef quality and consistency is used to determine the socially optimal tradeoff between meat quality/consistency and the deadweight loss associated with risk under grid pricing. Thus, a rich research agenda remains to be explored with this unique general research approach to contracting issues.

## APPENDIX 6.1

### Step by Step Procedure for Biological Growth Simulation

**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 6.1, 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 (Table 6.3). 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 6.1).

**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 6.1).

- 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 6.1).
- Step 7:** Calculate shrunk weight gain and empty body gain according to equations 32 and 34 in Appendix Table 6.1.
- 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 6.1, 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 6.1).
- 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 Garrett and Hinman (1969) (Equation 40 in Appendix Table 6.1).
- 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 5.1). Also determine quality grade from the accumulated empty body fat percentage following Guiroy et al. (2001).

**Step 12:** Repeat steps 4 to 11 for each additional day until the animal reaches target harvest body weight (simulation model 1), or predetermined days on feed are exhausted (simulation model 2).

**Step 13:** Compute and save the number of days required to reach the target harvest body weight (simulation model 1) or total shrunk weight gain during the feedlot days (simulation model 2), 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 6.2

### Estimated Densities of Actual and Simulated (Model 2) Carcass Performance Data

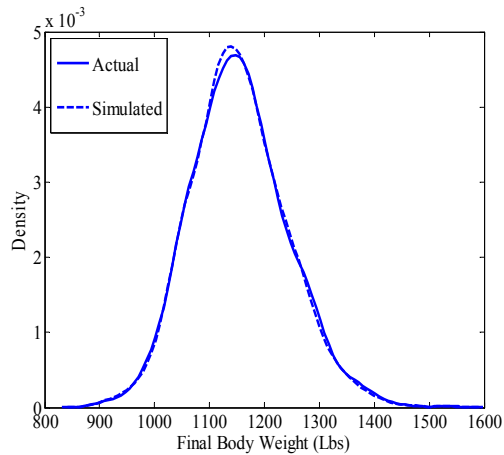


Figure A6.1a: Estimated kernel densities of actual and simulated final body weights (all cattle).

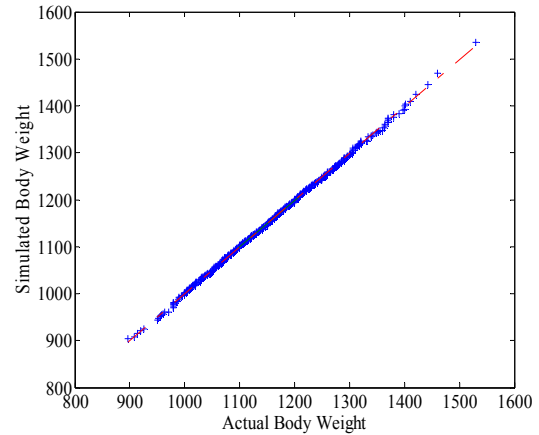


Figure A6.1b: Quantile-quantile plot of actual and simulated final body weights (all cattle).

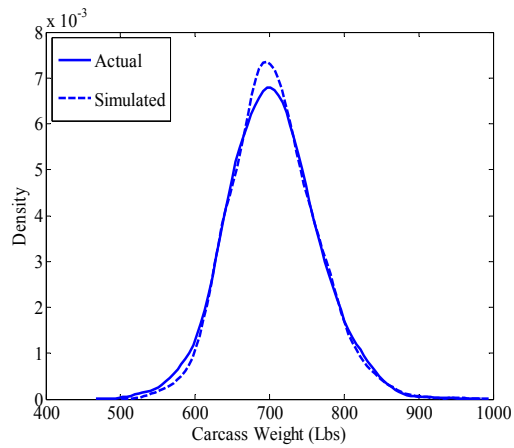


Figure A6.1c: Estimated kernel densities of actual and simulated carcass weights (all cattle).

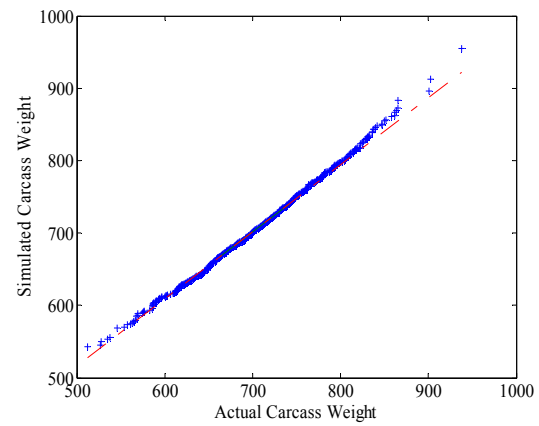


Figure A6.1d: Quantile-quantile plot of actual and simulated carcass weights (all cattle).

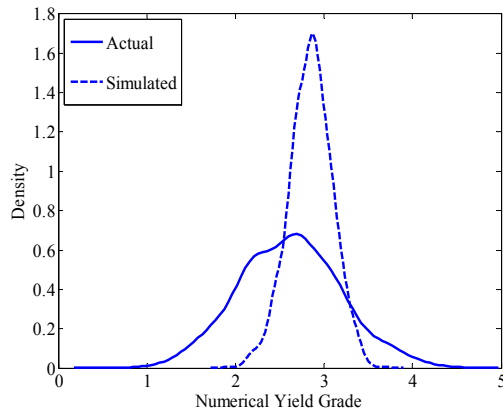


Figure A6.1e: Estimated kernel densities of actual and simulated yield grades (all cattle).

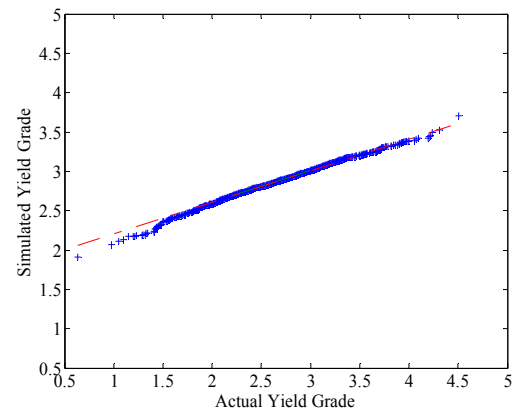


Figure A6.1f: Quantile-quantile plot of actual and simulated yield grades (all cattle).



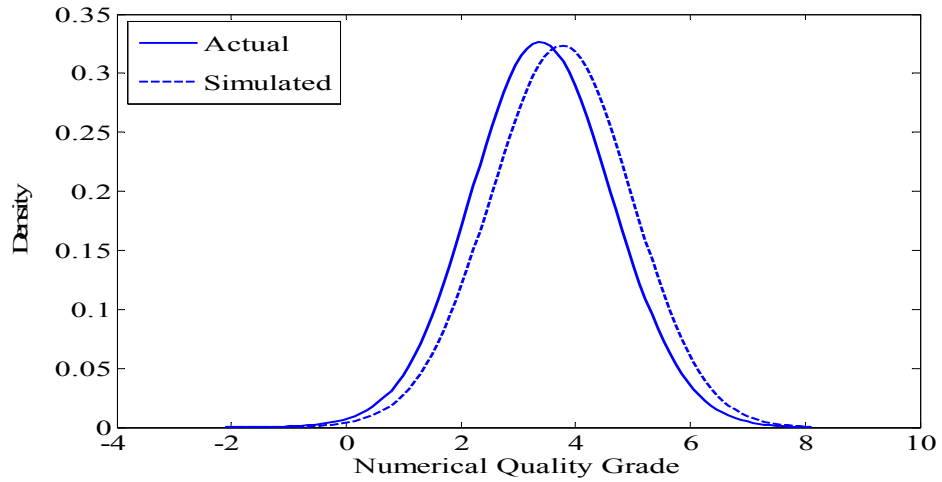


Figure A6.1g: Estimated kernel densities of actual and simulated quality grades (October cattle).

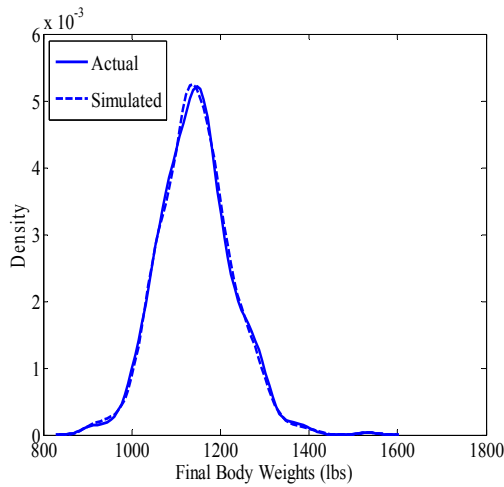


Figure A6.2a: Estimated kernel densities of actual and simulated final body weights (Oct. cattle).

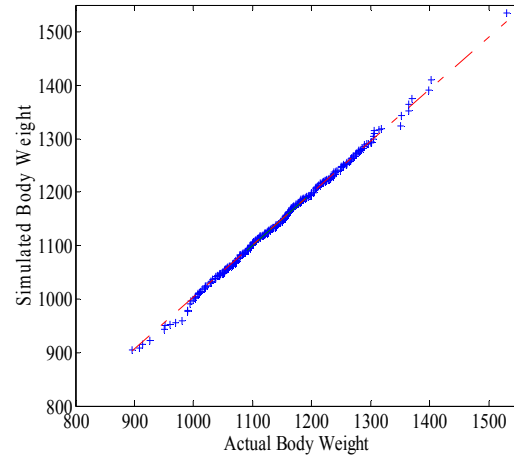


Figure A6.2b: Quantile-quantile plot of actual and simulated final body weights (Oct. Cattle).

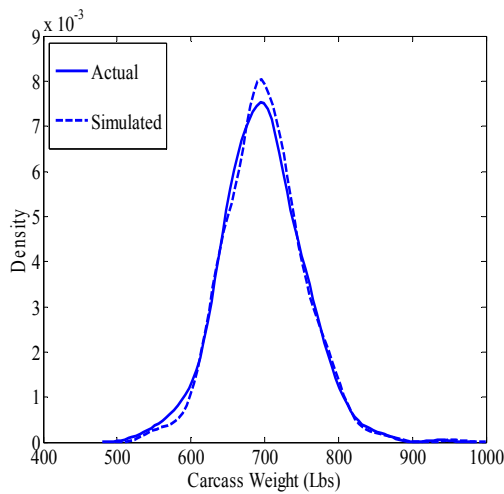


Figure A6.2c: Estimated kernel densities of actual and simulated carcass weights (Oct. cattle).

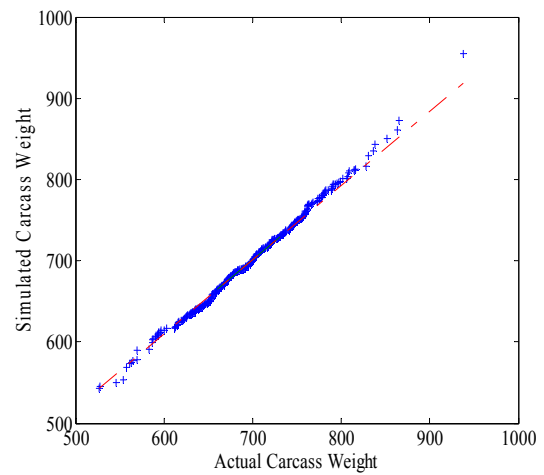


Figure A6.2d: Quantile-quantile plot of actual and simulated carcass weights (Oct. Cattle).

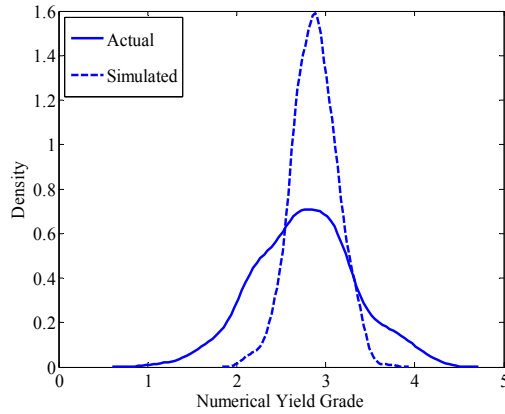


Figure A6.2e: Estimated kernel densities of actual and simulated yield grades (October cattle).

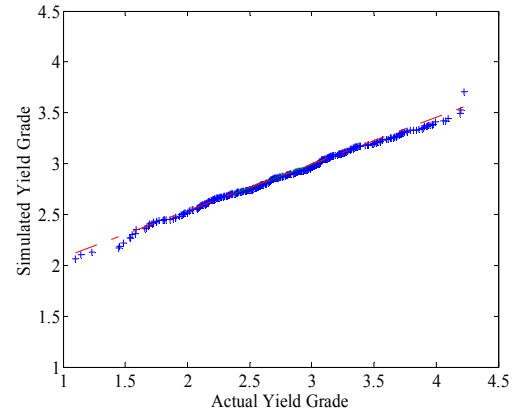


Figure A6.2f: Quantile-quantile plot of actual and simulated yield grades (October Cattle).

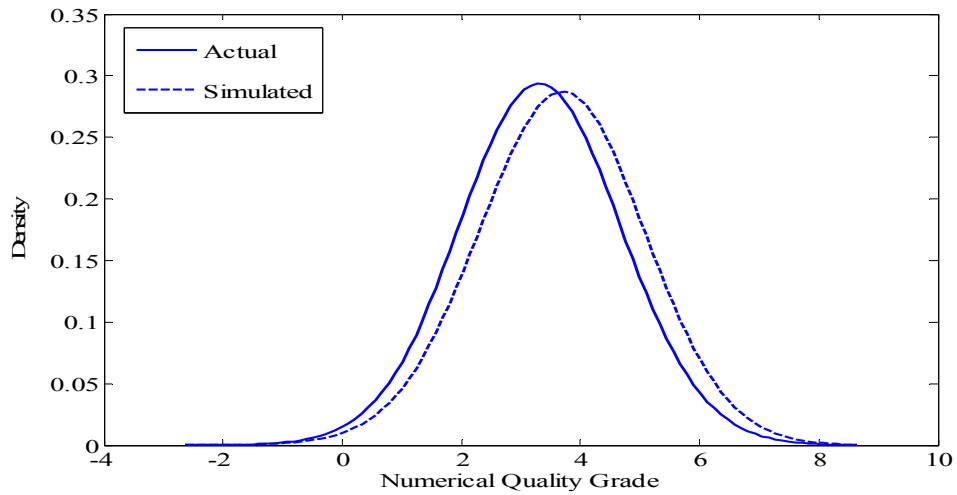


Figure A6.2g: Estimated kernel densities of actual and simulated quality grades (October cattle).

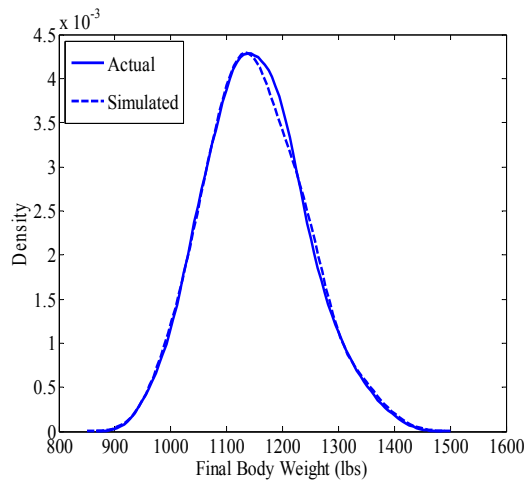


Figure A6.3a: Estimated kernel densities of actual and simulated final body weights (November cattle).

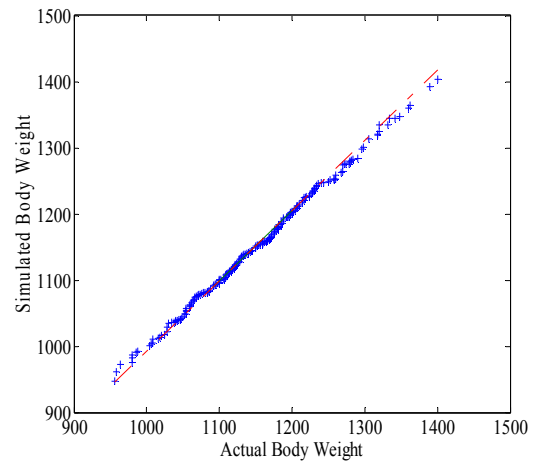


Figure A6.3b: Quantile-quantile plot of actual and simulated final body weights (Nov. Cattle).

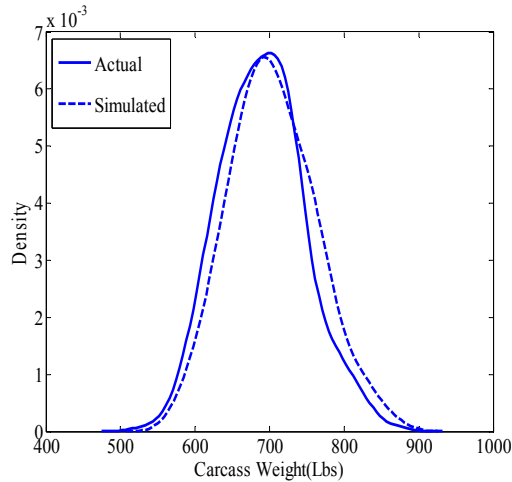


Figure A6.3c: Estimated kernel densities of actual and simulated carcass weights (Nov. cattle).

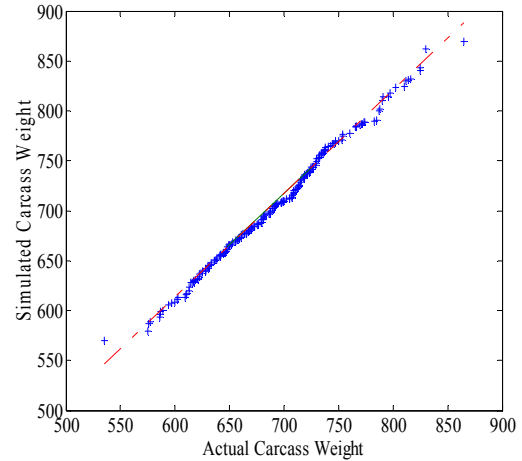


Figure A6.3d: Quantile-quantile plot of actual and simulated carcass weights (Nov. Cattle).

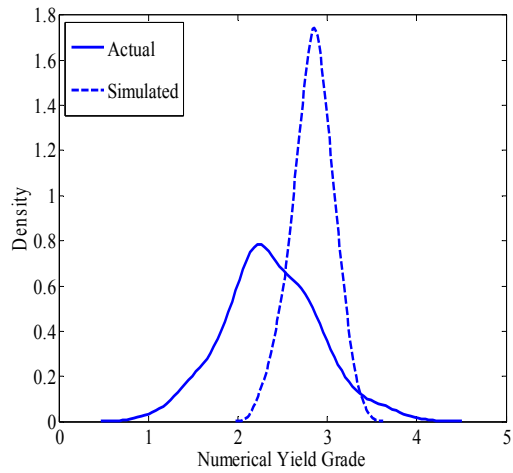


Figure A6.3e: Estimated kernel densities of actual and simulated yield grades (November cattle).

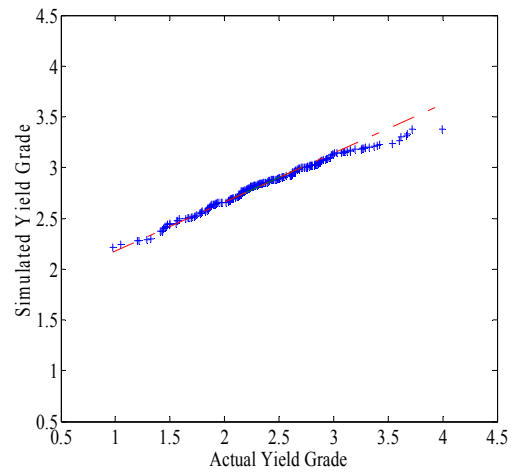


Figure A6.3f: Quantile-quantile plot of actual and simulated yield grades (November Cattle).

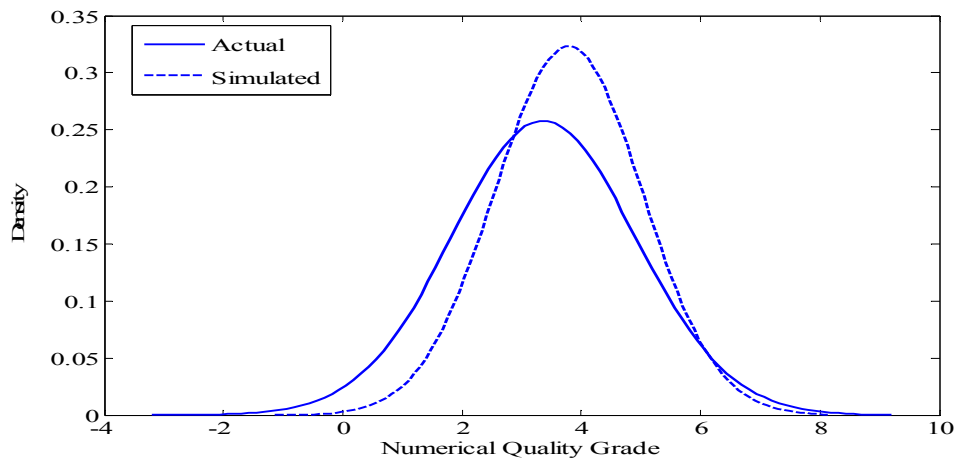


Figure A6.3g: Estimated kernel densities of actual and simulated quality grades (November cattle).

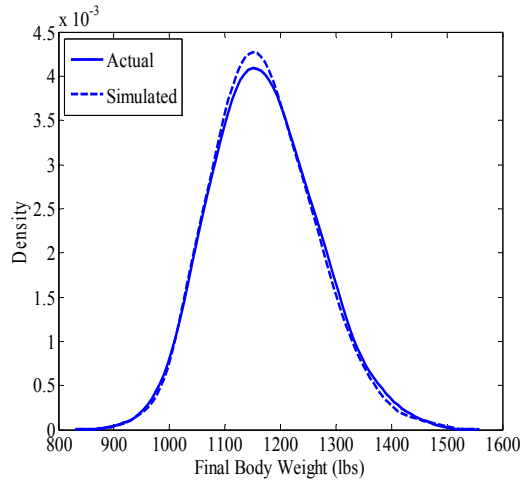


Figure A6.4a: Estimated kernel densities of actual and simulated final body weights (Dec. cattle).

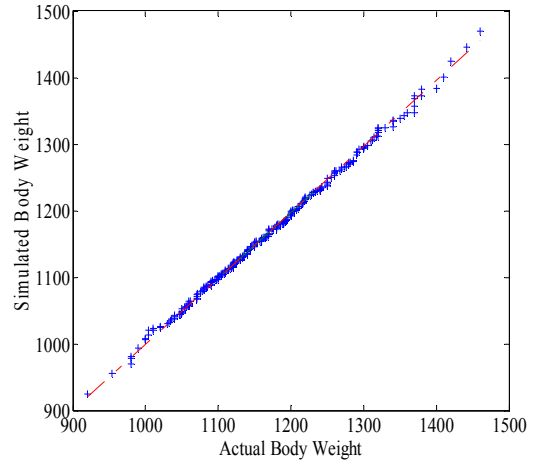


Figure A6.4b: Quantile-quantile plot of actual and simulated final body weights (Dec. Cattle).

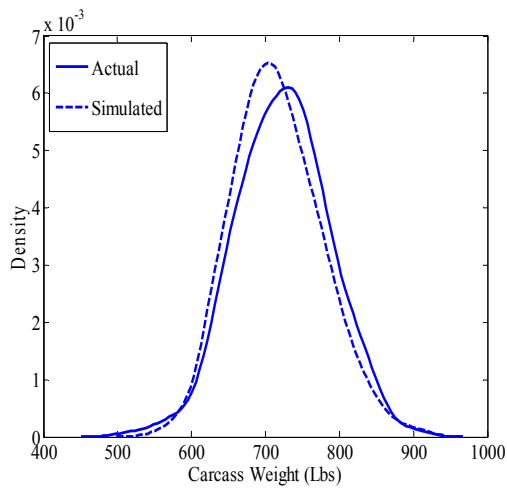


Figure A6.4c: Estimated kernel densities of actual and simulated carcass weights (Dec. cattle).

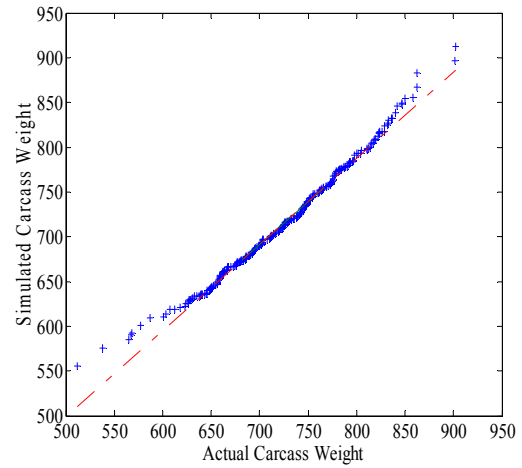


Figure A6.4d: Quantile-quantile plot of actual and simulated carcass weights (Dec. Cattle).

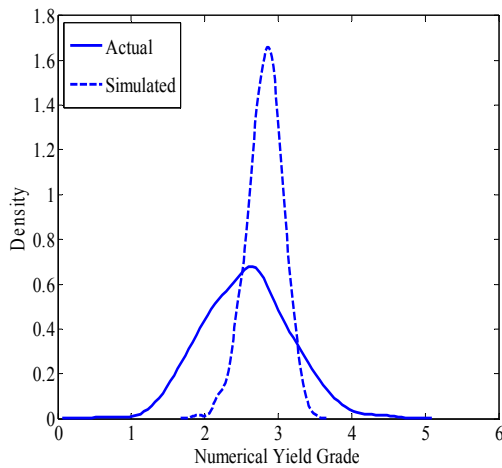


Figure A6.4e: Estimated kernel densities of actual and simulated yield grades (Dec. cattle).

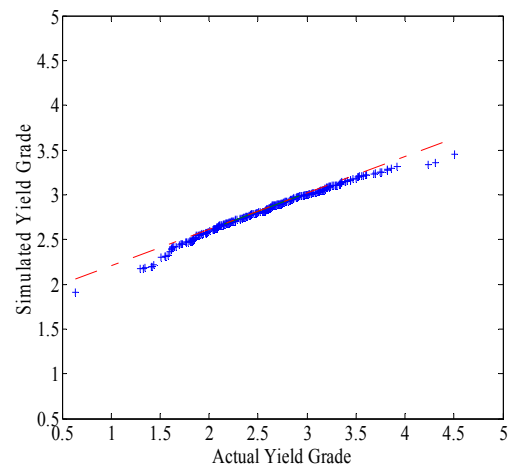


Figure A6.4f: Quantile-quantile plot of actual and simulated yield grades (Dec. Cattle).

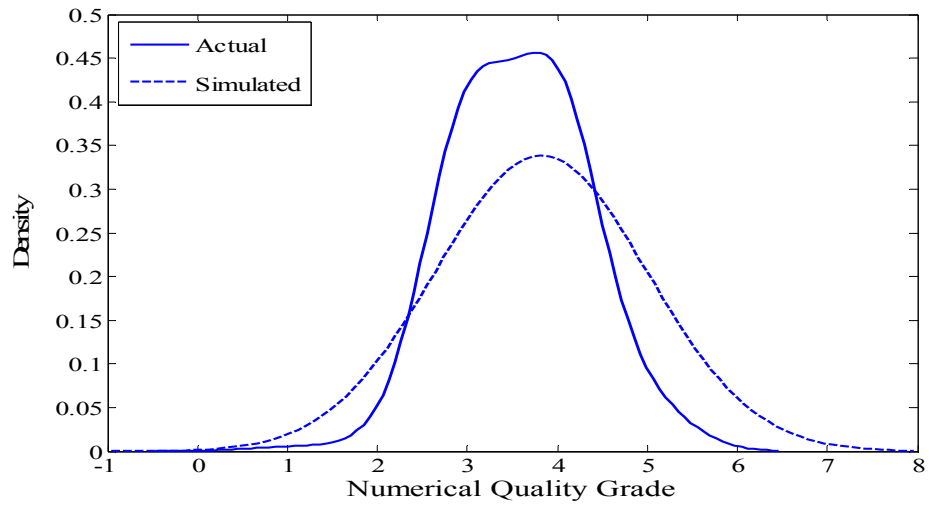


Figure A6.4g: Estimated kernel densities of actual and simulated quality grades (December cattle).

## APPENDIX 7.1

### 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,  $\text{Grid Base Price} = 100 \times (\text{Live Weight Price} / \text{Estimated Dressing Percentage}) + 0.01$ .
- 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 ( $\alpha$ ,  $\beta$ , and  $\gamma$ ) from the minimum and maximum attainable profits by the feeder and owner. Construct a parameter space with all plausible combinations of  $\alpha$ ,  $\beta$ , and  $\gamma$  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  $\alpha$ ,  $\beta$ , and  $\gamma$  in an array that satisfy the participation constraints of the cattle feeder and owner.
- Step 9:** For each combination of  $\alpha$ ,  $\beta$ , and  $\gamma$  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  $\alpha$ ,  $\beta$ , and  $\gamma$  under each  $\varphi$ .

**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  $\alpha$ ,  $\beta$ , and  $\gamma$ . Search for the owner's profit and utility maximizing  $\alpha$ ,  $\beta$ , and  $\gamma$ , and corresponding optimal feeding strategy of the feeder.

**Step 11:** Save the optimal combination of  $\alpha$ ,  $\beta$ , and  $\gamma$ , corresponding feeding strategies, and certainty equivalents of the cattle feeder and the owner for any particular combination of  $\varphi$  and  $\psi$ .

**Step 12:** Repeat Steps 9-11 for all plausible combination of  $\varphi$  and  $\psi$  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 6.1: Equations used in the biophysical growth simulation model.**

Eq. No	Conditions	LHS <sup>1</sup>	RHS <sup>2</sup>
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 $\leq$ 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.	$DMI_t$	$(SBW_t^{0.75} \times (0.2435 \times NEm_t - 0.0466 \times NEm_t^2 - 0.0869)) / NEm_t$
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 $\times$ 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	$Tc_t \leq -20^\circ\text{C}$	$DMIT_t$	1.16
	$20^\circ\text{C} < Tc_t \leq 20^\circ\text{C}$	$DMIT_t$	$1.0433 - 0.0044 \times Tc_t + 0.0001 \times Tc_t^2$
	$20^\circ\text{C} < Tc_t \leq 28^\circ\text{C}$	$DMIT_t$	$((1 - DMINC_t) \times 0.75 + DMINC_t) / 100 + 1.05$
	$Tc_t > 28^\circ\text{C}$	$DMIT_t$	$((1 - DMINC_t) \times 0.75 + DMINC_t) / 100 + 1$
12		$DMIM_t$	$1 - 0.01 \times Mud_t$
13		$AdgDMI_t$	$DMI_t \times DMIBF_t \times DMIB_t \times DMIMP_t \times DMIT_t$
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	$Tp_t \leq 20^\circ\text{C}$	$a_2$	$(88.426 - 0.785 \times Tp_t + 0.0116 \times Tp_t^2 - 77) / 1000$
	$Tp_t > 20^\circ\text{C}$	$a_2$	$(88.426 - 0.785 \times PETI_t + 0.0116 \times PETI_t^2 - 77) / 1000$

**Appendix Table 6.1 (continued)**

Eq. No	Conditions	LHS <sup>1</sup>	RHS <sup>2</sup>
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	$HideCode_t \leq 2$	$MudME_t$	$(1 - HCCode_t - 2) \times 0.2$
	$HCCode_t > 2$	$MudME_t$	$(1 - HCCode_t - 2) \times 0.3$
22		$HideME_t$	$(1 - HideCode_t - 2) \times 0.2$
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	$t = 0$	$EBF_t$	$(0.00054 \times EBW_t^2 + 0.037 \times EBW_t - 0.61) \times 0.85$
	$t > 0$	$EBF_t$	$EBF_{t-1} + FIG_t \times EWG_t \times 0.85$
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		$YG_t$	$0.15 \times CFP_t - 1.7$

<sup>1</sup> LHS=Left hand side of the equation; <sup>2</sup> 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).

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