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NEW INPUT AND OUTPUT RISK MANAGEMENT STRATEGIES FOR LIVESTOCK PRODUCERS

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ABSTRACT OF THESIS

NEW INPUT AND OUTPUT RISK MANAGEMENT STRATEGIES FOR LIVESTOCK PRODUCERS

Backgounding beef cattle is an inherently risky venture. Producers face production risks as well as marketing risks. If a backgrounding operation is to be viable, these risks should be addressed and effectively managed. While some effective risk management tools are currently available to livestock producers, some other potentially useful risk management tools, for various reasons, have been previously unavailable. Two such tools which could help livestock producers achieve the overall goal of managing net income risk are a program for managing feed ingredient nutrient and price variability in the selection of minimum cost feed rations and government subsidized livestock price insurance.

Due to lack of data and limited computational power of solvers, risk has seldom been introduced into the feed ration selection process. Presently, both feed ingredient nutritional data and appropriate solvers are available, allowing for risk to be fully considered in this decision-making process. Only recently has there been policy efforts to establish subsidized price or revenue insurance for livestock producers. The introduction of such insurance to livestock producers offers potential risk management benefit but also has the potential to introduce improper incentives to livestock producers.

This study will evaluate both of the aforementioned livestock risk management tools. In addition to evaluating their effectiveness, the policy concerns of subsidized livestock insurance will also be addressed. Results will be relevant to a broad range of entities. In addition to livestock producers wishing to manage the risks associated with their operations, agribusinesses that provide service to these producers such as feed sales or financial lending will benefit from knowing how these risk management strategies perform. Furthermore, policy makers who will structure livestock insurance products can hopefully do so more efficiently based on the results of the livestock insurance analysis.

Keywords: Risk Management, Insurance, Livestock, Feed Ration, Mathematical Programming, Technical Coefficient Risk

Brian K. Coffey
July 17, 2001

NEW INPUT AND OUTPUT RISK MANAGEMENT STRATEGIES FOR LIVESTOCK PRODUCERS

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July 17, 2001

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THESIS

Brian K. Coffey

The Graduate School

University of Kentucky

2001

NEW INPUT AND OUTPUT RISK MANAGEMENT STRATEGIES FOR LIVESTOCK PRODUCERS

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
at the University of Kentucky

By

Brian K. Coffey

Lexington, Kentucky

2001

Director: Carl R. Dillon, Professor of Agricultural Economics

Lexington, Kentucky

2001

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time to help me understand and model some of the complexities of the formulation of beef feed rations.

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CHAPTER I

INTRODUCTION

Beef production continues to be a major component of United States agriculture. According the 1997 Census of Agriculture, market value of all cattle and calves[1] produced comprised slightly more than 20% of the total market value of all United States agricultural production. Fed cattle (referred to as fattened cattle in 1997 census reports), or beef cattle fed specifically for slaughter, comprised about 10% of this total. Given this level of contribution to the national agricultural economy, it is worthwhile to focus some agricultural economic analysis on beef production. One broad objective of such analysis should be searching for ways to improve the viability and profitability of beef operations.

As with all types of agriculture, ability to manage the risk associated with a beef operation is paramount to the success of that operation. Unlike pork and poultry production, beef production has seen relatively little effort at vertical coordination through non-price means and thus cannot enjoy the risk sharing opportunities these provide. Beef producers, in general, focus on a specific phase of production (e.g. cow-calf production or cattle feeding) and must take full responsibility for managing the risks associated with that particular type of operation. Given this situation, two important roles of livestock economists are the evaluation of existing risk management strategies for beef producers and the identification and evaluation of novel risk management strategies. This study will focus on the latter by introducing and evaluating two novel

[1] The census category of cattle and calves will encompass beef cattle and calves sold as well as those sold for dairy or other purposes.

livestock risk management strategies. The analyses of this study will apply these strategies to beef production operations but the general framework for the strategies as well as conclusions from the evaluations should apply to a broader group of livestock producers.

Before introducing these strategies, it will be beneficial to first provide basic background information on beef production, followed by a brief overview of current risk management strategies available to beef producers. Then a review of selected risk literature will be used to establish the theoretical and methodological framework needed to evaluate the risk management strategies. After the strategies are introduced and evaluated, conclusions regarding this evaluation will be presented.

Beef Backgrounding

Beef cattle production takes place at three basic levels: cow-calf production, backgrounding, and finishing. Cow-calf producers own breeding stock and produce beef calves. These calves are usually weaned at about 400 to 600 pounds, depending upon breed effects and in which region of the United States they are raised. At this point the calves may be sent directly to the feedlot or they may enter a backgrounding program. Calves in a backgrounding program are fed until they reach weights of about 750 pounds. This weight gain can be accomplished through grazing programs (e.g., grazing cool season pasture in the southeastern U.S. or grazing winter wheat in the southern plains), feeding programs that rely on harvested forages and feed concentrates, or some combination thereof. At this weight the cattle are known as feeder cattle and are generally shipped to a feedlot where they enter intensive feeding programs until they

reach slaughter weight. There are risks and production conditions that are unique to each stage of production. Given these differences, it is often beneficial to focus livestock studies on a specific level of production. Backgrounding as defined above is a very common practice in the southeastern United States. This study will focus on the risks associated with these types of backgrounding opertations.

The profitability of backgrouding operations is influenced by risk from several different sources including production and marketing risk. Mortality and morbidity (i.e., reduced physical response due to illness) are two of the most common production risks that affect animal performance. These are often attributable, at least in some degree, to weather and environmental conditions, which can also influence performance directly. Another form of backgrounding production risk is uncertain feed ingredient composition. Specifically, if feedstuffs do not contain the expected amount of nutrients, animals will not achieve expected levels of weight gain. In addition to production risk, backgrounders face marketing risk. This is true of both inputs and outputs. Since feed and weaned calves are the two major inputs for a backgrounding operation, any fluctuation in their prices can drastically affect profitability. Backgrounders must purchase these inputs months in advance of the sale of feeder cattle. Therefore, volatility of feeder cattle (output) prices is also vital to backgrounders' profitability.

This study will focus on the marketing risk associated with backgrounding and the production risk of uncertain feed composition. Specifically this study will examine novel risk management strategies for price and composition risks associated with purchasing feed ingredients and marketing risk of selling feeder cattle. Before introducing these

strategies a brief explanation of commonly used strategies for managing input and output risks will be presented.

Current Livestock Risk Management

Producers wishing to manage marketing risk often utilize futures markets to do so. Many of the feed ingredients purchased by backgrounders have corresponding futures contracts that are traded on futures exchanges. Producers can hedge the purchase of these inputs to attempt to "lock in" a price subject to basis risk or they can purchase call options to establish a price ceiling for the ingredients. For feedstuffs such as grain by-products (which represent an important feed resource for many commercial backgrounding operations) there are no exact futures contracts. Producers can possibly hedge these using a closely related futures contract (Anderson and Danthine). However, this procedure, known as cross hedging, can be quite complicated. A more common approach, which is also used for traditional ingredients, is forward contracting. A producer can contract the purchase of feedstuffs in advance of the actual purchase thereby reducing price risk of the feed inputs.

Feeder cattle price risk can be managed using the same mechanisms. The Chicago Mercantile Exchange trades a feeder cattle futures contract. Just as with feed ingredients, producers may choose to hedge or cross hedge the sale of feeder cattle using this contract. Producers can also establish a price floor by purchasing a put option. If prices are favorable, it may be beneficial to contract the sale of feeder cattle in advance. As with inputs, forward contracting establishes a price in advance and reduces marketing risk of the output.

Another form of input risk that has received considerably less attention in risk management studies is input composition uncertainty. In the context of livestock production this is variability of nutrients in a given feed ingredient. Generally producers assume that nutrient levels are constant in feed ingredients from one purchase to the next. If, in reality, nutrient levels are lower than assumed, the nutritional requirements of the animals may not be met and therefore there will be fewer pounds of feeder cattle to sell at the end of a feeding period. This form of risk to livestock operations has been documented in animal science literature and briefly addressed in economic studies. However, it has yet to be modeled explicitly. Furthermore, it has yet to be incorporated into risk management strategies for livestock producers.

While livestock producers have alternatives for managing both input and output risk, it is worthwhile to continue to seek out and evaluate new alternatives. This study does just that. Risk management tools that have been, for all practical purposes, previously unavailable to producers are introduced and evaluated. These risk management strategies are discussed in the following section.

Novel Risk Management Tools

Managing Input Risk

Producers can choose a minimum cost combination of feed ingredients that satisfy the nutritional requirements of the animals from available feed ingredients using mathematical programming. This is a common approach in both academic research and applied decision tools. However, it is also possible to use this selection process to manage both the price and composition risk associated with feed ingredients. This risk

management strategy has gone largely ignored in agricultural economic research. Chapter III will specify and evaluate such a strategy by expanding the basic minimum cost feed ration model to consider both feed ingredient price and composition risk.

Managing Output Risk

Recent legislation has cleared the way for government subsidized livestock insurance. The Risk Management Agency of the USDA is currently evaluating livestock insurance products to be used in pilot programs around the country. These products will likely be sold by private firms in a form similar to European put options with premiums being subsidized by the government. The introduction of new risk management tool such as this could have major implications for beef production. Chapter IV of this study will simulate the effects of subsidized insurance on expected feeder cattle prices. The risk management ability of this insurance will then be evaluated. This chapter will also examine the policy implications of subsidized livestock insurance and form hypotheses of the potential effects on beef production of such a program.

Study Objectives and Contributions

The general objective of this study is to introduce and evaluate novel risk management strategies for livestock producers. Specifically, two novel strategies will be evaluated. These are the consideration of risk in the selection of feed rations and government subsidized livestock insurance.

Chapter III introduces the consideration of feed ingredient price and nutrient risk into the feed ration selection process. This expanded model will be an improvement over

previous ration selection models and decision aids that have largely ignored nutrient and price variability of feed ingredients. Economic studies have shown that these risks do influence variability of total feed cost and animal performance and therefore net income (e.g., Prevatt et al. highlight feedstuff price variability; Thomas et al. examine feedstuff nutrient variability). In addition to economic studies, recent animal science and nutrition studies have focused on nutrient variability in feedstuffs (Cromwell et al., DePeters et al.). The presence of these issues in such scientific studies justifies their being modeled explicitly in the context of an optimal feed ration selection process.

Recent feedstuff data availability and improvements in the computational power of optimization software makes the specification and modeling of an expanded model possible. Such a model will give producers the opportunity to manage risks associated with selecting a feed ration. In addition to providing information on the effectiveness of this risk management strategy, Chapter III will make both academic and applied contributions. The study will serve as one of the few examples of modeling technical coefficient risk utilizing Merrill's approach. Merrill developed this modeling technique nearly forty years ago but due to limitations of computational solvers it has gone virtually unused. The model presented in Chapter III will also serve as one of the only examples of a feed ration selection model that considers both price and nutrient risk involved in the feed ration process. This model should serve as a basis for more advanced decision tools for producers wishing to manage these risks.

Chapter IV evaluates the effectiveness of subsidized livestock price insurance compared to European put options. This chapter highlights the adoption of both European options and subsidized insurance over a wide range of risk attitudes. This

allows for effectiveness of these alternatives as risk management tools to be evaluated. Furthermore, willingness to pay for unsubsidized and subsidized risk management programs will be calculated. This information coupled with economic theory provides the basis needed to form hypotheses concerning the effects of subsidized livestock insurance. Specifically, the hypotheses will focus on unintentional effects of these programs on beef production. The formation and presentation of these hypotheses will make the results of the study relevant to a wide range of individuals.

In a broad sense, Chapter IV will serve as an example of the effects of risk on agricultural decision making. Specifically, the results will be of interest to livestock producers, who will soon need to evaluate the usefulness of similar insurance products to their respective operations. Such producers can look to these results for an example of how these products may affect their operations. The results from Chapter IV will also be of interest to policy makers who will soon be called upon to construct livestock insurance products. The hypotheses offered in Chapter IV should serve to highlight the concerns and possible dangers of constructing such risk management programs.

Organization of the Study

This study is structured around two central articles (Chapters III and IV). This may differ from previous theses or dissertations encountered by the reader and therefore a brief description of the organization of the study is warranted. Both Chapters III and IV are stand alone articles and can be reviewed independently of each other and all other portions of this thesis. However, the two articles are related by overlapping objectives,

methodologies, and subject matter. Given these overlaps, there is some benefit to presenting the two articles as parts of a larger livestock risk management study.

An introduction to this study has been presented in the preceding sections of this chapter. The review of selected literature in the following section describes related previous research and lays the foundations for the methodologies used Chapters III and IV. Much of the information in Chapters I and II will be repeated with more or less detail within Chapters III and IV. This is a necessary condition if both Chapters III and IV are to be stand-alone articles. This repetition should not detract from the study but rather will serve to reinforce those concepts that are core to the study. There will be similar repetition in Chapter V where a brief summary of the study will be presented. Conclusions from the study will follow this summary.

CHAPTER II

REVIEW OF SELECTED RISK LITERATURE

As outlined in the previous chapter, backgrounding beef cattle is a risky venture. Backgrounders face production and marketing risk. While production risks and their effects on animal performance can be controlled to some extent by sound management practices, they can by no means be eliminated. There are also a considerable number of agricultural economic studies that refer to the riskiness of feeder cattle prices (e.g., Johnson, Spreen, and Hewitt; Harrison et al.). Given this situation, examination of risk management and decision-making criteria for backgrounders is warranted. This chapter, will present a review of some widely accepted methods of examining risky decision making that can be applied to virtually any situation wherein a decision maker must choose between alternatives with risky outcomes. The following two chapters of this study will then apply some of these methods to the specific case of a beef backgrounder.

Choice Under Uncertainty

One of the most widely researched areas in economics is how individuals make decisions and evaluate available alternatives. This analysis is made much more interesting, realistic and complex when risk surrounding the alternatives is considered. In this section, a brief history of risky decision making will be presented. The generally accepted decision-making model of maximizing expected utility will be outlined along with some of its strengths and limitations. After this, alternative decision-making criteria will be given a more thorough review to establish the relevance of their use in the economic analyses of the following two chapters.

Expected Utility Framework

Nearly three hundred years ago Bernoulli proposed that individuals do not base risky decisions solely on the expected value of outcomes but rather on the utility (Bernoulli used the term "moral value") that they expect to receive from the outcomes. Since this time, economists, mathematicians and scientists from many other disciplines have endeavored to fully define the decision-making process when outcomes are uncertain. von Neuman and Morgenstern offer what is perhaps the most widely accepted model for choice facing uncertainty in their expected utility hypothesis.

Under the expected utility hypothesis, von Neuman and Morgenstern begin by stating that utility maximization is a rational goal when a decision maker is faced with risky choices. In this framework, an individual will evaluate the expected value and probability of occurrence of each alternative. This evaluation is carried out by first entering the probabilities and expected outcomes into an individual's utility function. It is then a matter of selecting the combination of available alternatives that maximizes the function. The manner in which individuals choose among available alternatives is then dependent upon their utility function, which reflects attitude toward risk.

Attitude Toward Risk

Some individuals, known as risk preferring or risk seeking, will seek out risky situations in hopes of realizing large payoffs at times. Others will only consider the expected values and give no consideration to the risk surrounding them. These individuals are commonly referred to as being risk neutral. A third possibility, and some would say the most common case, is an individual who avoids risk. This class of risk

averse decision makers actually maximize utility by reducing the variability surrounding the expected value of an outcome. Risk aversion has been the subject of many economic studies and can actually be quantified and used to show how much an individual is willing to pay to manage the risk associated with available choices. A classic example of this is calculating a risk premium or the amount an individual is willing to pay to avoid risk in a given situation.

Risk averse decision makers will seek to manage the risk associated with their alternatives. Risk averse individuals, in many cases, are willing to forgo some amount of expected income (a risk premium) to avoid entering into a risky situation (Arrow, Pratt). This risk attitude is the fundamental basis for risk sharing instruments such as insurance. If a decision maker's utility function is known, the risk premium that he or she will pay to avoid a risky situation can be quantified and used to arrive at willingness to pay for insurance (Pratt).

While both expected utility hypothesis and Pratt's method for calculating risk aversion are theoretically sound, each assumes that the utility function of the decision maker is known and specified. It is possible to specify utility functions using a properly designed set of interview questions (Anderson, Dillon, and Hardaker) and there are several economic analyses that use this approach (e.g., Officer and Halter; Lin, Dean, and Moore). While results from some studies have been promising, there are many factors ranging from type of questions asked (Roumasset, Young) to assumptions regarding functional forms (Lin and Chang) that can bias the specification of utility functions. Furthermore, even if properly implemented, eliciting utility functions is time consuming and arduous. In response to these limitations of the expected utility hypothesis,

alternative decision-making criteria have been developed that do not require that utility functions be known. This study will rely on such methodologies in the interest of circumventing the problems associated with specifying decision makers' utility functions.

Decision-Making Tools When Utility Functions are Unknown

It is neither practical nor, in some cases, even possible to specify a decision maker's utility function. Therefore applied economic decision-making analysis must often rely on alternative procedures of ranking risky alternatives. In general these approaches are designed to present a risk efficient set of choices, which is a subset of all available choices, and allow decision makers to choose from them. Any alternative not in the risk efficient set is said to be risk dominated and should not be considered by the decision maker. Two widely used techniques that follow this general framework are expected value variance (E-V) analysis and stochastic dominance criteria.

Expected Value Variance Analysis

Intrigued by the manner in which investors choose stocks in which to invest, Markowitz sought to explain how individuals choose an optimal investment mix from available risky stocks. Confronted with the problems mentioned earlier associated with specifying utility functions, Markowitz developed a procedure that requires only a measure of risk aversion to simulate utility maximizing decisions. Freund made similar contributions, apparently independent of Markowitz, to the development of a technique known as expected value variance (E-V) analysis.

E-V is widely used in agricultural economic research to model risky decision making. There has been some debate, however, as to whether E-V results are consistent with expected utility hypothesis results. It is now generally agreed upon that E-V analysis is consistent with expected utility theory in three cases: (1) the underlying income distribution is normal (Freund), (2) the distributions of the decision variable differ only by location and scale (Meyer, 1987), and (3) the underlying utility function is quadratic (Markowitz, Tobin). Given its presence in many economic studies and empirical evidence that demonstrates its closeness to expected utility maximizing choices (Levy and Markowitz), E-V analysis is a useful tool for evaluating risky decisions.

In addition to being used in optimization procedures such as Markowitz's investment problem (use of E-V in optimization will be addressed in detail in a following section), E-V can be used as a means of simply ranking mutually exclusive, available risky alternatives (Robison and Barry; Hardaker, Huirne, and Anderson). The E-V framework calculates the risk-adjusted returns or certainty equivalent (CE) for each alternative. The CE is the expected value of an alternative minus the variance surrounding the expected value times a risk aversion parameter. The CE of each alternative can be used to rank the alternatives (Robison and Barry).

Stochastic Dominance Criteria

Unlike E-V analysis, which is based solely on the first two moments of a distribution, stochastic dominance (SD) criteria consider the entire distribution and therefore are generally more robust analytical tools. This is because SD places fewer restrictions on the utility function of the decision maker and bases risk dominance on the

entire cumulative distribution function (CDF) of each alternative. Three types of stochastic dominance are used to rank risky choices. These are first degree stochastic dominance (FSD), second degree stochastic dominance (SSD), and stochastic dominance with respect to a function or generalized stochastic dominance (SDRF).

The least restrictive form of SD is FSD and only imposes the restriction that a decision maker prefers more to less. Consider the CDF's of two income (y) generating alternatives, A and B, represented by A(y) and B(y), respectively. Alternative A dominates B in the sense of FSD if for all values of y $A(y) \leq B(y)$ with at least one strict inequality. In other words, the CDF of A lies to the right of the CDF of B indicating that for any given probability a higher income level is associated with A than with B (Hardaker, Huirne, and Anderson). FSD does have limitations. If the CDF's of available alternatives cross then there is no dominance in the sense of FSD. This occurrence is common when evaluating several similar decisions. So when faced with many alternatives FSD is not likely to eliminate a large portion of them, thereby leaving the decision maker with a large number of alternatives still in the efficient set (Robison and Barry). To gain more discriminatory power, it is necessary to add more restrictions to FSD.

SSD assumes not only that more is preferred to less but that decision makers are risk averse for all values of y. This allows CDF's that cross to be evaluated in many cases. Using the same notation as in the FSD example, A dominates B in the sense of SSD if

$$\int_{+\infty}^{y} [A(y) - B(y)]\, dy \leq 0$$

for all values of y with at least one strict inequality (Hardaker, Huirne, and Anderson). Put into words, SSD compares the areas between the two CDF's. If the area between A(y) and B(y) where A(y) ≤ B(y) (Area X) is greater than the area between A(y) and B(y) where B(y) ≤ A(y) (Area Y) then A is dominant to B in the sense of SDD. However, if Areas X and Y are equal or if Area Y > Area X then SSD cannot discern between the two. Given this limitation of discriminatory power and the assumptions already in place it is very useful to have more robust SD criteria.

Meyer 1977 specifies SDRF, which is a more discriminatory and flexible test for risk dominance. SDRF is the most discriminatory of the SD criteria (Robison and Barry; Hardaker, Huirne, and Anderson). Also, FSD and SSD can be shown to be special cases of SDRF (see Meyer for explanation). These characteristics of SDRF make it the most robust and useful tool for risk analysis.

SDRF attempts to introduce the advantages of knowing decision makers preferences without eliciting utility functions. This is accomplished by relying on the specification of upper (Φ_U) and lower (Φ_L) bounds of the Pratt risk aversion coefficient, which is often easier to estimate than a utility function (Hardaker, Huirne, and Anderson). Assuming an individual has a utility function U(y), then the Pratt coefficient is equal to

(2.1)
$$\frac{-U''(y)}{U'(y)}.$$

Once L and U have been specified then a U(y) that minimizes

(2.2)
$$\int_{\Phi_L}^{\Phi_U} [B(y) - A(y)]U'(y)\,dy$$

is found. If the expression is positive then A is preferred to B. If the expression is zero, SDRF cannot rank the two alternatives. If the expression is negative, B might be

preferred to A. To verify this A(y) – B(y) is substituted into the brackets and the expression is reevaluated. If the minimum of the new expression is positive then B is definitely preferred to A. If the expression is again negative, SDRF cannot rank the alternatives.

Since SDRF is such a robust and powerful SD criteria, decision tools that utilize this approach have been developed. One such tool is the software developed by Raskin and Cochran, of which a thorough explanation is given by Goh et al. This software has been used in numerous agricultural economic risk analyses. For example Williams et al. use the program to evaluate crop insurance policies while Harrison et al. use it to rank feeder cattle marketing strategies.

Calculating Risk Preferences

Both E-V and SDRF require that risk aversion parameters be numerically specified. Once again the issue of the decision maker's utility function being unknown becomes relevant. Much the same as the decision-making criteria reviewed earlier, methods for calculating risk aversion parameters when utility functions are unknown have been developed. McCarl and Bessler offer such a method for estimating the upper bound of the Pratt risk aversion coefficient.

McCarl and Bessler propose a formulation in which the decision maker is said to maximize the lower limit of a confidence interval from a normally distributed set of returns. The formula is

(2.3) $$\Phi = 2Z_{a} / S_{y}$$

where Φ= risk aversion parameter, Z_α= the standardized normal one-tailed Z value of an α level of significance, and S_y is the relevant standard deviation under risk neutral returns. In this formulation, Z_α = 50% is considered to be risk neutral while Z_α greater than 50% is risk averse and Z_α less than 50% is risk preferring. This technique of estimating the Pratt risk aversion coefficient is applicable to E-V and SDRF analysis, as well as any procedure where a measure of risk aversion is required.

Risk in Mathematical Programming Models

While ranking available alternative choices is useful in decision analysis it is often beneficial to identify optimal combinations of alternatives.[2] Mathematical programming has been used extensively, especially in farm management and production economic studies, to do just that (e.g., Anderson, Dillon, and Hardaker; Beneke and Winterboer). Linear programming, a specific form of mathematical programming, is commonly used to model decision making as a constrained optimization. A limitation of basic linear programming models is the absence of risk or uncertainty from the modeling.

There are techniques available that introduce risk into the optimization procedure. Some of these techniques require nonlinear specification of either the objective function or constraints and thus have only become feasible as the computational power of solvers has increased. A description of introducing risk into mathematical programming models follows with more explanation being given to those techniques utilized in this study.

[2] Convex stochastic dominance (CSD) as developed by Fishburn can also be used to arrive at linear combinations of alternatives. As it is not utilized in this study, CSD was not explained in detail.

Objective Function Risk

Many mathematical programming models, such as Markowitz's portfolio selection model, must choose an optimal combination of alternatives from a group of available, risky alternatives. If only the expected value or mean return of each alternative is used to make this selection, the variability surrounding the expected value is ignored and the variability of the objective function value is also ignored. As Bernoulli hypothesized long ago and Markowitz observed in the stock market, decision makers do not make decisions solely on this expected value. One method of introducing the concept of objective function risk into mathematical programming models is an E-V framework.

E-V analysis (Markowitz, Freund), described in some detail in the previous section, considers the variance of the objective function value by considering the variance and covariance of the objective function contributions of the decision variables. Specifically, the expected objective function value is penalized by a risk aversion coefficient times the variance around the expected objective function value. This forces the optimization to consider objective function risk with the goal of simulating utility maximizing decision making. Numerous agricultural economic studies have utilized E-V analysis in a mathematical programming framework. For example, Boisvert and McCarl list many publications, too numerous to mention here.

One concern associated with E-V formulation is that it results in a quadratic objective function. Previously this has been a concern to some researchers given the complexity of a nonlinear model and the limitation of computational solvers. As a response to this problem Hazell developed the MOTAD (Minimization of Total Absolute Deviations), which linearly approximates E-V results based on total absolute deviations.

However, a nonlinear objective function is not ordinarily a problem to modern solvers. McCarl and Onal state that it is generally more efficient to allow solvers to deal with nonlinear objective functions than to perform a linear transformation. Since such solvers have been available it has been less necessary to rely on Hazell's MOTAD formulation.

An additional concern that has been raised is that the assumption of a quadratic utility function is quite restrictive. If this assumption is imposed it implies that absolute risk aversion increases with the level of payoff (Hardaker, Huirne, and Anderson). In response to this issue, Lambert and McCarl introduced DEMP (Direct Expected Maximizing Nonlinear Programming). This technique is less restrictive in regard to form of the objective function but requires that the utility of wealth function be specified. While utilized to some degree DEMP is not as widely accepted as E-V analysis to model objective function risk.

Two other techniques that consider objective function risk are Safety First (Roy) and Target MOTAD (Tauer). Safety First assumes that first and foremost a decision maker will make decisions such that some objective function value threshold is met. Similarly Target MOTAD considers a target income level and maximum allowable shortfall from this target. While useful to some degree these techniques are not as powerful or robust as E-V analysis, given that they do not consider the total variance of objective function contribution and objective function value. Therefore, neither is as observable in the economic literature as E-V analysis.

Technical Coefficient Risk

There can also be risk involved in the technical coefficients of inputs. That is, variability in the decision variables contributions toward the fulfillment of model constraints. This form of risk has a less pronounced presence in economic studies relative to objective function risk but some approaches are available.

Merrill offers an approach that is very similar to E-V analysis, both technically and intuitively. Merrill suggests that a given constraint can be made more binding by adding a penalty term consisting of a risk aversion parameter times either the variance or standard deviation around the expected contributions of decision variables to that constraint. This approach introduces nonlinearity into the constraints of mathematical programming model. This has historically been more troublesome to deal with than objective function nonlinearity. Wicks and Guise offer an alternative formulation that linearly approximates the variance or standard deviation of technical coefficients. They utilize a MOTAD approach to arrive at total deviations. The measure of total deviations is then transformed into the estimated standard deviation using a variant of the Fisher constant.

While the Wicks and Guise approximation was warranted at one time, solvers are now powerful enough to deal with nonlinear constraints directly in some cases. McCarl and Onal cite General Algebraic Modeling Systems (GAMS) MINOS algorithm as an example of one such solver. Furthermore, this study will demonstrate that this nonlinearity can be modeled directly without unreasonable complications and that Merrill's approach can be feasible.

Right Hand Side Risk

The final form of risk that is sometimes modeled in mathematical programming is right hand side (RHS) or available resource variability. Cocks offers discreet stochasitc programming as one technique for modeling RHS risk. While utilized to some degree, models often become cumbersome if numerous random variables are present. Researchers wishing to avoid this potential modeling difficulty often use Chance Constrained Programming. McCarl and Spreen state that Chance Constrained Programming is one of the most commonly used techniques of modeling RHS risk. Charnes and Cooper introduced this technique to deal with RHS uncertainty. The major requirement is that the decision maker be able to decide the frequency with which a constraint must be satisfied. Given this information and the probability distributions of the RHS, risk associated RHS limits can be modeled.

Study Application of Risk Analysis

The tools presented in this chapter can be used to model many forms of risk in agricultural decision making. The following two chapters evaluate specific cases relying upon some of these tools. Chapter III will introduce E-V analysis and Merrill's approach into a minimum cost feed ration linear programming model to account for price and nutrient variability, respectively. Chapter IV will utilize E-V and SDRF as means of evaluating government subsidized livestock insurance and comparing it to current risk management strategies.

CHAPTER III

DETERMINING OPTIMAL RATIONS CONSIDERING FEED INGREDIENT NUTRIENT AND PRICE RISK

Introduction

The large amount of agricultural economic literature that addresses uncertainty in production agriculture indicates the importance of the ability of agricultural decision makers to manage risk (e.g., Anderson, Dillon, and Hardaker; Boisvert and McCarl; and Hardaker, Huirne, and Anderson; Robison and Barry). Livestock producers are no exception and must make production decisions, such as input selection, in an uncertain environment. Feed is arguably the most important input, next to the actual animals, for a livestock operation in terms of impact on total expenses. This is evident in 1999 National Agricultural Statistics Service (NASS) data for all livestock farms in the United States. NASS reports that expenditures on feed in 1999 comprised 26.1% of total farm expenditures, representing the single greatest farm expense. Given this importance of feed to livestock operations, the selection of minimum cost feed rations using linear programming has, historically, been given considerable attention in agricultural economic research. However, the consideration of the risks associated with feed ration selection in the agricultural economic literature has been very limited.

Traditional linear programming minimum cost feed ration models are solved with the assumptions that all feed ingredient prices (objective function contributions) and nutrient levels (technical coefficients) are known with certainty. These models are available to producers in the form of decision-making tools that formulate minimum cost

rations subject to nutritional constraints. Once a producer chooses a ration for a typical backgrounding program, he or she will generally prefer to feed the same ration to a group of animals for the entire time that they are on feed. Depending on the size of the operation and its feed storage capacity, this will usually require multiple purchases of the feed ingredients during the feeding period. Therefore, if a ration is chosen by a model imposing the above assumptions, the producer is fully exposed to variability in the nutritional composition of feedstuffs from one purchase to the next. Furthermore, in the absence of any forward contracting or hedging activity, the producer is also vulnerable to fluctuations in feed ingredient prices. This ration will not be optimal to the producer if he or she is risk averse regarding nutrient variability, price fluctuation, or both. In past research, it has been necessary to impose the assumptions of certain prices and ingredient composition due to the limited computational power of solvers and the limited data on the variability of the nutritional composition of feedstuffs. The ability of modern solvers to deal with nonlinearity and more complex models in general coupled with the availability of more complete feed ingredient nutritional data from the National Research Council (NRC) now make it possible to employ relatively unused mathematical programming techniques and avoid imposing either of these restrictive assumptions.

A mathematical programming model that determines optimal feed rations by considering both feed ingredient nutrient and price variability can be achieved by relaxing both the assumption that technical coefficients are known with certainty and that objective function contributions are constant. Merrill offers an approach for dealing with technical coefficient uncertainty. Despite its intuitiveness, limitations of optimization solvers have prevented the utilization of this technique in any formal agricultural

economic literature since its conceptualization. The recent availability of the aforementioned NRC feed ingredient nutrient variability data coupled with the need to address feed ingredient nutrient variability make it possible and worthwhile to utilize this technique in the ration selection process. Essentially, Merrill's approach allows the probability of satisfying constraints (e.g., nutritional constraints) to be increased subject to a decision maker's aversion to technical coefficient risk. In the case of feed ration selection, this will result in a greater ability to accurately predict animal weight gain and total days on feed. The assumption that objective function contributions are constant can be relaxed using expected value variance (E-V) analysis. E-V is a technique that is widely used to model uncertainty of objective function contributions in agriculture and allows decision makers to choose alternatives with a more a predictable net income or in the case of a feed ration model, a more predictable total ration cost. Greater ability to predict total days on feed and ration cost results in greater ability to predict total feed cost. This enhanced ability to predict total feed cost results in a less variable net income and can be accomplished by expanding the traditional minimum cost feed ration model using the aforementioned modeling techniques.

This study will introduce these two components into the economic analysis of feed ration selection. This will result in a more comprehensive mathematical programming model that incorporates consideration of both nutrient and price variability into the ration selection process. Rations chosen with these considerations would be optimal to a decision maker subject to his or her level of aversion to each type of risk. In addition to this practical application, this study will make other worthwhile contributions. It will be one of the only applications of Merrill's technique, since its development, to

deal with technical coefficient uncertainty, which is generally difficult to address in any mathematical programming model. Furthermore, introduction of the NRC feed ingredient nutrient variability data will represent one of the first uses of this data in economic research.

The general objective of this study is to provide insight into how livestock and dairy producers can manage risks associated with selecting a feed ration. Specifically, this study analyzes how the consideration of feed ingredient price risk and nutrient variability affects the composition of optimal beef backgrounding[3] rations. In addition to making the aforementioned contributions, information resulting from this study will serve as a starting point for more advanced decision-making tools for large-scale livestock producers such as feedlots and dairies. Specifically, tools can be designed to consider managing price risk and nutrient variability of feed ingredients and selecting feed rations that are optimal to individual producers.

Literature associated with minimum cost feed rations, E-V analysis, and technical coefficient uncertainty will be presented and discussed to establish the theoretical framework of input selection facing uncertainty and to develop a methodology that specifically addresses feed ingredient price and composition risk. The economic model incorporating nutrient and price risk management will be defined. Finally, the results of this model will be presented for analysis and discussion with conclusions following.

[3] Backgrounding, as referred to throughout this paper, indicates producers who buy weaned calves weighing approximately 500 pounds to be sold at approximately 750 pounds. The 250-pound gain is achieved through a 4 to 5 month feeding program that utilizes both hay and feed concentrates.

Background

In basic production theory, prior to development of any risk analysis framework, a producer would know, with certainty, the prices and compositions of all inputs. In this scenario the minimum cost combination of feed ingredients to achieve a target level of average daily gain could be found by plotting the isoquant that represents all possible combinations of feedstuffs that would achieve this gain and subsequently finding the tangency with an isocost line. Since attributes of the inputs are deterministic, this point would also represent the optimal combination of feed ingredients that meet the nutritional requirements. In the real world, this is obviously not the case. Neither input prices nor the technical aspects of inputs (i.e., production effects) are known with certainty. These uncertainties will affect producers differently, depending on their attitude toward price risk. There have been adjustments to economic analysis to reflect these responses to risk. One economic analytical tool that identifies optimal input combinations from feasible inputs is mathematical programming. Mathematical programming has also become more flexible to deal with these uncertainties that are present in the real world of agricultural decision making.

The use of linear programming models that impose the above assumptions to select minimum cost feed rations has a long and well-established history. Stigler considered the minimum cost diets that exactly meet the nutrient requirements for human subsistence in one of the earliest examples prior to the full development of linear programming. However, the basic concept of satisfying a set of nutritional constraints while minimizing the cost of the diet is evident in Stigler's work. Traditional minimum cost feed ration models are set up in this very way and this basic formulation can be

modified to balance any type of ration for which these constraints are known (McCarl and Spreen).

Waugh was among the first to apply this model formulation to the selection of minimum cost livestock feed rations. Specifically, Waugh laid out a procedure using the then novel linear programming to formulate minimum cost dairy rations, noting that if all prices and nutritional compositions of feeds are known and properly specified then the resulting ration is indeed the minimum cost feasible ration. McCarl and Spreen state that, after Waugh's efforts, the determination of minimum cost feed rations for livestock has been one of the most common uses of linear programming (see Ashour et al.; Beneke and Winterboer; and Dorfman, Samuelson, and Solow for discussion and examples). In addition to a pronounced presence in academic literature of the basic minimum cost feed ration methodology, there is also plethora of software packages designed for applied use by producers (e.g, Taurus from The University of California at Davis).

While consideration of risk in studies focusing on minimum cost feed rations for livestock and dairy production is not prevalent, some examples exist. Thomas et al. offer an analysis of minimum cost dairy rations. Their study focused on the fact that the cost of relevant nutrients are not constant, even though traditional minimum cost feed ration models treat them as such. Thomas et al. address this issue by estimating the cost of net energy for lactation (NEl), total digestible nutrients (TDN), and crude protein (CP) based on low, medium, and high prices of corn (a very common energy component of dairy rations). They go on to show that using constant nutrient cost generally underestimates the cost of the ration. Other studies examining nutrient variability include Chen as well as Rahman and Bender. Each of these studies provides an analysis based on a target

probability for a constraint. Chen focuses on the protein requirement. In this formulation only protein variability is considered and an iterative modeling procedure is used. Chen provides an example of formulating minimum cost poultry rations and shows that as the target probability of meeting protein requirement increases so does ration cost. While this technique was appropriate at the time, modern solvers now allow for more efficient and exact modeling.

Prevatt et al. offer an analysis of the feasibility of backgrounding and finishing cattle in Florida. Minimum cost feed rations for backgrounding and finishing were determined based on available local and imported feeds. The study found that the variation of feed costs over time drastically affected the variability of net returns to hypothetical backgrounding and finishing operations in Florida. Using several levels of required net returns to management along with required rates of return associated with the risk of the returns, Prevatt et al. concluded that acceptance of beef backgrounding and finishing operations would depend upon individual risk preferences. The study also confirmed that this risk associated with the livestock operations was due, in no small part, to variation over time of feed ingredient prices. While both Thomas et al. and Prevatt et al. highlighted the effects of risk on the traditional approach to choosing minimum cost feed rations, no attempt was made to implement different modeling techniques. This study will implement Merrill's technique for modeling technical coefficient variability and an E-V framework to address both nutrient variability and price risk, respectively.

Relative to management of objective function risk, the consideration of technical coefficients uncertainty has a considerably less pronounced presence in the economic literature. Merrill offers one method for dealing with technical coefficient risk in which

the standard deviation (or variance) of the technical coefficient values are used to calculate the total standard deviation (or variance) of the constraint value based upon which decision variables enter the optimal solution. This standard deviation (or variance) is multiplied by a risk aversion parameter. The product of the two make up a penalty term that effectively makes the constraint more binding as the standard deviation of the technical coefficient value increases. Constraints modified with this approach are nonlinear. Due to the complexities associated with nonlinear constraints this modeling technique has gone relatively unused.

Despite its intuitiveness, the modeling concerns have all but prevented use of Merrill's technique. However, Wicks and Guise do offer a linear approximation of Merrill's approach. While this approach is a variation of Merrill's technique, it represents the most similar technique present in economic literature. Therefore it is worthwhile to briefly review the Wicks and Guise study. Wicks and Guise apply their modeling technique to the variability of feed available from pasture due to weather and other exogenous factors to Australian sheep and grain farms. In the Wicks and Guise study, absolute deviations of pasture yield were calculated using Hazell's MOTAD method. The deviations were coupled with a variant of the Fisher constant to arrive at standard deviations. Several levels of risk aversion were then analyzed to represent responses to technical coefficient risk across different producer risk attitudes. Intuitively, this approach is very similar to an E-V framework. That is, to decrease the variability of technical coefficients, a decision maker will realize a lower net income and depending on the individual's attitude toward risk, will make tradeoffs accordingly. Wicks and Guise even suggest that solutions from such a model should trace out a risk efficient frontier

similar to that of a usual E-V framework. Furthermore, they state that the frontier should also provide a means of ranking farm plans for these sheep and grain operations much the same as Thompson and Hazell rank risk efficient farm plans using E-V analysis.

McCarl and Spreen offer nutrient variability in feedstuffs, one issue on which this study focuses, as an example textbook application of the Wicks and Guise approach. However, in their example, a fixed amount of feed is being mixed as opposed to a ration mixed for the needs of specific animals and no empirical data are used to arrive at the nutrient variability of feed ingredients. Other than the example given by McCarl and Spreen, Tice offers one of the only applications of the Wicks and Guise technique outside of the original study.

E-V analysis (Markowitz, Freund) is very widely published in agricultural economic literature and deals with uncertainty of contributions to the objective function of a mathematical programming model, such as the prices of feed ingredients in a minimum cost feed ration model. However, there has been considerable debate as to whether E-V analysis is a theoretically appropriate method to represent optimal decision making. It is generally agreed upon that expected utility theory (von Neuman and Morgenstern) provides the theoretical base for choice facing uncertainty. E-V analysis can be consistent with expected utility theory in three cases: (1) the underlying income distribution is normal (Freund), (2) the distributions of the decision variable differ only by location and scale (Meyer), and (3) the underlying utility function is quadratic (Markowitz, Tobin). If any of these conditions are present it is generally agreed upon that E-V analysis is indeed consistent with expected utility theory. Many applications to agricultural decision making have used the satisfaction of one or more of the

aforementioned conditions to justify the use of E-V to model the decisions of producers when faced with net income risk (Boisvert and McCarl; Dillon, 1999; Dillon, 1992). In addition to these studies empirical evidence demonstrates the closeness of E-V analysis to the expected utility maximizing choices (Levy and Markowitz). Given this demonstrated consistency of E-V analysis with economic theory and its extensive use in modeling agricultural risk, it is an appropriate way to model an agricultural producer's response to uncertainty of input or output prices.

The well-established history of the feed ration linear programming formulation and the obvious impact of uncertainty on the selection of an optimal feed ration warrants the expansion of that formulation to allow producers to manage the risks associated with selecting a minimum cost feed ration. The importance of nutrient variability in feed ingredients is evident in recent attention given it by animal science studies (Cromwell et al., DePeters et al.). This importance makes it appropriate to give this form of risk ample consideration in selecting feed rations. Expanding the traditional model to include the Wicks and Guise technique offers a method of doing just that. The increasing acceptance of E-V analysis as a means of dealing with objective function risk suggests that it is a suitable means of addressing the uncertainty of feed ingredient prices.

In the following section the data necessary to specify an economic model that combines the traditional minimum cost feed ration model with both Merrill's approach and an E-V component is presented. With this data the economic model is specified. Results showing how producers can utilize the model in the selection of a feed ration to manage both price risk and nutrient variability are then presented with conclusions following.

Data

Feed ingredient prices were collected from *Feedstuffs*, for the Chicago market, between 1993 and 1999, with four exceptions. Alfalfa hay and prairie grass hay prices were collected from the USDA Oklahoma weekly hay report for the same time period. Hay data were collected from Oklahoma due to the fact that no prolonged hay price series for the Chicago market could be found. Current bulk prices for limestone and dicalcium phosphate were used in lieu of a historic price series. Historic prices of these supplements are not generally recorded due to the extremely low variability and therefore could not be obtained. This should not pose any limitations to the study since supplements such as limestone and dicalcium phosphate generally comprise a very small component of total ration cost and have price series that exhibit little variability. All prices were left in nominal terms in the interest of simulating real world conditions in which producers face the risks associated with nominal prices of inputs. Descriptive statistics for the price series of all feed ingredients being considered are presented in Table 3.1. In addition to prices of feed ingredients, expected nutritional composition and variability must be specified.

The expected levels and variability of nutrients in all feed ingredients were obtained from the 2001 NRC Nutrient Requirements of Dairy Cattle. These data rely on various sources including the 1996 (and 2000 Update) NRC Nutrient Requirements of Beef Cattle. The expected levels and standard deviations of the relevant nutrients are shown in Table 3.2. It should be mentioned that the standard deviations for NEg and NEm were not reported explicitly. This is due to the fact that direct measurement of levels of NEm and NEg requires laborious feeding experiments. The alternative to

feeding experiments is to approximate amounts of the energies using accepted functional relationships, as defined by the NRC, between each of them and acid detergent fiber (ADF). NRC 2001 reports ADF values and standard deviations allowing the standard deviation of ADF to be taken through the appropriate transformations to arrive at standard deviations for NEg and NEm. A mathematical presentation of this transformation is presented in the Appendix to this chapter. With the nutritional composition of the available feedstuffs specified, it is also necessary to determine the nutritional requirements of the animals to set the right hand side lower limits for the nutritional constraints within the model.

The nutrient requirements for medium frame steers were obtained from the 1984 Edition of NRC Nutrient Requirements of Beef Cattle. Instead of using the reported tables, the equations that specify these requirements as they relate to body weight, target average daily gain, and dry matter intake were used. This allows the model to determine a ration given only a body weight and target average daily gain and does not limit these values to integers. These equations are presented as a part of the economic model in the following section. This set of data fulfills the requirements of the specification of an economic model that considers both nutrient and price variability in the selection of feed rations. These data are sufficient to specify a model that will address both feed ingredient nutrient variability and price fluctuation.

The Economic Model

The economic model in this study expands the traditional minimum cost feed ration model to the selection of rations that are optimal, given individual risk aversion, for a typical beef backgrounder facing uncertain feed ingredient prices and variable

nutrient levels in available feedstuffs. Producers will respond differently to these uncertainties, depending on their attitude toward risk. The methodology in this particular study assumes that the producer will minimize total feed costs depending on his or her individual aversion to feed ingredient price risk and variability of nutrients in those feed ingredients and that this selection of an optimal ration is the equivalent of maximizing utility.

The model is designed to choose the amount of each feed ingredient, in pounds, as fed per-head-per-day. The objective function is specified as follows:

(3.1) $$\min \ \overline{RC} + \Phi \sum_{t} \left(\frac{1}{T-1} \right) \left(RC_t - \overline{RC} \right)^2 .$$

The objective function is minimized subject to the following constraints:

(3.2) $$\sum_{t} \frac{1}{T} RC_t - \overline{RC} = 0$$

(3.3) $$\sum_{j} p_{j,t} F_j - RC_t = 0, \ \forall t$$

(3.4) $$\sum_{j} a_{i,j} F_j - \Psi \left(\sum F_j^2 s_{i,j}^2 \right)^{1/2} = LL_i, \ \forall i$$

(3.4a) $$\frac{\sum_{j} a_{NEm,j} F_j}{\sum_{j} F_j} - NEm_d = 0$$

(3.4b) $$\left[W^{0.75} \left(0.1493 NEm_d - 0.0460 \ NEm_d^2 - 0.0196 \right) \right] - DMI = 0$$

(3.4c) $$\frac{\left(3.34 DMI + 2.75 W^{0.5} + 2 W^{0.6} + GP \right)}{0.594} - LL_{pr} \leq 0$$

(3.4d) $0.077W^{0.75} - LL_{NEm} = 0$

(3.4e) $0.0557W^{0.75}(ADG)^{1.097} - LL_{NEg} = 0$

(3.4f) $2(0.0154W + 0.071GP) - LL_{Ca} = 0$

(3.4g) $1.18(0.028W + 0.039GP - LL_{P} = 0$

(3.4h) $\left(\frac{268 - 1.638W^{0.75}ADG^{1.097}}{ADG}\right)ADG = GP$

(3.5) $F_j \geq 0, \ \forall j$

Indices include:

t = time period (i.e., week) with T representing the total number of ,
j = individual feed ingredients and may represent corn, soybean meal (44% crude protein), soybean meal (49% crude protein), corn gluten feed, distiller's dried grain, brewer's dried grain, dehydrated alfalfa,wheat middlings; alfalfa hay, or prairie grass hay and
i = individual nutrients and may represent net energy for maintenance (NEm), net energy available for gain (NEg), protein (pr), Calcium (Ca), or phosphorous (P)
d = indicates that the amount of a nutrient is measured as fed in the actual ration.

Endogenous decision variables are:
RC_t = ration cost in time t,
$\overline{RC}$ = mean ration cost over all t,
F_j = Feed ingredient j, and
DMI = total dry matter intake of pounds of feed per day by an animal.

Exogenous components of the model are:
$p_{j,t}$ = price of the jth feed ingredient in time t,
W = body weight of the animal in kilograms and,
ADG = target average daily weight gain in kilograms,
GP = grams of protein deposited in the muscle tissue of an animal, and
$\sigma^2_{i,j}$ = the variance of the ith nutrient in the jth feed ingredient

Right hand side lower limits are:
LL_i = lower limits of all nutrients (i).

Risk aversion parameters are:
Ψ = nutrient variability aversion parameter and
Φ = price risk aversion parameter.

The objective function (Equation 3.1) minimizes the risk-adjusted, mean total ration cost per head per day. This is represented by $\overline{RC}$ less a penalty for variability in RC_t. This penalty is composed of the variance of RC_t across all time periods multiplied by the price risk aversion parameter Φ. This price risk aversion parameter was specified using the approach offered by McCarl and Bessler in which $\Phi = 2 Z_\alpha / S_y$. In this formulation Z_a = the standardized normal one-tailed Z value of an a level of significance, and S_y is the relevant standard deviation under risk neutral decisions levels. In this study, S_y was calculated using 500 pound medium frame steers being fed to achieve two pounds of average daily gain (ADG) by a producer with a risk neutral attitude. This class of livestock is very common among Kentucky backgrounders and the risk aversion parameters resulting from this standard deviation should adequately represent a backgrounder's attitude toward price variability across all sizes of livestock and all target average daily gains. The E-V quadratic variance term obviously introduces non-linearity into this objective function. The availability of non-linear programming (NLP) solvers makes it relatively easy to deal with this nonlinearity. McCarl and Spreen suggest that in most cases it is no longer necessary to attempt to transform the objective function into a linear form and that it is often more efficient to allow the solver to deal with the nonlinearity. The objective function is minimized subject to several necessary constraints (Equations 3.2 to 3.5).

Equations 3.2 and 3.3 define RC and $\overline{RC}$. The sum of the prices of each feed ingredient ($p_{j,t}$) times the amounts of the corresponding feed ingredient included in the ration (F_j) is equal to the total ration cost per head per day in time period t (RC_t). The

mean of RC_t across all t is $\overline{RC}$. In addition to these constraints, the ration must meet certain nutritional requirements (also including a risk aversion component) as show in Equation 3.4. Specifically, the ration must contain adequate amounts of NEm, NEg, protein, calcium, and phosphorous. Equations 3.4a to 3.4h define nutritional lower limits for equation 3.4.

Lower limits (LL_i) for all nutrients considered by this model were specified using equations in the 1984 NRC Nutrient Requirements for Medium Frame Steers (as shown in Equations 3.4a to 3.4h).[4] Equations 3.4a to 3.4c define the protein requirement. This model uses the exact equations defined by the 1984 NRC guidelines to define this requirement. In the past feed ration selection models have approximated dry matter intake as opposed to calculating the actual NEm in the ration in megacalories per kilogram (NEm_d) and DMI directly. This is largely due to the fact that the relationship between NEm_d, DMI, and LL_{pr} is nonlinear. This particular study opts for calculation procedure of the protein requirement presented in NRC 1984 to avoid relying on an exogenous approximation of DMI. The nonlinear constraints did not pose a problem to the NLP solver and this method will be closer to a true optimization than an approach that utilizes an approximation. Calculation of the lower limits (LL_i) for NEm, NEg, calcium, and phosphorous, which are linear, are shown in equation 3.4d through 3.4h, respectively.

Another factor that separates this model from those in previous feed ration selection studies is that is does not assume that the amounts of all nutrients in all available feed ingredients are known with certainty. Nutritional constraints for NEm,

[4] The 1984 version was chosen over the more recent editions, in part due to the use of crude protein (as opposed to metabolic protein) in specifying the protein requirements. This avoids certain technical complexities. These complexities warrant consideration in practical ration balancing applications and nutritional research but would add very little to this specific discussion.

NEg, and protein are expanded from traditional nutritional lower limit constraints to address the variability of these nutrients in available feed ingredients. Specifically, these constraints are made more binding by multiplying the nutrient risk aversion parameter (Ψ) by the standard deviation of the relevant nutrient in the entire ration ($\left(\sum F_j^2 \sigma_{i,j}^2\right)^{1/2}$). Only binding constraints are affected by this approach (Wicks and Guise; McCarl and Spreen). However, this poses no real problem since, as noted by McCarl and Spreen, uncertainty in non-binding constraints is of little concern to a decision maker. However, for binding constraints it is reasonable that a decision maker would seek to manage the uncertainty surrounding the technical coefficients of inputs.

The nutrient risk aversion parameter (Ψ) was specified assuming nutrient levels across feed ingredient samples are normally distributed. Standardized normal one-tail z values corresponding to levels of risk aversion represent nutrient risk aversion parameters. This ensures that the binding constraint(s) become more binding in a way that shows an individual's desire to increase the probability of realizing the required nutrient level in a feed ration. For example, to represent an individual who would prefer to be certain of realizing at least the required amount of a nutrient 65% of the time (as opposed to 50% of the time for risk neutral), the z score that represents the 65^{th} percentile of the normal distribution was used. The two exceptions to this are the constraints for phosphorous and calcium. For these constraints it is assumed that Ψ is equal to zero. While the levels of calcium and phosphorous do vary in many available feed ingredients their levels are, for all practical purposes, constant in limestone and dicalcium phosphate. Since these ingredients can be used to fulfill the entire requirement for both calcium and phosphorous and still represent less than 3% of the ration cost, it is reasonable to assume

that decision makers would not devote time and energy to managing the variability to these minerals in the ration. Variability of nutrients for all feedstuffs is defined as the standard deviation of nutrients ($\sigma_{i,j}$) as reported in the 2000 NRC Nutrient Requirements of Beef Cattle. This availability of standard deviations of nutrients in selected feed ingredients makes it possible to use these to directly model Merrill's approach.

With the economic model defined in this section it is possible to select rations that are not simply minimum cost but optimal to a decision maker given his or her aversion to nutrient variability and price risk. The model will be specified for specific cases in the following section. The results of these specifications will be presented and discussed. Following these results a brief summary along with conclusions will be offered.

Selection of Optimal Rations

Optimal rations were chosen for numerous model specifications to account for different weights of livestock (W), different target average daily gains (ADG), and various levels of aversion to nutrient and price risk. The livestock classification of medium frame steers was used in all cases and W was varied from 400 to 800 pounds in 100-pound increments to account for the growth of animals in a typical backgrounding program. ADG was varied across 1.0, 2.0, and 3.0 pounds per day. Nutritional requirements for a 500-pound, medium frame steer, as calculated by the model, are as follows: 666.50 grams of crude protein, 29.31 grams of calcium, 14.70 grams of phosphorous, 2.93 megacalories of available NEg, and 4.51 megacalories of NEm. Requirements for all other sizes of livestock considered under each target ADG are not reported. It is important to again note that these requirements are reported as calculated

by the model given only W and ADG. Varying levels of both nutrient and price risk aversion were specified by varying Z_a in the calculation of each. Varying levels of aversion to nutrient variability (Ψ) were considered over a wide range of significance levels. Only the levels of 0.50 (risk neutral), 0.60 (low aversion), 0.80 (medium aversion), and 0.90 (high aversion), indicating a desire to realize at least the required amount of nutrients 50%, 60%, 80%, and 90% of the time, are reported. Significance levels of 0.50 (risk neutral), 0.75, 0.80, and 0.85 represent the four reported levels of price risk aversion. These represent an individual's preference to realize the same or lower feed costs 50%, 75%, 80%, or 85% of the time, respectively.

Optimal rations were then determined for all combinations of W, ADG, Ψ, and Φ. However, given the substantial amount of information this generated (240 separate model runs), only the optimal ration compositions for 500-pound medium frame steers fed for 2 pounds ADG will be discussed.[5] The compositions of the rations are presented in Table 3.3. The corresponding mean costs, standard deviations of costs, and coefficients of variation of cost are presented in Table 3.4. It should be noted that, while these rations meet basic nutritional needs, no formal constraint addresses the amount of roughage in the diet. A certain level of roughage is needed to maintain rumen function. Also, no formal constraint addresses total intake. Inclusions of these constraints would allow for the calculation of more practical diets. However the risk management principles that are central to this study can be adequately demonstrated without their inclusion. Thus omitting these constraints should not detract from the overall value of the study. From

[5] Results of other specifications were, qualitatively, very similar with respect of both price and nutrient risk management. These results are available upon request from the authors.

these results it is possible to determine the model responses to both nutrient and price risk aversion as well as the costs of these responses.

From the twelve available ingredients, the model balanced rations primarily using either a combination of corn and wheat middlings or corn and corn gluten feed. Distiller's dried grain entered in small amounts as the aversion to nutrient risk was increased. Limestone entered every ration as an inexpensive, non-variable source of minerals. The amounts of limestone are very small and of consistent magnitude. In the remainder of the discussion, no further mention will be given to limestone as a component of the ration. These basic trends in the composition of the feed rations provide for interesting discussion concerning the management of price and nutrient risk to arrive at optimal rations.

The minimum cost feasible ration assuming no aversion to nutrient or price risk is composed approximately equal amounts of corn and wheat middlings. As aversion to nutrient risk is increased with no consideration given to price risk, the model effectively manages the variability of NEg, as the NEg constraint is the most binding constraint. Constraints for NEm, protein, calcium, and phosphorous are, in most cases, not binding and are therefore are virtually unaffected by Merrill's approach. As nutrient risk aversion is increased to the Low and even Medium level, the model response is to simply add more of the feed ingredient that comprised the minimum cost ration. This appears to be the least cost method of increasing the probability of meeting the NEg requirement, since the increase in the mean amount of available NEg will be greater than that of the standard deviation. The result is a total ration with a less volatile amount of NEg, in terms of coefficient of variation.

An illustration of the risk management response described above is illustrated by increasing the probability of meeting the NEg requirement from 50% to 80% while ignoring price risk. This adjustment involves increasing the amount of corn and wheat middlings by 0.84 and 0.02 pounds, respectively. The result of this ration adjustment is that, with all external factors such as weather and health being equal, the probability that the animals will gain at least 2 pounds per day is increased from 50% to 80%. The amount of NEg in the risk averse ration is less variable, in terms of the coefficient of variation. This is shown in Table 3.5, which displays the effects of risk management on variability of NEg. Specifically, the coefficient of variation decreases by 0.40%. However, as shown in Table 3.4, this increase in certainty of realizing the NEg requirement comes at a cost of about $0.03 per head per day. It is also worthwhile to note that managing for nutrient variability, while ignoring price variability, generally results in a moderate increase. This tradeoff between a higher ration cost and a higher probability of realizing the required NEg is presented as a frontier of nutrient risk efficient points in Figure 3.1. Selecting among rations located on the frontier would require a decision maker to compare the risk management benefit to the cost of achieving it given their attitude toward risk and choose accordingly. In addition to controlling the variability of the NEg in the ration, the model can select rations with a more stable price series.

Upon introduction of aversion to price risk, assuming nutrient risk neutrality, the model looks to substitute among available feedstuffs to arrive at an optimal ration. At the 75% price risk aversion level, wheat middlings leave the optimal combination entirely and corn gluten feed enters. This is to be expected since, as shown in Tables 3.2 and 3.1,

the composition of the two feeds are very similar while corn gluten feed has a price series that is roughly half as variable, in terms of coefficient of variation. All rations that are balanced assuming some level of aversion to price risk are primarily comprised of corn and corn gluten feed. As price risk aversion increases, however, the amounts of corn gluten feed in the ration increases and the amount of corn decreases, proportionally (See Table 3.3). This substitution of corn gluten feed for corn in optimal ration results in a decrease in the standard deviation and coefficient of variation of the price of the ration. Table 5 shows this reduction in volatility. Much the same as nutrient risk management, price risk management comes at a cost. Specifically, the optimal ration for a producer who is 75% price risk averse costs about $0.01 more per head per day compared to the risk neutral cost minimizing ration. However the coefficient of variation is only 17.06%, compared to 23.65% for the risk neutral optimal ration. Depending upon an individual's attitude toward price risk, any of these rations listed in Table 3.3 might be optimal. It would be up to the decision maker to select among all risk efficient choices, which would include some ration combinations not reported in Table 3.3, to arrive at a ration that matches his or her desire to control price variability.

The set of available ration choices is presented in a mean-variance framework as an E-V frontier in Figure 2. For the sake of a smoother graph, the figure contains several levels of risk aversion in addition to the reported levels. This E-V frontier is presented as a set of risk efficient expenses and thus appears as the mirror image of the more common presentation of a set of returns. This frontier shows the possibility of accepting higher expenses for the sake of less variable feed expenses and therefore the ability to manage net income risk with the selection of optimal feed rations. Presenting such a frontier to a

producer allows a risk averse producer to see the increases in mean costs necessary to achieve a given variance of feed expense and then make tradeoffs to arrive at his or her optimal solution (McCarl and Spreen). For example, in a 150-day backgrounding program, to achieve the price variance associated with the optimal ration for the most price risk averse producer $3.00 of revenue per head would be forgone. While price and nutrient risk can be managed independently, the model can consider both simultaneously.

It is important to examine the way in which managing for price risk affects nutrient variability and vice versa. For instance, moving from price risk neutral to the 75% level of price risk aversion while ignoring nutrient risk increases the standard deviation of NEg while the mean level remains the same. This results in an increase in the coefficient of variation of NEg from 16.65% to 20.32%. While other examples are less drastic, accounting for higher levels of price risk aversion within a given level of nutrient risk aversion always increases the variability (in terms of the coefficient of variation) of NEg. On the other hand, managing for nutrient risk while holding price risk constant generally results in a slight decrease of the coefficient of variation of total ration cost. The model has the capacity to manage both types of risks, but there are tradeoffs for doing so. Depending upon a decision maker's attitude toward nutrient variability and/or price risk he or she can evaluate these tradeoffs and determine individual optimal rations accordingly. The results of this study indicate that after such an evaluation the ration that is optimal to a nutrient or price risk averse producer will be noticeably different than the minimum cost ration that would be recommended by traditional models.

Summary and Conclusions

Given the impact of feed cost on total livestock production expense the determination of a feed ration warrants careful consideration by livestock producers. Historically, agricultural economic research has approached this procedure by identifying the minimum cost combination of available feed ingredients that satisfy nutritional requirements using linear programming. Linear programming models that select minimum cost feed rations have had a pronounced presence in academic research and are prevalent as applied decision tools. Although useful, these models have generally imposed the assumptions that feed ingredient nutritional compositions and prices are known with certainty. Livestock producers indeed do not know these with certainty and must select feed ingredients in a risky environment with regard to nutrient composition and prices of feed ingredients. Therefore, it is worthwhile to expand the traditional models to choose optimal rations considering variability in the nutritional compositions and prices of feed ingredients.

The traditional model can be expanded to consider nutrient variability and price risk using Merrill's approach and E-V analysis, respectively. Expanding the model in this way makes both methodological and applied contributions to agricultural economic research. The generally ignored issues of real world nutrient and price uncertainty are introduced into a very well researched area of livestock economics, that is, feed ration selection. Results show that minimum cost feed rations are not optimal to all producers. Furthermore, the problematic issue of technical coefficient risk is addressed using a modeling technique that is novel with the exception of its initial application. The expanded model allows decision makers to select rations that are optimal subject to their

aversion to nutrient variability and/or price risk. Managing either type of risk comes at the expense increasing the ration cost. If a decision maker evaluates the situation and determines that risk management benefits outweigh the expense then there are methods for dealing with both feed ingredient nutrient and price risk.

In general, producers wishing to control only the variability of nutrients in the ration should increase the amounts of the optimal ingredients. The magnitude of this increase will vary depending on which ingredients are in the optimal ration with no consideration given to risk. However this is not true when managing for both risks simultaneously. In these cases the model does substitute among available ingredients by changing the relative amounts of ingredients in the ration and bringing in small amounts of new ingredients. Controlling price risk requires substituting among inputs in all cases. In some cases new ingredients enter the optimal ration while at other times the relative amounts of the ingredients in the base ration is changed. New ingredients are expected to have a higher expected price but will have a less variable price series, as was shown by corn gluten feed replacing wheat middlings. Both types of risk management come at the expense of increasing ration cost. For example, in this study a producer who is 80% risk averse with regards to nutrient variability and price variability would be willing to pay $0.12 per head per day above the price of the minimum cost ration to select a ration that is optimal to him or her. Using these results and basic methods of managing nutrient and price risks advanced decision tools can be developed. Alternative rations can be presented in the form of a set of risk efficient choices as was done in this study. Decision makers can then weigh the costs and benefits of all feasible alternatives then formulate rations that are better suited to their individual attitude toward risk.

Appendix to Chapter III

NRC 2000 reports the standard deviations of acid detergent fiber (ADF) in selected feedstuffs. Metabolizable energy (ME) can be expressed as a linear function of ADF that depends upon the type of feed ingredient in question (American Feed Manufacturers Association). Given this information, it is a very systematic procedure to transform the standard deviation of ADF into the standard deviation of ME. The relationship between ME and both net energy for maintenance and net energy for gain is approximated by the NRC 1984 and 2000 as:

(A3.1) $NEm = 0.0105\ ME^3 - 0.138\ ME^2 + 1.37\ ME - 1.12$

and

(A3.2) $NEg = 0.0122\ ME^3 - 0.174\ ME^2 + 1.42\ ME - 1.65.$

The statistical properties of a function are such that for a function:

(A3.3) $Y = aX^3 + bX^2 + cX + d,$

where X is a normally distributed, random variable it is true that:

(A3.4) $$Var(Y) = a^2\,[\,E(x^6) - E(x^3)^2] + b^2\,[E(x^4) - E(x^3)^2] + c^2[E(x^2) - E(x)^2\,] + 2ab[E(x^3) - E(x^3)\,E(x^2)] + 2ac[E(x^4) - E(x^3)\,E(x)] + 2bc[E(x^3) - E(x^2)\,E(x)].$$

In this notation, $E(x^i)^k$ represents the ith moment of x raised to the kth power (if k is omitted it is understood that k = 1). It is possible to derive the standard deviations for NEm and NEg in feedstuffs for which standard deviations of ADF are reported based on the first six moments of the functions for NEm and NEg expressed in terms of ME. Assuming that NEg, NEm, and ME are normally distributed these moments can be expressed in terms of the mean and variance of those functions using the moment generating function:

(A3.5) $$e^{\left(mt+1/2t^2\,\sigma^2_{ME,j}\right)}$$

where the limit of the ith derivative of e with respect to t as t approaches zero is the ith moment of the distribution. Following this procedure, the first six moments of the ME distribution were calculated and used to arrive at the standard deviations of NEm and NEg in every feed ingredient.

Chapter III References

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Table 3.1. Descriptive Statistics of Feed Ingredient Price Series Available to the Model

	Mean ($ / ton)	Standard Deviation ($ / ton)	C.V.[1] (%)	Max ($ / ton)	Min ($ / ton)
Alfalfa Hay	93.03	13.77	14.81	125.00	55.00
Brewer's Dried Grain	102.81	25.15	24.47	155.00	65.00
Corn	97.12	22.09	22.74	187.50	71.43
Corn Gluten Feed	96.50	13.97	14.47	141.00	76.00
Dehydrated Alfalfa	128.17	12.18	9.51	150.00	110.00
DiCalcium Phosphate	380.00	0.00	0.00	380.00	380.00
Distiller's Dried Grain	124.62	16.26	13.05	185.00	93.00
Limestone	110.00	0.00	0.00	110.00	110.00
Prairie Grass Hay	66.62	9.35	14.04	82.50	50.00
Soybean Meal (44%)[2]	193.12	37.53	19.44	299.00	136.00
Soybean Meal (49%)[2]	205.93	36.85	17.89	310.00	148.00
Wheat Middlings	74.55	21.01	28.18	150.00	45.00

Source: Alfalfa and Prairie Grass Hay were taken from various weekly USDA Oklahoma Hay reports, prices for Limestone and Dicalcium Phosphate are November 2000 bulk prices, all other price series came from 365 consecutive weekly observations from Ingredient Market Report. *Feedstuffs*. 1993 to 1999.

1. C.V. = coefficient of variation and is the standard deviation expressed as a percentage of the mean.
2. 44% and 49% represent the estimated crude protein available in each type of soybean meal

Table 3.2. Dry Matter Basis Nutritional Composition of Feed Ingredients

	Dry Matter (%)	NEm[1] (Mcal/kg)	NEg[1] (Mcal/kg)	Crude Protein (%)	Calcium (%)	Phosphorous (%)
Alfalfa Hay	90.90	1.14	0.58	17.00	1.19	0.24
	(2.06)	(0.137)[4]	(0.144)[4]	(1.63)	(0.01)	(0.06)
Brewer's Dried Grain	90.20	1.51	0.91	29.20	0.29	0.70
	(3.70)	(0.014)[4]	(0.015)[4]	(13.0)	(0.10)	(0.05)
Corn	90.00	2.24	1.55	9.80	0.03	0.32
	(0.88)	(0.194)[4]	(0.211)[4]	(1.06)	(0.07)	(0.04)
Corn Gluten Feed	90.00	1.94	1.30	23.80	0.07	0. 95
	(1.69)	(0.174)[4]	(0.188)[4]	(1.06)	(0.05)	(0.29)
Dehydrated Alfalfa	91.80	1.34	0.77	18.90	1.51	0.25
	(1.50)	(0.057)[4]	(0.060)[4]	(0.68)	(0.13)	(0.02)
DiCalcium Phosphate	97.00	0.00	0.00	0.00	22.00	19.30
	(0.00)	(0.00)[4]	(0.00)[4]	(0.00)	(0.00)	(0.00)
Distiller's Dried Grain	90.30	2.18	1.50	30.40	0.26	0.83
	(2.19)	(0.340)[4]	(0.368)[4]	(3.55)	(0.23)	(0.15)
Limestone	1.00	0.00	0.00	0.00	34.00	0.02
	(0.00)	(0.00)[4]	(0.00)[4]	(0.00)	(0.00)	(0.00)
Prairie Grass Hay[2]	91.00	1.00	0.45	6.40	0.35	0.14
	(1.42)	(0.137)[4]	(0.144)[4]	(1.63)	(0.01)	(0.06)
Soybean Meal (44%)[3]	89.10	2.06	1.40	49.90	0.40	0.71
	(1.22)	(0.004)[4]	(0.004)[4]	(1.25)	(0.11)	(0.04)
Soybean Meal (49%)[3]	90.90	2.06	1.40	51.80	0.46	0.73
	(1.88)	(0.228)[4]	(0.247)[4]	(3.45)	(0.80)	(0.20)
Wheat Middlings	89.30	1.60	1.00	18.7	0.17	1.01
	(1.49)	(0.017)[4]	(0.018)[4]	(1.15)	(0.15)	(0.13)

Source: 2000 Update of the 1996 National Resource Council (NRC) Nutrient Requirements for Beef Cattle

Note: The numbers in parentheses are standard deviations. Some the relative standard deviations were considered suspect according to expert opinion. Specifically, the NEg variability of corn relative to wheat middlings was higher than anticipated. Changing these data could obviously affect the model results as the NEg constraint is the most binding. Experimentation on the relative variability based on more recent feed ingredient data (NRC 2001) did not qualitatively alter the results.

1. NEm = Net Energy Required for Maintenance, NEg = Net Energy Required for Gain
2. No standard deviation for ADF in prairie grass was reported, therefore NEm and NEg variances for alfalfa hay were used to approximate the corresponding variances in prairie grass hay.
3. 44% and 49% represent the estimated crude protein concentration in each type of soybean meal on an as fed basis. The compositions are reported on a dry matter basis, resulting in higher reported protein levels.
4. Variability data for Soybean Meal (44%) was questionable due to a very small sample size. Due to this variability data for Soybean Meal (49%) was also used for Soybean Meal (49%).
5. The standard deviations for NEm and NEg are not reported by the NRC but were calculated based on their functional relationship to Acid Detergent Fiber (ADF) and the NRC reported standard deviations for ADF. See the appendix to this chapter for a detailed explanation of this relationship.

Table 3.3. Compositions of Feed Rations for 500 pound Medium Frame Steers Fed for 2 Pounds Average Daily Gain Across Price and Nutrient Risk Aversion Levels

Price Risk Aversion[1] (%)	Nutrient Risk Aversion[2]	Corn	Wheat Midds	Distiller's Dried Grain	Corn Gluten Feed	Limestone
		(Pounds / head / day on an As Fed Basis)				
50	Neutra	5.64	5.80			0.16
	Low	5.95	5.82			0.16
	Medium	6.38	5.82			0.16
	High	1.17	12.86			0.13
75	Neutral	5.74			4.47	0.18
	Low	5.58			5.11	0.18
	Medium	5.64			5.61	0.17
	High	5.54		0.56	5.63	0.17
80	Neutral	4.88			5.48	0.18
	Low	5.04			5.75	0.18
	Medium	5.18		0.20	5.91	0.17
	High	5.17		0.73	5.84	0.17
85	Neutral	4.23			6.24	0.17
	Low	4.58			6.29	0.17
	Medium	4.74		0.44	6.12	0.17
	High	4.84		0.89	6.04	0.17

Note: While these rations meet basic nutritional needs, no formal constraint was specified to address the amount of roughage in the diet. A certain level of roughage is needed to maintain rumen function. Also, no formal constraint addresses total intake.

1. Feed price risk aversion coefficients were calculated via the procedure offered by McCarl and Bessler. A brief explanation of the interpretation of this coefficient is presented in the text of this paper. See McCarl and Bessler for a detailed presentation.

2. Nutrient risk aversion coefficients are the standardized normal one-tailed Z values corresponding to 0.50 (Neutral), 0.60 (Low), 0.80 (Medium), and 0.90 (High) levels of significance.

Table 3.4. Means, Standard Deviations, and Coefficients of Variation (C.V.) of Feed Ration Costs for 500-pound Medium Frame Steers Fed for Two Pounds Average Daily Gain Across Price and Nutrient Risk Aversion Levels

Price Risk Aversion[1] (%)	Nutrient Risk Aversion[2]	Mean (Dollars / head / day)	Standard Deviation	C.V. (%)
50	Neutral	0.499	0.118	23.65
	Low	0.515	0.121	23.50
	Medium	0.535	0.126	23.55
	High	0.543	0.146	26.89
75	Neutral	0.504	0.086	17.06
	Low	0.527	0.088	16.70
	Medium	0.554	0.092	16.61
	High	0.585	0.094	16.07
80	Neutral	0.511	0.083	16.24
	Low	0.531	0.086	16.20
	Medium	0.559	0.090	16.10
	High	0.588	0.093	15.82
85	Neutral	0.516	0.081	15.70
	Low	0.535	0.085	15.89
	Medium	0.563	0.089	15.81
	High	0.591	0.092	15.57

1. Feed price risk aversion coefficients were calculated via the procedure offered by McCarl and Bessler. A brief explanation of the interpretation of this coefficient is presented in the text of this paper. See McCarl and Bessler for a detailed presentation.

2. Nutrient risk aversion coefficients are the standardized normal one-tailed Z values corresponding to 0.50 (Neutral), 0.60 (Low), 0.80 (Medium), 0.90 (High) levels of significance.

Table 3.5. Means, Standard Deviations, and Coefficients of Variation (C.V.) of Net Energy Available for Gain in Rations for 500-pound Medium Frame Steers Fed for Two Pounds Average Daily Gain Across Price and Nutrient Risk Aversion Levels

Price Risk Aversion[1] (%)	Nutrient Risk Aversion[2]	Mean (Mcal)	StDev (Mcal)	C.V. (%)
50	Neutral	2.933	0.488	16.65
	Low	3.131	0.515	16.44
	Medium	3.397	0.552	16.24
	High	3.111	0.139	4.48
75	Neutral	2.933	0.603	20.56
	Low	3.172	0.621	19.59
	Medium	3.481	0.651	18.69
	High	3.766	0.650	17.26
80	Neutral	2.933	0.596	20.32
	Low	3.171	0.620	19.54
	Medium	3.470	0.638	18.38
	High	3.757	0.643	17.11
85	Neutral	2.933	0.603	20.57
	Low	3.173	0.624	19.68
	Medium	3.461	0.628	18.13
	High	3.752	0.639	17.04

1. Feed price risk aversion coefficients were calculated via the procedure offered by McCarl and Bessler. A brief explanation of the interpretation of this coefficient is presented in the text of this paper. See McCarl and Bessler for a detailed presentation.
2. Nutrient risk aversion coefficients are the standardized normal one-tailed Z values corresponding to 0.50 (Neutral), 0.60 (Low), 0.80 (Medium), 0.90 (High) levels of significance.

Figure 3.1. Mean-Probability Frontier of Nutrient Risk Efficient Ration Choices for a 500-Pound Medium Frame Steer Fed for Two Pounds Average Daily Gain Assuming Price Risk Neutrality

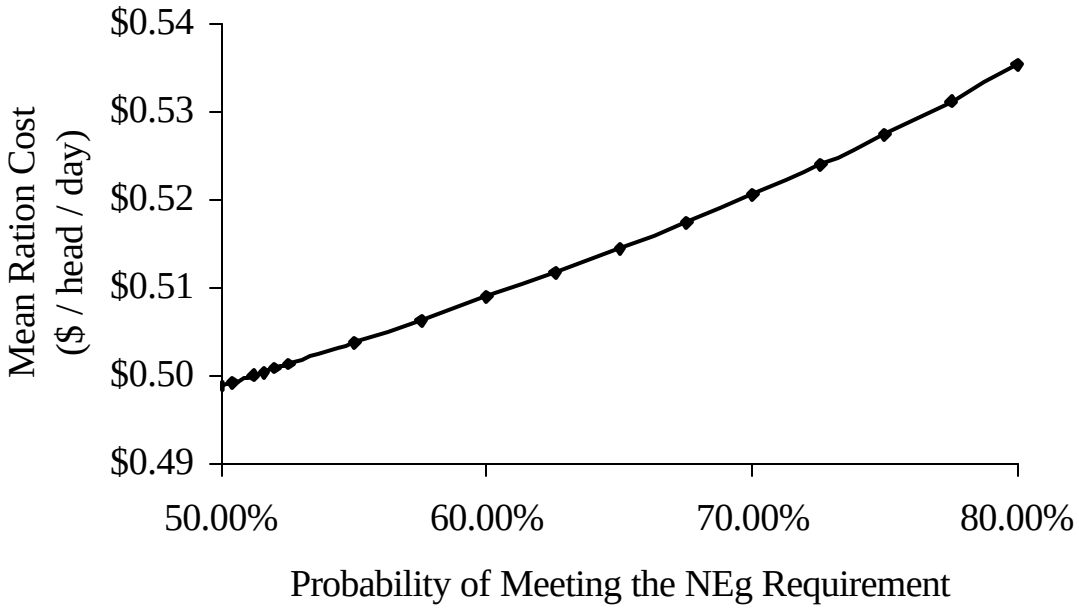
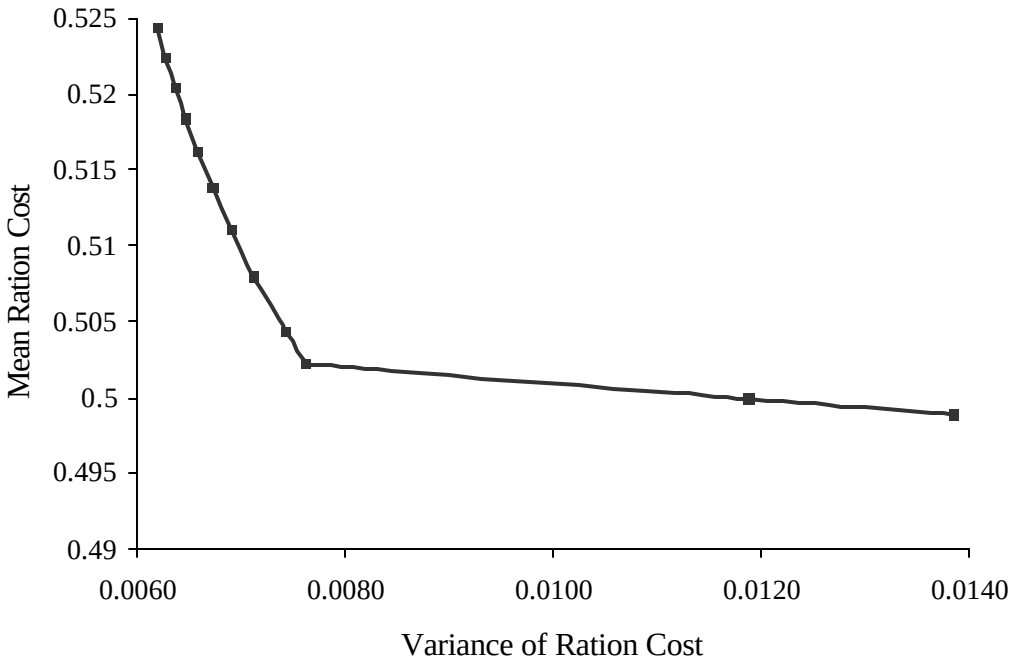


Figure 3.2. Mean-Variance (E-V) Frontier or Risk Efficient Ration Choices for a 500-Pound Medium Frame Steer Fed for Two Pounds Average Daily Gain Assuming Nutrient Risk Neutrality



CHAPTER IV

INTRODUCING THE EFFECTS OF GOVERNMENT SUBSIDIZED LIVESTOCK INSURANCE AS A RISK MANAGEMENT TOOL

Introduction

Over the past few years, there has been a noticeable change in agricultural policy that has involved expanding the role of risk management and insurance. Subsidized crop insurance that insures either crop yields or revenues has been the focus of much legislation and debate. In general, crop insurance programs involve government subsidies to producers to cover a portion of insurance premiums along with reinsurance (and, in some cases, direct subsidies) to private firms that provide the insurance. While these programs offer farmers a means of risk management, they have often been costly and have drawn criticism for the incentives they create (Skees 1999a, Turvey). Recent legislation has now cleared the way to introduce similar insurance programs for livestock. Currently, the USDA's Risk Management Agency is evaluating proposals for livestock insurance products to be used in pilot programs. Like crop insurance programs, these programs have the potential to establish risk sharing markets that will allow producers to manage net income risk associated with livestock production and, if subsidized by the government, also have the potential to introduce perverse incentives to livestock producers. With this in mind, it is worthwhile to carefully evaluate the situation of livestock producers and the potential effects of subsidized livestock insurance.

Given the lack of vertical integration or cooperation in the beef industry, beef producers generally have limited opportunity to share the risk of their respective operations and are left to design individual risk management strategies. One type of risk

that greatly influences profitability is marketing or price risk. Futures market hedging and cash forward contracting provide opportunities to manage price risk. However, these alternatives come at a cost. For example, futures options offer a mechanism to establish a price floor for some premium. If futures markets function efficiently, this premium reflects the true value of the option. Producers realize that they will not always exercise these options and therefore in some years will actually forgo income in exchange for being insured against possible loss. Thus, the option premium (and therefore the risk it is priced to manage) is internalized into their decision-making process. In general, the premiums a producer will expect to pay are at least as much as the payments they realize, over the long run. The same can be said for actuarially fair price insurance, which functions much like a European put option and can only be exercised when it expires. As long as these instruments are fairly priced, decision makers will choose to utilize them or not based upon their individual risk preference. Specifically, more risk averse producers will forgo a larger proportion of expected income to realize a given decrease in the variability of that income.

If the same risk management instruments are offered with subsidized premiums, the true risk is not internalized into the decision-making process and as a result, producers will be inclined to take on more risk than they would with fairly priced insurance (Skees 1999b). In the case of beef production, this can mean producing more beef and/or producing beef under riskier conditions. As producers realize that the true value of the insurance is greater than the amount they must pay, they are likely to expand their operations to levels that result in their being exposed to the same level of risk as

they were prior to the subsidy. This behavior has been shown in some studies regarding subsidized crop insurance and crop production (Skees 1999a and 1999b, Turvey).

The general objective of this study is to highlight the effects of government subsidized insurance on the actual risk faced by livestock producers. Three possible marketing alternatives that a livestock producers might face will be evaluated: (1) selling feeder cattle with no means of price protection, (2) purchasing actuarially fair European put options, and (3) purchasing insurance in the form of European put options with a portion of the premium subsidized by the government. Each alternative will be ranked according to its risk efficiency for a variety of risk attitudes ranging from risk preferring to risk neutral to risk averse. Ranking will be done using Expected Value Variance (E-V) Analysis and Stochastic Dominance Criteria. Consequently, a contribution of this study that goes beyond the objectives will be a comparison on stochastic dominance and E-V analysis that will highlight similarities and differences in the performance of the two commonly used dominance criteria. Results from both dominance analyses will be used in conjunction with economic theory and related prior research to meet the specific objectives of this study. These objectives include identifying which marketing alternatives are preferred for different levels of risk aversion, measuring the impact of subsidization on this preference and forming hypotheses of the possible effects of subsidized insurance on beef production decisions. While not testable at this point due to lack of data, such hypotheses will represent a useful focus for future research in this area. Results will be of interest to policy makers wishing to implement programs that allow livestock producers to manage marketing risk while introducing appropriate incentives to these producers.

To complete this analysis, it will be necessary to present a brief review of choice under uncertainty. This will be followed by an explanation of how the three previously mentioned marketing alternatives of a livestock producer are simulated. The three alternatives can then be ranked and the results of this ranking can be discussed and conclusions can be drawn.

Choice Facing Uncertainty

There has been a considerable amount of research directed at economic behavior facing uncertainty. The classic model for choice under uncertainty is the expected utility framework as proposed by von Neuman and Moargenstern. In this framework, an individual will maximize utility subject to the probabilities of the occurrence of available alternatives. The way that a decision maker responds to the risk surrounding the alternatives is therefore dependent upon his or her utility function. Some individuals will prefer risky ventures due to the possibility of large payoffs. These individuals are typically said to be risk preferring. Some decision makers might have risk neutral attitudes and will give no consideration to the riskiness of an alternative but rather base decisions on the expected or mean outcome. The remaining individuals are said to be risk averse. This class of risk averse decision makers has been the subject of many economic studies, too numerous to mention here.

Decision makers that are risk averse will seek to manage the risk associated with their alternatives and, in some cases, will even be willing to pay to avoid entering into a risky situation (Arrow, Pratt). This risk attitude is the fundamental basis for insurance. If a decision maker's utility function is known, the risk premium that they will pay to avoid

a risky situation can be quantified and used to arrive at willingness to pay for insurance (Pratt). However, the specification of utility functions for livestock producers (as well as any group of individuals) would be extremely time consuming and arduous. Therefore this paper will rely on methodologies that circumvent the problems associated with specifying decision makers' utility functions.

Conceptual Framework

While theoretically sound, the von Neumann and Moargenstern approach is very difficult to use in an applied sense, as it requires that the utility function of the decision maker be known and specified. Since it is neither practical or, in some cases, even possible to specify a decision maker's utility function, many alternative procedures have been developed to rank risky alternatives. In general these approaches are designed to present a risk efficient set of choices, which is a subset of all available choices, and allow decision makers to choose from them. Any alternative not in the risk efficient set is said to be risk dominated and should not be considered by the decision maker. Two widely used techniques that follow this general framework are expected value variance (E-V) analysis and stochastic dominance criteria.

E-V analysis (Markowitz, Freund) is widely published in agricultural economic literature as means for ranking risky decisions. However, there has been debate as to whether E-V analysis is a theoretically appropriate method to represent optimal decision making. It is generally agreed upon that expected utility theory (von Neuman and Moargenstern) provides the theoretical base for choice facing uncertainty. E-V analysis is consistent with expected utility theory in three cases: (1) the underlying income

distribution is normal (Freund), (2) the distributions of the decision variable differ only by location and scale (Meyer 1987), and (3) the underlying utility function is quadratic (Markowitz, Tobin). If any of one of these conditions is present it is generally agreed upon that E-V analysis is indeed consistent with expected utility theory. In addition to a presence of many economic studies, empirical evidence demonstrates the closeness of E-V analysis to the expected utility maximizing choices (Levy and Markowitz).

In this study it is necessary, as mentioned earlier, to simulate livestock prices. In general, prices are not expected to be normally distributed and therefore the returns associated with prices may or may not be normally distributed. Furthermore, comparing a case of no price protection with purchasing a put option, which effectively truncates a distribution at a certain price (strike price – premium), ensures that the two alternatives do not differ only by location and scale. Given these shortcomings, only under the assumption of a quadratic utility function can E-V be expected to be consistent with expected utility theory. This assumption is rather restrictive, given that it implies that absolute risk aversion increases as the level of payoff increases so that at some level marginal utility of wealth becomes negative (Robison and Barry; Hardaker, Huirne, and Anderson). Even though these assumptions are not met, E-V analysis is still a strong analytical tool. Robison and Barry provide a detailed discussion of why this is true. In the context of this study, E-V analysis provides a straightforward method of calculating the willingness to pay for a particular marketing alternative. Such a measure will provide results necessary for achieving the aforementioned goals of this study. A brief explanation of E-V analysis as it applies to this study is presented in the following paragraph.

If alternatives A and B are mutually exclusive and/or not correlated, they can be ranked by calculating the certainty equivalent (CE) or risk adjusted returns for each alternative using E-V analysis as follows:

(4.1) $$CE_A = E(A) - \Phi(Var(A))$$

(4.2) $$CE_B = E(B) - \Phi(Var(B))$$

where E(A) and E(B) are the expected values of A and B, respectively and Var(A) and Var(B) represent the variance of each. Φ is a risk aversion coefficient. If $CE_A > CE_B$ then A dominates B, if the two are equal then both A and B might be in the risk efficient set of choices. However, for two choices with equal expected returns, the one with the lower variance is preferred (i.e., the risk dominant choice).

Given that the assumptions required for E-V to be consistent with expected utility theory may not hold in this study, another test for dominance should be used to test the robustness of the E-V results. For this reason, the choices will be analyzed using stochastic dominance (SD) criteria as a means of ranking livestock marketing strategies. Three types of stochastic dominance are generally used to rank risky choices. These are first degree stochastic dominance (FSD), second degree stochastic dominance (SSD), and stochastic dominance with respect to a function (SDRF) or generalized stochastic dominance (Meyer 1977). SDRF is the most discriminatory and flexible test for risk dominance among the three SD criteria mentioned (Robison and Barry; Hardaker, Huirne, and Anderson). Also, FSD and SSD can be shown to be special cases of SDRF (see Meyer for explanation). These characteristics of SDRF make it the most robust and useful tool for this analysis. FSD and SSD will be referred to in parts of the analysis but the reliance upon ranking choices will be placed upon SDRF.

Unlike E-V analysis, which is based solely on the first two moments of a distribution, SD criteria consider the entire distribution and therefore can generally deal with non-normality of the distributions involved. This is because SD places fewer restrictions on the utility function of the decision maker and bases risk dominance on the entire cumulative distribution function (CDF) of each alternative.

SDRF, like E-V, introduces the advantages of knowing a decision maker's preferences without actually eliciting utility functions. This is accomplished by relying on the specification of upper (Φ_U) and lower (Φ_L) bounds of the Pratt risk aversion coefficient, which is often easier to estimate than a utility function (Hardaker, Huirne, and Anderson). Assuming an individual has a utility function U(y), then the Pratt coefficient is equal to:

(4.3) $$\frac{-U''(y)}{U'(y)}.$$

Once Φ_L and Φ_U have been specified then a U(y) that minimizes

(4.4) $$\int_{\Phi_L}^{\Phi_U} [B(y) - A(y)]U'(y)\,dy$$

is found. If the expression is positive then A is preferred to B. If the expression is zero, SDRF cannot rank the two alternatives. If the expression is negative, B might be preferred to A. To verify this A(y) – B(y) is substituted into the brackets and the expression is reevaluated. If the minimum of new expression is positive then B is definitely preferred to A. If the expression is again negative, SDRF cannot rank the alternatives.

Both E-V and SDRF require the estimation of risk aversion coefficients. McCarl and Bessler offer a method for calculating the Pratt risk aversion coefficient when the

utility function is unknown. In their formulation the decision maker is said to maximize the lower limit of a confidence interval from a normally distributed set of returns. The formula is:

(4.5) $$\Phi = 2Z_{a} / S_{y}$$

where Φ = risk aversion parameter, Z_a = the standardized normal one-tailed Z value of an a level of significance, and S_y is the relevant standard deviation under risk neutral returns. This method will be used to estimate risk aversion coefficients for both E-V and SDRF. S_y is represented by the standard deviation of the expected price assuming the producer does not attempt to manage price risk (this expected price will be defined in detail later in the paper) and Z_α will be specified from 5% to 95% in 2.5% increments. In this formulation, Z_α = 50% is considered to be risk neutral while Z_α greater than 50% is risk averse and Z_α less than 50% is risk preferring. Some of the extreme values of Z_α are not likely realistic levels of risk preference for agricultural producers but serve to illustrate how individuals of different levels of risk aversion respond to available choices.

The ranking of the three aforementioned beef cattle marketing strategies will be completed in the following sections of this paper. First, it will be necessary to specify the type of beef producer to be analyzed and make any necessary assumptions. Then the alternatives of no price protection, fairly priced European put options and subsidized price insurance can be ranked using E-V and SDRF. After establishing the analytical procedure of this study, the results of all the analysis will then be reported and discussed with conclusions following this discussion.

Analytical Procedure

Assumptions Regarding the Livestock Producer

When examining livestock production it is often necessary to limit the examination to a specific level of production. This is because different levels of livestock production may require very different management practices and decision-making procedures. For example, cow-calf producers must purchase breeding stock and expect to recover this investment over a period of a few years. Backgrounders, on the other hand, purchase weaned calves (approximately 500 pounds) and sell them to feedlots a few months later as feeder cattle (approximately 750 pounds). They are more concerned about short run prices and conditions than cow-calf producers. For the purposes of this study, backgrounders will be used.

The assumption will be made that the backgrounder purchases weaned calves and will sell them in 150 days. Therefore, the producer is concerned with the expected price of feeder cattle 150 days from the date of purchase. One common method of estimating this expected price is the feeder cattle futures market contract. Specifically, the price of the feeder cattle contract that will expire in roughly 150 days will represent the expected price for a producer with no price protection. In fulfillment of the goals stated earlier, this study will approximate the risk associated with this expected price and offer two risk management strategies to determine producers' willingness to manage price risk using fairly priced European put options and subsidized price insurance that is structured as a European put option.

Simulation of Expected Prices

Representation of the risk associated with the expected price when no risk management strategy is used requires further specification of the distribution of possible prices. The use of historic prices for this specification would likely complicate this analysis. There would inevitably be price movements that are specific to the time period chosen and therefore the volatility of those prices may only be appropriate in the context of that specific time period. A more general specification of prices that represents a realistic level of price volatility circumvents these potential problems. This specification can be accomplished based upon the variance and mean of an expected feeder cattle futures price.

Many consulting services report implied volatilities of futures market contracts. These are usually calculated using Black's formula for pricing futures options. A known premium and strike level are used to solve for the implied volatility. This measure of volatility represents the anticipated coefficient of variation of the distribution of possible prices for a contract. It is then a matter of simple arithmetic to derive the standard deviation and variance for the distribution. This study will use $88.50 / cwt the expected price and 11.0% as the volatility measure (which was the futures price level and implied volatility for the September feeder cattle futures contract as reported by PM Publishing Options Analysis in mid April 2001). This results in a standard deviation of $9.74 / cwt and a variance of 94.77. As stated earlier, normally distributed prices are not commonly observed. It is more likely that these prices will take on a distribution similar to a gamma distribution. Based on the first two moments of the distribution (mean and variance), a cumulative function of the gamma distribution can be fully specified. This function can

be inverted such that for a given probability, it returns a number that is expected to occur at that probability level in the gamma distribution. By selecting 1000 random probabilities, ranking them in ascending order, and inserting them into the gamma distribution one at a time, an accurate representation of the distribution around the expected price can be obtained. This distribution will represent the marketing alternative of selling feeder cattle with no means of price protection and will be referred to as NoIns.

Two price risk management strategies will also be proposed. The first will be European put options, noted as PRM. These options can be purchased by producers to establish a price floor and can only be exercised at the time of maturity (i.e., approximately the sale date of the feeder cattle). This alternative is simulated based on the first alternative. A strike level and price are selected. This study will use a 95% strike level, which translates into a \$84.07 / cwt strike level or price floor. With the first distribution ranked in ascending order each observation n_i is evaluated. If is it less than \$84.07 / cwt then an indemnity payment (IP_i) is added to it so that it equals \$84.07 such that,

(4.6)
$$\begin{aligned} IP_i &= \$84.07 - n_i, \forall\, n_i < \$84.07 \text{ and} \\ IP_i &= 0, \forall\, n_i \geq \$84.07. \end{aligned}$$

As a starting point for the analysis, the option premium will be calculated based on these actual payments rather than on an option pricing formula. This premium (PREM) is calculated as:

(4.7)
$$PREM_f = \frac{1}{N}\sum_i IP_i .$$

In this formulation PREM is simply the average of all payments. N is the total number of simulated prices and all other variables maintain their previous definitions. This

specification of $PREM_f$ ensures that the total of all IP_i equals the total of all $PREM_f$, thus the options are actuarially fair. With the previously specified strike level, $PREM_f$ = \$2.02 / cwt. This method of calculating an actuarially fair premium provides a straightforward, simple analysis of the effects of options and subsidized insurance on risk and has been used for these reasons in other insurance studies (e.g, Williams et. al). It is also useful to analyze the options using a theoretically correct premium.

Black offers a method for calculation of a theoretical premium price for futures options that results in premium that more closely resembles premiums actually paid by producers. Harrison uses Black's premiums in the comparison of purchasing feeder cattle options to other backgrounding risk management strategies. Black's formula is derived from Black and Schoales formula for pricing stock options and relies mainly on the volatility (or implied volatility) of futures market prices, risk free interest rates, and the current price of the futures contract. In the interest of brevity, Black's formula will not be reported here. Leuthold, Junkus, and Cordier present a complete explanation of Black's formula along with examples. For the aforementioned example, Black's premium ($PREM_b$) will equal \$5.16 / cwt. Several examples of actuarially fair premiums and premiums calculated using Black's method are presented in Table 4.2 to illustrate the effects of volatility and interest rates on the cost of price insurance.

At this point the price distribution for PRM can be specified by:

(4.8) $$n_i + IP_i - PREM \ \forall i,$$

where PREM = $PREM_f$ for an actuarially fair premium and PREM = $PREM_b$ for Black's theoretical premium.

The second risk management strategy is a subsidized price risk management program. Specifically, this program will represent government subsidized price insurance and will be referred to as SubPRM. This insurance will maintain the form of the European put option but producers will receive a subsidy (SUB) from the government that is a certain percentage of the premium. Thus the distribution for SubPRM becomes

(4.9) $$n_i + IP_i - PREM + SUB*PREM, \forall i,$$

where PREM can represent either $PREM_f$ or $PREM_b$ In this study SUB = 50% resulting in an out-of-pocket expense for SubPRM of \$1.01 / cwt when PREM = $PREM_f$ and \$2.58 for PREM = $PREM_b$. It should be noted that this subsidy level was chosen simply to illustrate the effects of a government subsidy. Subsidies on crop insurance premiums are limited to 59% while the Dairy Options Pilot Program subsidizes 80% of dairy option premiums. Based on these programs, subsidies on livestock insurance premiums could fall anywhere in the 59% to 80% range. The descriptive statistics for all three alternatives are reported in Table 4.1 and the CDF of each is shown in Figure 1. With the three choices clearly laid out, it is now possible to simulate producers' acceptance of the alternatives by ranking the choices E-V and SD criteria.

Ranking the Risky Alternatives

The ranking of NoIns, PRM, and SubPRM will be accomplished in a two-step process. First, only the choices of NoIns and PRM will be available to producers. Under this scenario there are no government incentives that subsidize risk management. A producer must choose to be fully exposed to market risk or attempt to manage that risk at some cost determined by the futures market.

The second scenario will compare NoIns with SubPRM. With government subsidies in place, PRM would still be a feasible alternative. However, no rational decision maker would choose PRM. This is because SubPRM dominates PRM under the E-V framework for all values of Φ, since the variance of prices under each alternative is the same but the expected price of SubPRM is greater. Furthermore, PRM is dominated by SubPRM in the sense of FSD. This makes it unnecessary to evaluate the two using SSD or SDRF since the results will hold (Robison and Barry). In other words, for the second scenario anyone wishing to manage marketing risk would always choose SubPRM over PRM and anyone wishing to take on that risk would always choose NoIns, therefore PRM is never in the risk efficient set. This procedure will be used first assuming actuarially fair options and insurance and subsequently assuming Black's theoretical premium for each. The results of this ranking are presented and discussed in the following section.

Results and Discussion

Scenarios 1 and 2 (NoIns vs. PRM and NoIns vs. SubPRM, respectively) were analyzed using E-V and SDRF. Computer software developed by Cochran and Raskin was used to rank choices by SDRF. This software has previously been used to rank risky alternatives relating to both feeder cattle marketing (Harrison et al.) and crop insurance programs (Williams et al.). Goh et al. offer a complete description of the software.

In scenario 1, under both E-V and SDRF, producers who have any level of risk aversion will choose PRM when the options are actuarially fair. Risk neutral producers would be indifferent between NoIns and PRM. However, since the decrease in variance

comes at no decrease in expected price, it is reasonable to assume that risk neutral producers would purchase the fairly priced options. Based on these results, producers who maximize utility based on income realized at least 50% of the time choose PRM. This comes as no surprise since the actuarially fair options decrease volatility without decreasing expected price. Only risk preferring producers (i.e., $\Phi < 0$) would not purchase the options since paying a premium eliminates some positive price risk associated with selling feeder cattle. When options are priced using Black's method, a narrower range of risk attitudes prefer PRM to NoIns. This result is also expected since Black's premium decreases the expected price along with volatility. In this case, producers evaluate this tradeoff according to their level of risk aversion. The results of this comparison are reported in Table 4.3. The next step in the analysis is to evaluate the effects of a government subsidized insurance in the form of European put options.

An anticipated effect of a subsidy on the purchase of insurance is that individuals who previously received no marginal benefit from the managing the risk of their respective operations now realize a benefit and therefore purchase insurance. This result is demonstrated across both methods of risk analysis as well as both methods of option pricing. For subsidized insurance based upon actuarially fair options, SDRF indicates that a greater amount of producers (relative to E-V) who would not choose PRM in scenario 1 choose SubPRM in the second scenario. This difference in the two techniques is shown in Table 4.3. These differences are due to the fact that SDRF bases decisions on the entire distribution of each alternative while E-V relies solely on the first two moments of the distribution. SDRF recognizes, to some degree, that primarily downside risk is being foregone and therefore even individuals with only a slight aversion to risk would be

better off utilizing PRM. E-V merely recognizes that the variance has decreased at the expense of a decreased expected price and judges the tradeoff accordingly with no regard to the type of risk that has been mitigated. It should be noted that when premiums are actuarially fair, both E-V and SDRF show that some risk-preferring individuals would actually purchase the price insurance when premiums are subsidized. Under both techniques, these are individuals who prefer more risk to less because they are willing to weather the volatility of a marketing strategy due to the chance of large payoffs at times.

Relative to actuarially fair premiums, subsidized insurance based upon Black's theoretical premiums is not the risk dominant choice for as many risk attitudes. This is to be expected since Black's premium offers roughly the same benefit at a higher cost. This is a useful comparison since Black's premiums more accurately reflect actual option premiums faced by producers. Therefore willingness to purchase PRM and SubPRM at Black's premium should more accurately describe willingness to buy real world options and subsidized insurance. As mentioned earlier, it is possible to calculate this willingness to pay for both PRM and SubPRM.

The E-V approach calculates an individual's CE (or risk-adjusted returns) for a given situation. Given this CE it is possible to approximate the willingness to pay by producers of different risk attitudes for PRM and SubPRM. It should also be noted that this willingness to pay assumes that PRM and SubPRM are the only marketing strategies available to livestock producers and that they are mutually exclusive. This does not drastically limit the discussion as this study looks to identify broad trends in the effects of subsidized livestock price insurance on risk faced by producers.

Willingness to pay for PRM and SubPRM can be determined by comparing the CE of NoIns with that of PRM and SubPRM, respectively, assuming that PRM and SubPRM were free. That is, equations 4.8 and 4.9 were modified to leave out the (PREM) term. The CE of NoIns was then subtracted from each. The result is the maximum premium that a person of each risk attitude would forgo to utilize the risk management strategy. These measures of willingness to pay are shown in Table 4.4. Willingness to pay for PRM is the same under actuarially fair premiums and Black's premiums. Introducing a subsidy obviously changes the willingness to pay for these risk management products. As expected, for both actuarially fair premiums and Black's premium, the CE (and therefore willingness to pay) increases by the amount of the subsidy. Since Black's premium is larger and the subsidy is based on a percentage of the premium, willingness to pay for SubPRM is always greater using Black's premium.

Once the subsidy is introduced, under either premium calculation method, a producer can now realize the same expected price variance as with PRM but now realize a higher expected price. This means that SubPRM actually has a lower absolute volatility (C.V.) than PRM (see Table 4.1). All individuals who did not wish to purchase PRM and for whom this increase in CE results in a willingness to pay that is greater than PREM will now purchase SubPRM. It is also true that any individual whose CE is greater than PREM in scenario 1 would choose to purchase PRM. E-V analysis allows these changes in willingness to pay to be examined for all levels of risk aversion.

The case of the risk aversion level of 47.5% assuming an actuarially fair premium provides an interesting example of how the marginal benefit that comes from managing risk is affected by the subsidy. In scenario 1, an individual with risk preference level of

47.5% would be willing to pay only $1.36 / cwt for PRM and if forced to pay PREM for PRM would realize a marginal benefit of -$0.66 / cwt (willingness to pay – PREM). Under Scenario 2 the same individual is willing to pay PREM for SubPRM and receives a marginal benefit ($0.35 / cwt) from doing so. The same scenario exists for the risk aversion levels of 52.5% to 62.5% assuming Black's premium. It is important to note that no risk-preferring individuals are persuaded by the subsidy to purchase subsidized insurance under Black's premium.

In the presence of greater price volatility, risk management results differ from those reported previously. For example, if a futures price volatility of 18.14% is used to simulate the marketing alternatives, Black's premium will be $7.19 (see Table 4.2) the subsidy will result in risk neutral producers purchasing subsidized insurance. The subsidy of $3.60 would be greater than 11.11% volatility since it is based upon a percentage of the premium. In fact, in this scenario, the expected feeder cattle price with subsidized insurance is greater than with no price protection and the volatility is lower. Therefore it is unambiguous that all risk neutral and risk averse producers prefer to purchase subsidized insurance. Consequently, this implies that subsidized insurance dominates no price protection in the sense of SSD. It should be noted that if the subsidy were increased by at least 10%, E-V results also indicate risk preferring individuals would actually be persuaded to purchase subsidized insurance that is based upon theoretically correct options. Furthermore, under an 80% subsidy (the level of the Dairy Options Pilot Program) some risk preferring individuals (all those with a risk aversion level of 40% or greater) would purchase subsidized insurance. Other results from this level of volatility are not reported but are available upon request from the authors. For

the riskier situation, the subsidy is greater. This indicates that, as long as the subsidy is based on a percentage of the premium, producers facing a more volatile expected price will receive a greater benefit from the subsidy.

These results show, as anticipated, that offering a subsidized insurance product could very well effect the decision-making process of certain producers, depending upon their risk attitude. In general the subsidy obviously makes SubPRM more attractive than PRM to all producers. However, for many producers, the difference is enough to actually change their optimal risk management strategy from doing nothing to purchasing price insurance.

Summary and Conclusions

Livestock producers, like all agricultural decision makers, will choose production and marketing practices that maximize utility. The feasible production and marketing practices will generally have some level of uncertainty associated with them. How an individual evaluates these feasible alternatives to maximize utility is a function, in part, of his or her attitude toward risk (Anderson, Dillon, and Hardaker; Boisvert and McCarl; Hardaker, Huirne, and Anderson; Robison and Barry). This study focused on marketing risk and basically ignored production risk (and all other sources of risk) during the analysis. In the case of a backgrounder looking to sell feeder cattle in roughly 5 months, the marketing risk or uncertainty is the feeder cattle price fluctuation over that 5 months. In the real world, producers can purchase European options to establish a price floor thus mitigating the downside feeder cattle price fluctuations. This study introduced this marketing alternative (with premiums calculated actuarially and using Black's method)

along with the alternative of not managing price risk in Scenario 1. Next, in Scenario 2, subsidized insurance, in the form of subsidized European options (once again, with premiums calculated actuarially and using Black's method) was offered along with the do nothing strategy as alternatives. For both scenarios the optimal choice for a variety of risk aversion levels was chosen using E-V analysis and SDRF. The differences in the two scenarios were interesting and highlighted the effects of a subsidy on the risk faced by livestock producers.

In Scenario 2, when subsidies were based upon actuarially fair premiums, a wider range risk attitudes, including some risk preferring individuals, found price risk management appealing. This was true for both ranking techniques. E-V results show that the marginal benefit producers realize from managing price risk is increased by the amount of the subsidy. This translates into an increased willingness to pay for subsidized insurance compared to fairly priced options (see Table 4.4). This trend was also observed in the realistic case involving premiums calculated using Black's method. Furthermore, as feeder cattle price volatility increased, the effects of the subsidy increased in terms of persuading individuals who previously did not manage risk to do so. These results should be of concern to policy makers. If individuals who have an inherent desire to seek risk (i.e., $\Phi < 0$) now realize a positive marginal benefit from purchasing insurance, it is conceivable that they will use this benefit to finance operation expansions or new ventures that require taking on additional risk. This practice can result in producers bearing as much or more risk as they did before the subsidy was introduced. Furthermore, the very presence of this subsidy as rent to be collected by livestock producers can change the structure of livestock production. If rational decision makers

realize that this rent is available to them only if they produce livestock, then livestock production may then become a desirable (possibly optimal) method of earning income. If producers are attracted only by this rent, they may or may not have the management skills to run a livestock operation. In these cases subsidies could go to fund livestock price risk management that is being used in lieu of sound management practices.

These are only some of the possible general effects of subsidized livestock insurance. It is beyond the scope of this study to attempt to quantify production responses to subsidized insurance. However, by using proven and accepted tools for evaluating risky decision making and by observing past instances in the crop sector, as this paper has done, it is possible to form hypotheses concerning the possible changes in beef production brought about by subsidized price insurance. This study presents two hypotheses:

Hypothesis 1: Beef prices could remain at depressed levels for abnormally long time periods if subsidized price insurance is available to beef producers.

Hypothesis 2: Some level of beef production would take place that would not exist without subsidized price insurance for livestock.

Economic theory combined with results of this analysis can be used to justify these hypotheses. If the additional benefits realized due to the subsidy are used to invest in increasing feeder cattle production, there are likely to be noticeable changes in beef cattle production. For example, when market prices for beef are low enough, a decrease in the quantity of finished cattle (cattle ready for slaughter) occurs. This results in a

decreased demand for feeder cattle by feedlots which translates into lower feeder cattle prices. In this case the backgrounders examined in this study would now be willing to pay less than before for weaned calves. As a response to this, cow-calf producers are likely to liquidate herds to some degree and decrease calf production. Unless there is a change in consumer demand for beef, this decrease in production by the entire sector is eventually realized at the slaughter level and prices begin to recover. While this cycle is less defined in recent years, it can still be observed in beef production.

With subsidies on price insurance in place, backgrounders (and other levels of productions) would now be responding to signals that are based on receiving this subsidy, in addition to market signals. They might find that there is no reason to cut back production so quickly when prices are declining since they are guaranteed the subsidy in addition to a price floor. If feeder cattle production was kept at higher levels than the market would normally support there would be more finished cattle and, subsequently, more beef than the market demands. This excess supply could serve to keep beef prices and cattle prices at other levels of production low for prolonged periods of time. Simultaneously, production would be at abnormally high levels. Furthermore, individual livestock producers might utilize riskier management and/or production strategies given their expectations of receiving the subsidy. Taxpayer dollars in the form of subsidies would be financing livestock production that, otherwise, would not be taking place.

As stated earlier, these hypotheses cannot be tested as of yet. However, the tools used to identify and explain the general trends in supply response are well established and accepted methods of analyzing risk. Given this and that the hypotheses drawn here can be rationalized using basic economic theory, they warrant a reasonable level of

consideration. The results of this study and the hypotheses offered in this section should serve to give some perspective to the structuring of these livestock insurance policies and provide a focus for future research in this subject area.

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Table 4.1. Descriptive Statistics of Three Price Distributions of Feeder Cattle Marketing Alternatives

	Mean ($ / cwt)	Standard Deviation ($ / cwt)	C.V. (%)
No Price Risk Management	88.50	9.843	11.11
Actuarially Fair European Put Options	88.50	7.396	8.38
Subsidized Insurance Based on Actuarially Fair Premiums[1]	89.51	7.396	8.26
European Put Options Priced via Black's Method[2]	85.29	7.396	8.67
Subsidized Insurance Based on Black's Premiums[1,2]	87.90	7.396	8.41

1. The subsidy equals 50% of the option premium.
2. Premiums were calculated Black's formula for theoretical futures option premiums assuming a current futures price of $88.50, 11.11% volatility, 4 % risk free interest rate, and 150 days to maturity.

Table 4.2. Actuarially Fair Premiums and Black's Theoretical Premiums for European Put Options for Feeder Cattle

Risk Free Interest Rate (%)	Volatility of Futures Prices (%)	Actuarially Fair Premium ($ / cwt)	Black's Theoretical Premium ($ / cwt)
4.0	11.11	2.02	5.23
	15.14	3.31	6.40
	18.17	4.29	7.19
6.0	11.11	2.02	5.16
	15.14	3.31	6.33
	18.17	4.29	7.11
8.0	11.11	2.02	5.09
	15.14	3.31	6.25
	18.17	4.29	7.03

Note: Current futures price is assumed to be $88.50 per cwt. The strike price is $84.07 / cwt and the option is assumed to expire in 150 days.

Table 4.3. Ranges of Risk Aversion Levels for Which Each Marketing Alternative is Preferred to No Price Risk Management Under Expected Value Variance (E-V) or Stochastic Dominance (SDRF) Analysis

	Range of Risk Aversion Levels[1]	Range of Risk Aversion Coefficients[1]
Actuarially Fair European Put Options		
E-V	50.0% and greater	0.0 and greater
SDRF	50.0% and greater	0.0 and greater
Subsidized Insurance Based on Actuarially Fair Premiums		
E-V	47.5% and greater	-0.01780 and greater
SDRF	40.0% and greater	-0.05145 and greater
European Put Options Priced via Black's Method[2]		
E-V	65.0% and greater	0.07830 and greater
SDRF	72.5% and greater	0.12202 and greater
Subsidized Insurance Based on Black's Premiums[2]		
E-V	52.5% and greater	0.01780 and greater
SDRF	55.0% and greater	0.02562 and greater

1. Risk aversion coefficients were calculated via the procedure offered by McCarl and Bessler. A brief explanation of the interpretation of this coefficient is presented in the text of this paper. See McCarl and Bessler for a detailed presentation.
2. Premiums were calculated Black's formula for theoretical futures option premiums assuming a current futures price of $88.50, 11.11% volatility, 4.0 % risk free interest rate, and 150 days to maturity.

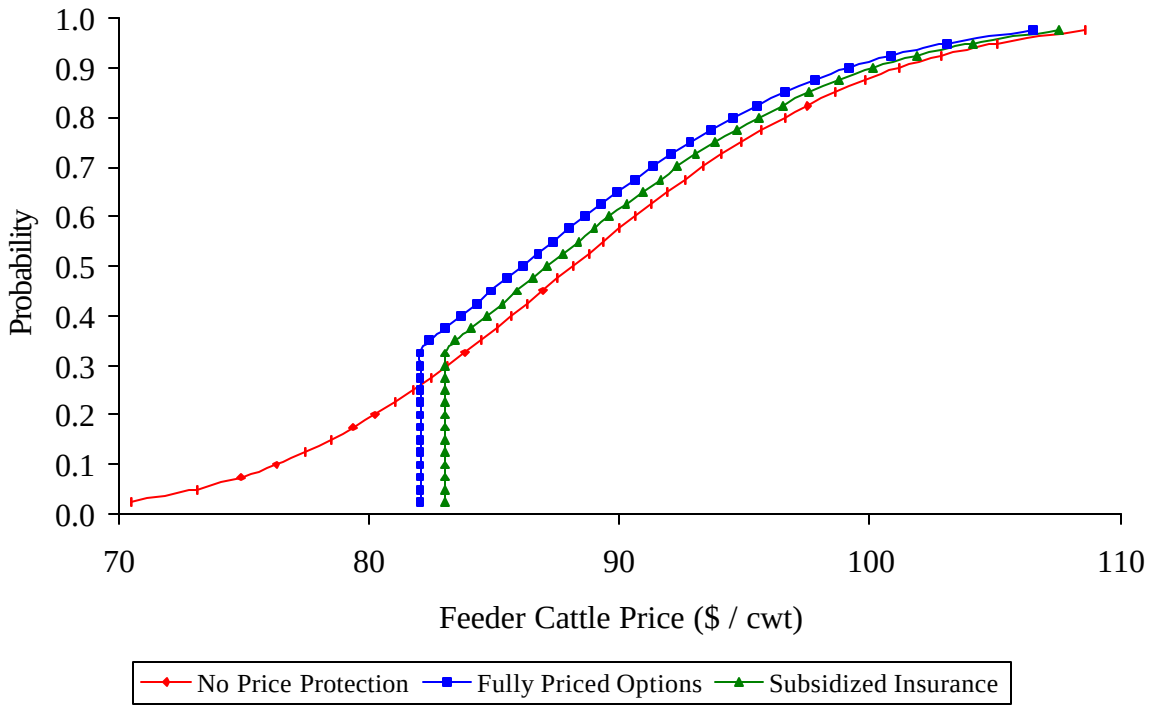
Table 4.4. Willingness to Pay for European Put Options

Risk Aversion Level[1]	Risk Aversion Coefficient[1]	European Put Options ($ / cwt)
5%	-0.33455	-12.03
30%	-0.10657	-2.46
40%	-0.05145	-0.14
42.5%	-0.03864	0.40
45%	-0.02562	0.95
47.5%	-0.01780	1.27
50%	0.0	2.02
52.5%	0.01780	2.77
55%	0.02562	3.10
57.5	0.03864	3.65
60%	0.05145	4.18
62.5%	0.06508	4.76
65%	0.07830	5.31
67.5	0.09231	5.90
70%	0.10657	6.50
72.5%	0.12202	7.15
75%	0.13728	7.79
77.5%	0.15361	8.48
87.5%	0.23388	11.85
95%	0.33455	16.08

1. Risk aversion coefficients were calculated via the procedure offered by McCarl and Bessler. A brief explanation of the interpretation of this coefficient is presented in the text of this paper. See McCarl and Bessler for a detailed presentation.

Note: Willingness to pay represents the amount that the risk-adjusted return per cwt is changed when European put options are purchased. To determine whether a decision maker of a given risk aversion level would purchase these options or subsidized insurance this willingness to pay can be compared to $2.02, $1.01, $5.23, and $2.62 for actuarially fair premiums, subsidized actuarially fair insurance, options priced via Black's method, and subsidized Black's premium. Black's formula assumed 11.11% volatility, 4.0% risk free interest rate, and 150 days to maturity. In all cases the subsidy used was equal to 50% of the relevant premium.

Figure 4.1. Cumulative Distribution Functions of Feeder Cattle Marketing Alternatives



Note: The distribution of No Price Protection is based on an expected price of $88.50 / cwt with a volatility of 11.11% distributions of Fully Priced Options and Subsidized Insurance are based on actuarially fair premiums and a 50% subsidy of that premium, respectively.

CHAPTER V

CONCLUSIONS

Summary of Risk Analyses

Beef producers, like all farmers, must make decisions such as input selection and how to market output in an uncertain environment. Backgrounders in particular must purchase feed ingredients and weaned calves with the intention of feeding the calves and selling them as feeder cattle in a few months. The net income risk of a backgrounding operation is drastically influenced by the risks surrounding the purchase of feed ingredients and the sale of feeder cattle. Backgrounders who are risk averse would prefer to forgo some amount of expected net income to realize a more predictable net income. The amount of net income that a producer will forgo in exchange for a decrease in volatility of net income is dependent upon his or her level of risk aversion. While strategies exist for risk averse producers to manage net income risk, there are other potentially effective strategies that have gone relatively unexplored. This study introduced and evaluated two such novel risk management strategies. These strategies are aimed at managing net income risk by managing risks associated with purchasing feed ingredients and selling feeder cattle, respectively. A summary of the analysis regarding each of these strategies follows.

Summary of Optimal Feed Ration Determination

Given the impact of feed cost on total livestock production expense the determination of a feed ration warrants careful consideration by livestock producers. A common approach to this determination is identifying the minimum cost combination of

available feed ingredients that satisfy nutritional requirements using linear programming. Linear programming models that select minimum cost feed rations have had a pronounced presence in academic research and are prevalent as applied decision tools. Although useful, these models have generally ignored the risks associated with purchasing feed ingredients, of which feed ingredient nutrient variability and price risk are the most critical. Therefore, it is worthwhile to expand the traditional model to choose optimal rations considering variability in the nutritional compositions and price variability of feed ingredients.

The traditional model was expanded in Chapter III to consider nutrient variability and price risk. This expansion included introducing a Merrill's technique for modeling technical coefficient uncertainty and an E-V framework to consider objective function risk. There were both methodological and applied contributions to agricultural economic research resulting from this expansion.

Chapter III contributed to the mathematical programming literature by explicitly modeling the problematic issue of technical coefficient risk using Merrill's approach. Due to limitations of computational solvers, Merrill's approach is absent from the literature with the exception of one study in which Wicks and Guise utilized a linear approximation of the technique. Given the advancement of computational solvers for optimization and the recent availability of reliable feed ingredient nutrient variability data, this study was able to model Merrill's approach directly.

A contribution to applied livestock economic literature was the demonstration that minimum cost feed rations are not optimal to all producers. This implies that if a risk averse producer chooses rations using traditional linear programming decision aids, he or

she is exposed to more risk than would be preferred. The expanded model allows decision makers to select rations that are optimal subject to their aversion to nutrient variability and/or price risk. Model results indicate that, in many cases, producers wishing to control the variability of nutrients in the ration need only to increase the amounts of the optimal ingredients. The magnitude of this increase will vary depending on which ingredients are in the optimal ration with no consideration given to risk. Controlling price risk usually requires bringing new ingredients into the optimal ration or changing the relative amounts of the ingredients in the base ration. Managing the two types of risk simultaneously requires more complex combinations of the two strategies listed above. These results and basic methods of managing nutrient and price risks could be the basis for more advanced decision tools. These decision tools can present alternative rations in the form of a set of risk efficient choices as was done in this study. Decision makers can then weigh the costs and benefits of all feasible alternatives and then formulate rations that are optimal given their individual attitude toward risk.

Summary of Subsidized Livestock Insurance Analysis Summary

Chapter IV focused on marketing risk of a backgrounder who anticipates selling of feeder cattle five months in the future. This marketing risk is the feeder cattle price fluctuation over that five months. Producers can currently purchase European options to establish a price floor thus mitigating the impact of downside feeder cattle price fluctuations. This study compared this marketing alternative (with premiums calculated actuarially and using Black's method) to the alternative of not managing price risk. Next, subsidized insurance, in the form of subsidized European options (once again, with

premiums calculated actuarially and using Black's method) was compared to the do nothing strategy. In both comparisons, the optimal choice for a variety of risk aversion levels was chosen using E-V analysis and SDRF.

When subsidized insurance was based upon actuarially fair premiums, a wider range of risk attitudes, including risk preferring individuals, found price risk management appealing. This was true for both ranking techniques. When premiums were calculated using Black's method fewer individuals found price risk management appealing, relative to actuarially fair premiums, and no risk-preferring individuals were compelled to purchase insurance at a 50% subsidy. However, as either volatility of feeder cattle prices or subsidy level increased, risk preferring individuals were indeed persuaded to purchase insurance under Black's premiums. It is evident how these results could be of concern to policy makers.

If individuals who have an inherent desire to seek risk now realize a positive marginal benefit from purchasing insurance, it is conceivable that they will use this as means to finance the taking on of additional risk. This practice can result in producers bearing as much or more risk as they did before the subsidy was introduced. Furthermore, the very presence of this subsidy as rent to be collected by livestock producers can change the structure of livestock production. If rational decision makers realize that this rent is available to them only if they produce livestock, then livestock production may then become a desirable (possibly optimal) method of earning income. If producers are attracted only by this rent, they may or may not have the management skills to run a livestock operation. In these cases subsidies could go to fund livestock price risk management that is being used in lieu of sound management practices.

Chapter IV evaluated these results to form two hypotheses of the potential effects of subsidized livestock insurance on beef production. These are:

Hypothesis 1: Beef prices could remain at depressed levels for abnormally long time periods if subsidized price insurance is available to beef producers.

Hypothesis 2: Some level of beef production will take place that would not exist without subsidized price insurance for livestock.

While not testable at this point, the hypotheses drawn here can be rationalized using basic economic theory. Therefore, they warrant a reasonable level of consideration in the structuring of livestock insurance products as well as future livestock economic research. Hopefully the results and the hypotheses offered in Chapter IV will encourage policy makers to consider the incentives that subsidized livestock insurance actually introduces to producers and subsequently look to introduce appropriate incentives.

Risk Management Contributions

As previously stated, the general objective of this study was to introduce and evaluate novel risk management strategies for beef producers. While risk management in agriculture has been a widely researched area, the strategies presented in this study have gone largely unexplored. There have been various reasons, as discussed throughout this study, for the absence of the analysis of these strategies. However, at this juncture it is entirely feasible and worthwhile to examine the risk management potential of selecting optimal feed rations (as opposed to strictly minimum cost feed rations) and subsidized

livestock insurance. The analysis of each strategy in this study can serve to focus future research in livestock risk management.

The model for selecting optimal feed rations can be applied to other types of livestock producers such as dairies or feedlots. The model in Chapter III can be readily changed to formulate rations for any group of animals for which nutrient requirements are known. However specification of such models may be limited by feed ingredient data. The nutrient variability data in Chapter III represents perhaps the best available data of that type. It is often difficult to obtain such data for certain feed ingredient or for specific states or regions of the country.

While basic in terms of the methods and data used, the analysis of subsidized insurance should offer some perspective of how useful this will be as a risk management tool. This aspect of the analysis will soon be of interest to livestock producers as livestock insurance products become available. Regardless of the form these products take, the analytical framework in Chapter IV will be applicable to their comparison with each other and other risk management strategies. Furthermore, the analysis of subsidized livestock insurance highlights policy concerns of making such a risk management tool available to producers. Specifically, the results show that such products can easily introduce unintentional incentives to producers. Chapter IV should serve as a basic example of the effects of risk management and its subsidization that can be modified to examine these issues in almost any context.

Conclusions

Given the importance of beef to the United States' agricultural economy and the trend of a decreasing government role in agricultural risk management, a major role of livestock economists is to evaluate possible alternatives for improving beef producers' ability to manage risk. This study has performed this evaluation for two such alternatives, minimum cost feed ration selection and subsidized livestock insurance, as they apply to a beef backgrounder. Certain results of this study are useful only to beef backgrounders. However, some results have a much broader application. Feed manufacturers may also have a desire to purchase ingredients that result in a more predictable nutrient composition. Agricultural lenders would benefit from knowing the effectiveness of livestock insurance as a risk management tool, as they evaluate livestock producers' qualifications for credit. In addition to these applied uses of the results, the analytical frameworks and overall conclusions can benefit a broad range of individuals.

Successful introduction of Merrill's technique into a mathematical programming model paves the way for expanded research into the effects of technical coefficient risk. Applying widely accepting methods to the evaluation of subsidized livestock insurance offers a basic framework for analyzing price variability and the effects of a government subsidy that is widely applicable. In general, the results discussed and conclusions offered by this study coupled with the questions raised by it should serve to improve the agricultural producers' understanding of risk in agricultural decision making.

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PROFESSIONAL PRSENTATIONS:

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