Beef-cattle production functions and economic optima in commercial feedlots

BEEF-CATTLE PRODUCTION FUNCTIONS AND ECONOMIC OPTIMA IN COMMERCIAL FEEDLOTS

by

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STATEMENT BY AUTHOR

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

LIST OF TABLES

ABSTRACT

Using experimental data, a production function for feedlot cattle is estimated. This information, in conjunction with price information, is utilized to determine economic optimum feeding methods. A departure from conventional economic decision making theory is necessary due to the nature of market price determinations in the beef cattle industry. Production decisions must be based upon discontinuous revenue functions, the implications of which are discussed in detail.

The highest concentrate treatment examined was optimal within a relevant price range. A custom feedlot owner will maximize his net revenue by maximizing the net revenue of the owner of cattle being fed. Cattle owners having their animals custom fed and feedlot owners feeding their own cattle receive maximum net revenue over time by feeding the animals until average net revenue is maximized. Maximum average net revenue does not necessarily coincide with the point at which total net revenue is maximized for one lot of cattle, although both points occur when the average grade, and therefore price per cwt. of a lot changes. If animals are fed beyond a given grade change, they must be fed at least until the next grade and price change occurs.

CHAPTER I

INTRODUCTION

Livestock production represents a significant portion of Arizona's agricultural sector. In 1976, 41.5 percent of the cash receipts from all farm marketings were from livestock and livestock product sales. Total cash receipts from livestock and livestock product marketings were $534.4 million. Fed cattle marketings in Arizona totaled 795,000 head in 1976.

Over 25.7 billion pounds of beef were consumed in the United States in 1976, and over 90 percent of this meat was produced domestically. Average per capita consumption was 129 pounds.

The search for optimal beef production methods is therefore highly important not only to the beef producer interested in supporting himself, but also to most Americans who take part in the consumption of such a large quantity of beef.

Although economic theory has been utilized to varying degrees in the study of livestock production decisions, many important questions remain unanswered. While traditional approaches to livestock production problems have provided us with a framework for analysis, strict adherance to the general assumptions of economic theory may lead one to ignore certain knowledge specific to beef production problems. This study focuses on the application of the theory of the firm to the beef production process, keeping in mind the necessity in an applied study for the conclusions and recommendations to conform to reality.

The analysis begins with a brief outline of the theories and concepts of production economics which necessarily are the basis for any study of this nature. This outline is followed by a discussion of some of the most important past studies of the economics of livestock production. This background allows formulation of the analysis so as to carry out the specific objectives of this study.

Objectives and General Procedures

The first objective of this work is to estimate a production function for cattle in Arizona feedlots including a determination of the rates at which forage and grain substitute in the beef-fattening process, a determination of the rate at which feeds are transformed into beef gains for different forage-grain rations, a determination of the time required to produce different levels of gain for different rations, and a determination of carcass grade produced from various rations.

The basic data on feed composition, treatment of experimental animals, weight gains and carcass grades were provided by the Department of Animal Science, The University of Arizona, from experiments carried out under Regional Research Project W-145. Cost data were obtained from U.S.D.A. statistics, and information on actual feedlot operation were obtained from various sources including personal interviews.

Multiple regression analysis is used to estimate a growth response function for the experimental animals. Marginal rates of substitution are examined, and an elasticity of production coefficient determined. Equations relating feed consumption to time are estimated for different rations, and the relationship between carcass grade and ration fed are estimated.

The second and final objective of this study is to estimate, under different price conditions, the combinations of feed, gain, carcass grade, and the number of lots per year that would maximize yearly net revenue. This objective is carried out from the points of view of a feedlot owner feeding his own cattle, a custom feedlot, and a cattle owner having his animals custom fed. In each case the optimal solution is contrasted with the optimum which would occur if the objective were to maximize net revenue from one lot of cattle.

This objective is accomplished by combining physical information derived under the first objective with cost and price data, and applying accepted principles from the theory of production. When this theory in some instances proves inadequate the decision rules are modified as necessary to complete the determination of economic optima under conditions conforming to reality.

CHAPTER II

THEORETICAL BACKGROUND

Decison making at the firm level is based upon what is commonly called production economics, a science dealing with the production of a commodity or commodities from various combinations of inputs, or factors of production. Production economics consists of a set of theories based upon both physical and economic relationships, and is utilized in developing business strategies with some objective, most commonly profit maximization, in mind.

Production Function Concept

Production functions provide the physical or biological information necessary to the decision making process. A production function expresses the various combinations of inputs that are needed to produce a given quantity of output, or the maximum possible output which can be produced with any specified quantities of the various necessary inputs, given a particular state of technology.

Physical production may be a function of any number of resources, and may exhibit any of several types of input-output relationships (Figure 1). Additions of each successive unit of a resource, other inputs held constant, may increase output at a constant rate, an increasing rate, or a decreasing rate. It is also possible for all of the above rates to exist at some point in a given production process as depicted in Figure 1d. According to the law of diminishing returns,

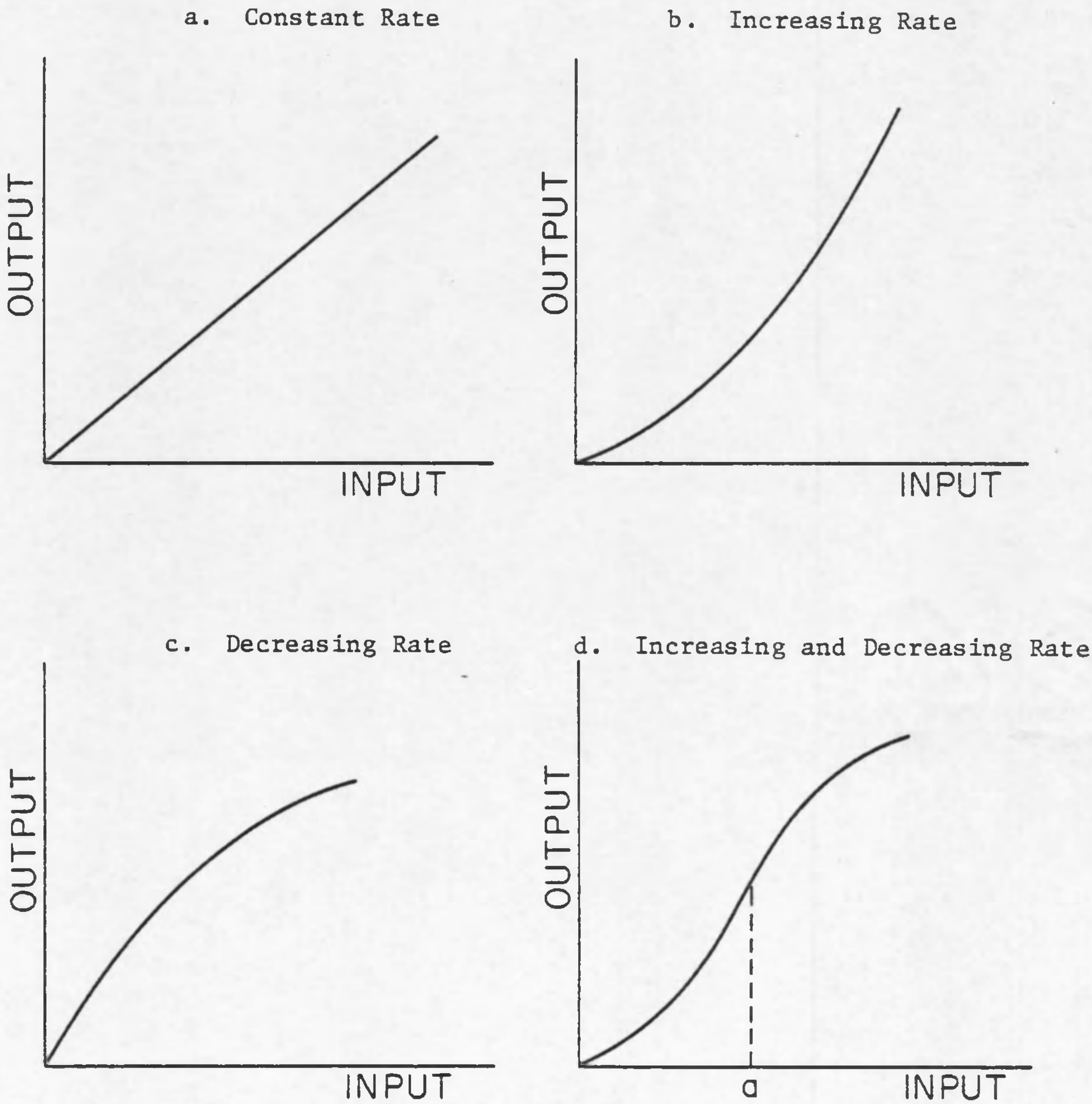


Figure 1. Output responses to increasing input levels.

where at least one input is held constant, some level of input of any other factor of production exists in any production process beyond which the addition of each successive unit of an input will increase output at a decreasing rate (i.e., point a in Figure 1d).

Once a production function is estimated for any production process, additional physical relationships can be derived from that function which are necessary in the decision making process. The most important of these relationships are marginal physical product functions, average physical product functions, product isoquants, marginal rates of substitution, and the elasticity of production.

The marginal physical product of any input is defined as the addition to output which occurs as the result of the addition of one more unit of that particular input, all other inputs held constant. Graphically, it is seen as the slope of the total physical product function. Mathematically, marginal physical product (MPP) can be expressed as:

$$MPP_x = \frac{\partial TPP}{\partial X}$$

where TPP is total physical product, or a mathematical expression of the relationship between the product and the input X, all other inputs held constant.

Buse and Bromley (1975, p. 109), define average physical product (APP) as the total amount of output divided by the total level of the variable input used to produce that quantity of output. Algebraically, average physical product can be calculated as:

$$APP = \frac{TPP}{X}$$

Graphically, the average physical product for any level of variable input is the slope of a line from the origin to the point on the TPP curve which is of interest. Figure 2 shows a "textbook type" total physical product curve with its associated average and marginal physical product curves.

In any production process there are likely to be variable inputs which substitute for each other to some degree within certain ranges of both inputs. The physical concept which indicates at what rate any two inputs substitute for each other is that of the isoquant, or isoproduct curve. An isoquant is a line in the resource plane which shows all possible combinations of two variable inputs which will produce a given level of output. An isoquant map shows a number of isoquants for different levels of output (Figure 3). Isoquants are derived from a production function, in the case of two variable inputs, by algebraically manipulating the function so that the quantity of one input is expressed as a function of output and the quantity of the other variable input, all other inputs except those two held constant. The marginal rate of substitution (MRS), of one input for another is given by the slope of an isoquant, and tells the amount by which one input will change when the quantity of another input changes and output remains constant. Isoquants are generally thought to have negative slope, as illustrated in Figure 3, and to be convex to the origin.

Elasticity of production is defined as the percentage change in output which will occur as a result of a one percent increase in input, or:

$$Ep = \frac{\%\Delta Y}{\%\Delta X} = \frac{\partial Y}{\partial X} \cdot \frac{X}{Y} = \frac{MPP}{APP}$$

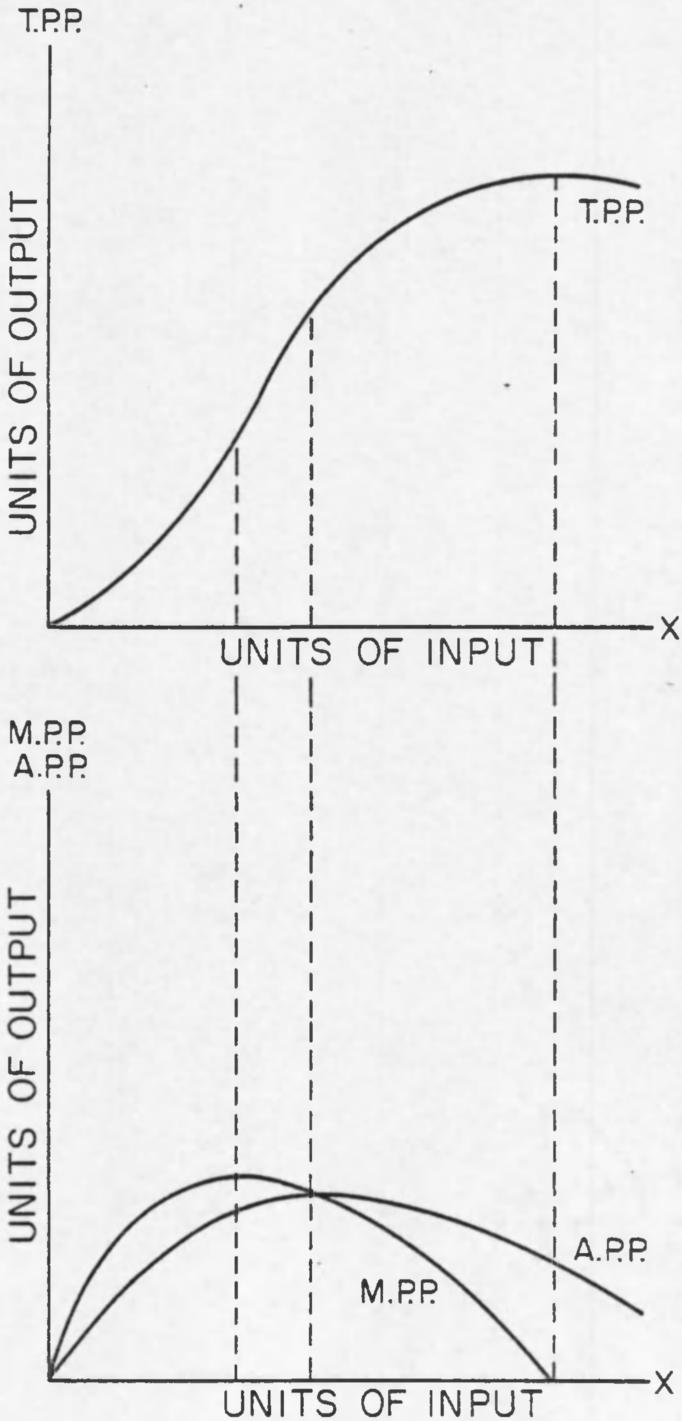
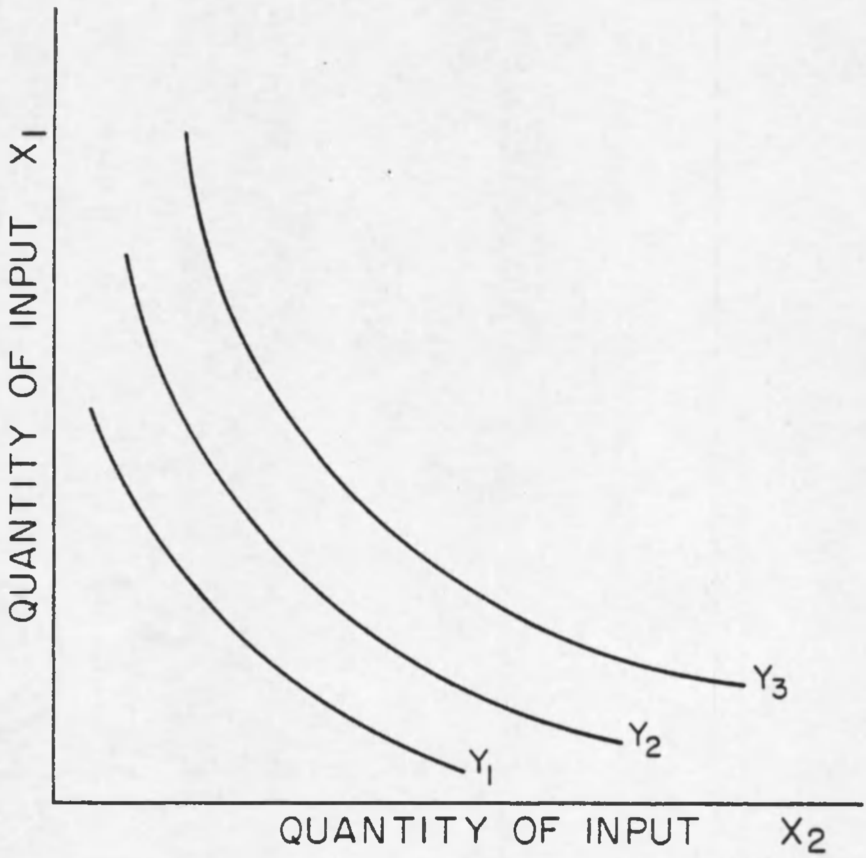


Figure 2. A total physical product curve with associated average and marginal physical product curves.



$Y_1, Y_2, Y_3 \rightarrow$ output levels

$Y_1 < Y_2 < Y_3$

Figure 3. Isoproduct curves or isoquants.

Production is commonly divided into three stages which are defined by the elasticity of production. Stage one of production exists when the elasticity of production is greater than one and the MPP is greater than APP. In stage one both total and average product will be increased by utilizing more of the variable inputs. Stage two is that range of production in which the elasticity of production is a value between zero and one. MPP is less than APP, but greater than zero. When the elasticity of production is less than zero, production is said to be in stage three. If production is in stage three, discarding some of the variable resource will increase the return to both fixed and variable resources (Heady and Dillon 1961, p. 40). Economically, as long as a firm is not influencing prices, it should produce at least to the point of maximum APP, or the beginning of stage two, and not past the point of maximum TPP, if it produces anything at all.

So far the discussion has only included physical relationships involved in production. In order to complete the decision making process, information is needed about the values of relevant inputs and outputs. The following section describes the use of price information in conjunction with information derived from production functions so as to determine economic optima.

Profit Maximization

Although profit maximization is not necessarily the objective of every business firm, it is probably the most extensively used criterion upon which economic decisions are made. For this reason it is assumed in the following discussion that the objective of the firm is to maximize profit.

In order to proceed with this analysis it is necessary to define certain terms. Economic profit is the difference between total revenue and total cost. Total revenue is the revenue received from selling Y units of output at a price P_y. Total cost consists of all fixed costs plus the cost of whatever amount of each variable input is used, including some payment to the entrepreneur. Marginal factor cost is defined as the change in total cost which occurs with the introduction of one additional unit of input. Total value product (another expression of TR) is equal to the price of the output times the quantity of the output or TPP. Average value product is defined as the price of the output times APP, and marginal value product is equal to the price of the output times MPP. These relationships are summarized below:

$$\pi = \text{profit} = TR - TC$$

$$TR = P_y \circ Y$$

$$TC = FC + P_{xi} \circ X_i$$

$$MFC = \frac{\partial TC}{\partial X}$$

$$TVP = P_y \circ TPP$$

$$AVP = P_y \circ APP = \frac{TVP}{X}$$

$$MVP = P_y \circ MPP = \frac{dTVP}{dX}$$

Buse and Bromley (1975) suggest that there are three fundamental questions to be answered when making production decisions. First, what product should be produced? Second, how much of that product should be produced? And finally, what is the best possible means to accomplish that production? Since this study focuses directly upon cattle feedlots already in existence, the product to be produced has already been chosen and is live beef, or fed cattle. The first question having been answered, the remaining two deserve further attention. Specification of the optimum quantity of inputs automatically specifies an optimum output for a given total physical product function. Therefore, by determining the best possible means of production, one also determines how much of the product should be produced.

Economic theory states that in order to maximize profits the firm should utilize each input to the point where the MVP of that input is equal to the marginal factor cost of that input (MFC). If the feedlot can be assumed to be buying its resources in a competitive market, the marginal factor cost of any resource is equal to the price of that resource. This necessary condition for profit maximization can be expressed mathematically as:

$$P_y \cdot \frac{dY}{dX_i} = P_{X_i}$$

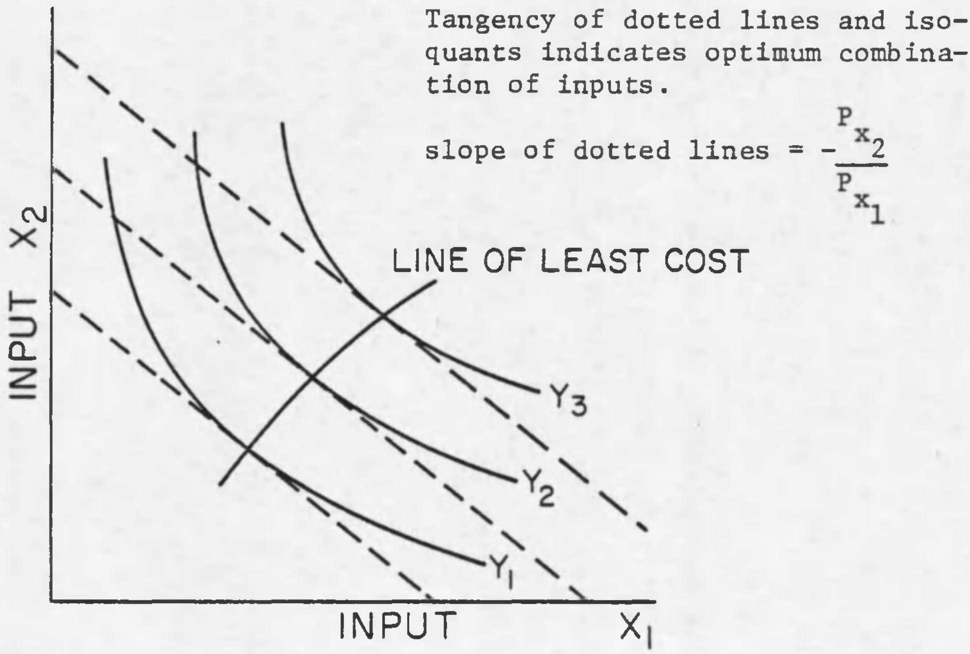
where P_y is the price of the output Y, P_{xi} is the price of the input X_i, and $\frac{dY}{dX_i}$ is the MPP of X_i in the production of Y. If only one variable resource is utilized in the production process, and VMP is assumed to be declining, the above condition is sufficient for profit maximization. However, a production process in which more than one variable factor of production is used has the possibility of substitution of inputs. If inputs can be substituted for one another, an additional criterion becomes relevant for profit maximization. Factors should be utilized in the production process in such proportions that the marginal rate of substitution of any input for another is equal to the negative of the inverse price ratio of the two inputs, or:

$$\frac{dX_1}{dX_2} = - \frac{P_{x_2}}{P_{x_1}}$$

where X_1 and X_2 are factors of production and P_{x_1} and P_{x_2} are their respective prices. If both the above conditions exist simultaneously, the combination of inputs, quantity of each input and quantity of output which should be produced is specified so as to maximize profit. These profit maximizing conditions are illustrated in Figure 4.

Revenue Maximization over Time

While profit maximization for a single production period may be accomplished using the techniques described above, profit maximization over time is not accomplished by simply repeating the above process over and over again if the firm runs a continuous operation. A feedlot is a good example of such an operation. "In a continuous operation, in which each lot of cattle is replaced immediately by a new lot, the operator is concerned with maximizing his average net revenue over time" (Faris 1960, p. 755). Faris (1960, p. 766) states that the optimum time to replace enterprises that can be held various lengths of time is when the "marginal net revenue from the present enterprise is equal to the highest amortized present value of anticipated net revenue from the following enterprise." If enterprises are to be replaced within the span of a year, as they are in feedlots, it can be assumed that the discount rate for time preference is zero, and amortized present value becomes equal to expected maximum average net revenue. The optimum replacement



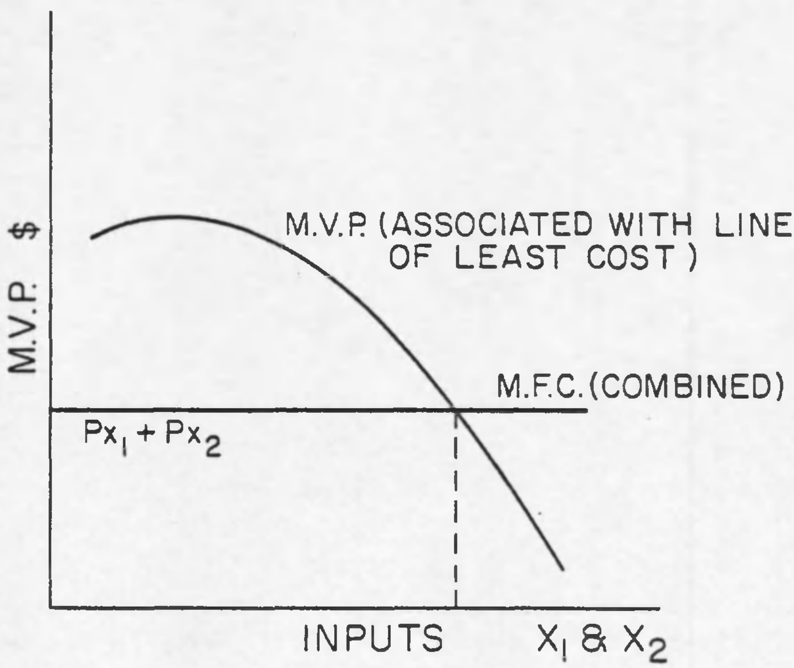


Figure 4. Optimum proportions of inputs and total quantity of inputs which will maximize net revenue.

time then occurs when marginal net revenue from the present lot equals expected maximum average net revenue from the next lot. If feeding is continued beyond this point, marginal net revenue will be less than maximum average net revenue for the next lot, reducing total revenue for the year.

The preceding paragraphs have explored the basic principles of production theory necessary to any study of production and economic optima. Because of the nature of the actual beef cattle production and marketing processes, the above theory may need to be modified in empirical application. Such modifications are presented in Chapter IV.

CHAPTER III

LIVESTOCK PRODUCTION STUDIES: THE STATE OF THE ART

Analyses of the many facets of livestock production have taken place over many years, and have included purely physiological as well as economic studies. The present paper is concerned with determining the physiological response of feedlot cattle to various experimental treatments, and the economic implications of the observed response. However, before this analysis takes place it may be useful to examine some of the past work in this area to obtain an historical background and present status of livestock production studies.

Conventional Approach

A detailed study of the cattle feeding industry in Arizona was carried out by Menzie, Hanekamp and Phillips (1973). A discussion of physical and economic characteristics of commercial cattle feeding operations was emphasized with investigations into custom feeding practices, the Arizona feed situation, supplies of feeder cattle, governmental controls, sources and methods of feedlot financing, and fat cattle marketing. Although some of the numerical values presented have changed since the time of the study, a firm basis for an understanding of the way feedlots in Arizona operate is presented.

Some of the earliest and most comprehensive economic studies of livestock production were carried out by Earl O. Heady in conjunction with various others. The most significant of these were "Production Functions and Substitution Coefficients for Beef" (Heady and Dillon 1961) and "Beef-Cattle Production Functions in Forage Utilization" (Heady et al. 1963). The first of these studies utilized existing experimental data in the estimation of beef cattle production functions. The second utilized data from experiments designed specifically for that study. The objectives and procedures for both studies were similar. Therefore, a discussion of the 1963 study covers the procedure and findings of both experiments.

The experiment was carried out to determine the combinations of pasture forage and corn which would maximize profits. Specifically, the problems addressed were of selecting the least-cost pasture forage-corn ration, that would place the beef cattle on the market finished to a given grade, at the time when the expected market price would maximize profits.

Several alternative least squares regression equations were used to estimate production surfaces with the best results being obtained from quadratic functions. The functions estimated included beef gain as a function of pounds of corn, pounds of roughage and temperature deviations from the mean maximum temperature for the overall feeding period.

From the estimated production functions were derived the marginal rates of substitution of corn for soilage at various levels of beef gain. These marginal rates of substitution were found to be diminishing.

Time equations were estimated which express the total time required to consume a given quantity of corn and soilage as a function of the corn and soilage fed. These equations were used to predict the time required to produce various levels of gain for different soilage-corn rations. It was found that the time required to produce a given level of gain decreases as the proportion of corn in the ration increases. Also, for a given feeding period, the maximum level of gain is attained with the heaviest corn ration.

The steers were graded at definite intervals during the feeding period and a functional relationship that expressed grade as a function of the corn and soilage fed was estimated.

Price functions which represented the grade of the steers during the feeding period as well as the market price associated with that grade were derived and used in profit equations. Estimated profits from feeding steers various rations for feeding periods of various lengths under various feed-price assumptions were presented in tabular form. Usually, the greatest profits were obtained by feeding the heaviest corn ration, but when the price of soilage was low relative to the price of corn, the most profitable ration included less corn.

Equations and a procedure also are given in the text for obtaining the optimum feeding period for any given ration under different feed-price conditions, and for obtaining the optimum ration with different feed-price assumptions.

Goodrich et al. (1974) did statistical and economic analyses of 17 university experiments to determine the influence of corn silage level on the performance of steer calves fed to market weight. They found that average daily gain was influenced in a quadratic manner by percent corn silage in the ration, and a given increase in the amount of corn silage decreased daily gain to a greater extent when high levels of corn silage were fed than when the ration contained low levels of corn silage. Amount of feed per 100 pounds of gain increased linearly as the amount of corn silage increased.

Nonfeed costs for 600 pounds of gain increased, but feed costs decreased, as the amount of corn silage in the ration increased. Feed costs utilized in this study favored the feeding of high silage rations for one lot of cattle, but it must be realized that animals fed 80% corn silage take about 2-1/2 months longer to reach market weight than those fed 10% silage dry matter. For feeders that keep their lots full at all times, the corn price at which high silage rations should be fed is dependent on the magnitude of the gross margin (market value minus initial cost). At large gross margins, high grain rations should continue to be fed even though the corn grain price is high.

Zulberti, Reid and Casler (1973) state that "biological efficiency" is equivalent to the "average physical product" of economics. They present the computational equations to calculate the voluntary daily intake of beef cattle for a given set of values of the variables involved, and the rate of gain any intake produces. Their findings indicate that as daily intake of feed of a given quality increases, biological efficiency (body weight gain per kg. of feed) also increases. This increase occurs because a large portion of the feed intake is used for maintenance and only a relatively small part for production. The above implies that average physical product is continuously increasing for feed of any concentration until the daily voluntary intake restriction is reached. As a result, ad libitum feeding systems are always the optimum way of feeding if feeding is to take place at all.

A study which examined the choice of the optimum type as well as the economically optimum amount of ration for feeding cattle in Arizona was carried out by Farrish and Marchello (1976). They found that the optimum weight steer to produce increases with either increases in the price of fed cattle or decreases in feed prices, for either a low or a high concentrate ration. However, for the high grain ration, the optimum weight of steer to produce never exceeds 1,000 pounds under any of the price conditions examined. The claim is also made that the likelihood of the low grain ration being more economical increases as the weight of steer produced increases. Their results indicate that in the recent past it may have paid cattle feeders in Arizona to produce somewhat lighter animals and to utilize other than high grain rations.

Although the Farrish and Marchello study dealt specifically with cattle feeding in Arizona and utilized data from the same project as this study, their results are questionable for several reasons. First, the data utilized were insufficient causing the estimated production functions to be statistically insignificant. Secondly, a correct distinction between fixed and variable costs was not made and consequently determinations of economic optima were inaccurate. Finally, replacement of cattle for year-round feeding and implications of the ownership of cattle being fed were not examined as decision making factors.

The California Net Energy System

In 1968, Lofgreen and Garrett introduced the California net energy system designed for use in the growing and finishing phase of the beef cattle industry. This system was tested over the years at experiment stations, in commercial feedlots, and by nutrition consultants working with the cattle feeding industry and its adaptability to practice has been demonstrated. The system was first presented in the scientific literature in 1968 by Lofgreen and Garrett.

The system separates the requirements for maintenance from those for body weight gain and expresses a net energy value for each of these two functions. This separation is necessary because the partial efficiency of energy utilization for maintenance is higher than it is for production. The net energy of a feed varies with the level of feeding, being higher at low levels of feeding and decreasing as feed intake increases. It is obvious, therefore, that a system based upon net energy must take this difference into consideration by listing separate net energy values for different physiological functions or incorporating efficiency of utilization values for these functions.

The most recent and most comprehensive presentation of the above system is given in a publication entitled Nutrient Requirements of Beef Cattle (National Academy of Sciences 1976). Included are discussions of feed consumption and rates of gain, nutrient requirements of growing cattle, and the composition of feedstuffs including the energy value of various feeds.

Ewen M. Wilson (1976) utilized the California Net Energy System to test the hypothesis that feedlot cattle production takes place in Stage I and to analyze relative economic efficiencies of two energy-specific rations. He concluded, as did Zulberti et al. (1973) that cattle feeding is constrained by voluntary appetite to Stage I of production, where the production function is expressed as the daily feed-gain relationship for rations of specified energy density. The implication is that in a positive profit situation cattle ought to be fed for maximum daily gain, since this is equivalent to the lowest attainable point on the average cost curve. When two rations of different energy concentrations were compared, the higher energy ration was preferred on grounds of physical and economic efficiency over a relevant range of corn and cattle prices.

The most extensive applications of the California net energy system have been made by Ray Brokken and associates. They assert that traditional models for assessing technical and economic efficiency of cattle feeding have been found to be inadequate (Brokken et al. 1976). His objective, therefore, is to develop an alternative framework for estimating effects of changes in ration nutrient concentration on animal performance under a range of production conditions and types of animals. The framework is incorporated in a dynamic profit function and its use discussed and demonstrated under various optimizing criteria. Brokken shows that high energy rations remain economical even at relatively high grain prices. This framework implies sigmoid shaped grain-roughage isoquants concave to the origin over the finishing range of grain-roughage ratios, and convex at lower grain to roughage ratios. In addition, trade-off curves for successive levels of gain become progressively tipped in favor of grain. This progressive tipping suggests that a high roughage ration is relatively more efficient in the early stages of a finishing program (although such a ration may not be optimum) and that a high concentrate ration becomes relatively more efficient as the finishing program progresses.

A study by Sonka, Heady and Dahm (1976) estimated gain isoquants to be used in a decision model for swine production. Historic estimates of livestock production functions have used repeated observations on the same animals to estimate the overall gain surface. These estimates therefore involve autocorrelation. To circumvent this problem the authors estimated gain isoquants directly by means of an instrumental variable approach. A swine experiment was designed for the purpose with protein supplement and corn serving as the substitute inputs, and with protein supplement estimated as the instrumental variable. Isoquant equations were then predicted for various weight intervals.

Although this experiment was with swine, it seems that a valid method for obtaining good estimates of gain isoquants has been documented which can be applied to any livestock feeding experiment which is designed accordingly.

The studies which have been mentioned in this section are by no means all of those dealing with the economics of livestock production. They do, however, discuss most of the principal developments in this field of research. The insight provided by the authors mentioned, as well as others, serves as a starting point for this study.

CHAPTER IV

ANALYSIS OF THE PHYSICAL/BIOLOGICAL DATA

The data utilized in this study were generated through the cooperation of the Experiment Stations of The University of Arizona, New Mexico State University and Utah State University as a part of Western Regional Research Project W-145, entitled "Impacts of Relative Price Changes of Feeds and Cattle on Marketing of U. S. Beef." In addition, cooperation was received from the Chavez County Cattle Company of Roswell, New Mexico, in execution of the feeding trials (Marchello 1976).

Experimental Design

Sixteen steer calves of mixed breeds were obtained from each of twelve cooperating ranches in Texas, Utah, New Mexico and Arizona. At the outset of the experiment these calves were about six months old, weighed between 450 and 500 pounds and had been weaned approximately three weeks before. Of the sixteen calves from each herd four were slaughtered to give initial carcass composition information, and the remaining twelve were randomly assigned to three feedlot treatments and two replications.

The three treatments basically consisted of a low, medium and high concentrate ration. Table 1 shows the composition of the four basic rations that were fed in varying proportions to make up the three treatments. All rations included Rumensin and Stilbesterol. Animals on the low concentrate ration (treatment I) were fed ration 1 or ration

Table 1. Composition of experimental rations.

Ration No.	1	2	3	4
(ingredient)		percent		
Corn	56.0	56.0	40.0	77.5
Alfalfa	35.0	32.5	50.0	12.0
Beet solubles[a]	6.0	6.0	8.0	6.0
Fat	.5	.5	--	1.0
Premix[b]	2.5	2.5	2.0	3.5
Bay Mix[c]	--	2.5	--	--
TOTAL	100.0	100.0	100.0	100.0

a. Steffen's Filtrate.

b. Premix Supplies: Pro/NPN, CA, P, K, Mg, Salt, $AmSO_4$, Vit. A.

c. Bay Mix consists of hay and a wormer.

2 for the first 37 days, and ration number 3 for the remainder of the feeding period. Calves on treatment II, or the medium concentrate ration, were fed ration 1 or ration 2 for 37 days, ration 3 for 57 days, ration 1 or 2 for 61 days and finally ration number 4 until termination of the feeding period. Steers on the high concentrate ration (treatment III) were fed ration 1 or ration 2 for 94 days and ration 4 for the remainder of the feeding period. These three treatments were fed in six pens with 24 steers per pen.

The calves were group weighed by pen and entered the feedlot on December 1, 1975. Termination of the feeding period occurred when the individual animals attained an outside fat thickness over the twelfth rib of not more than 0.4 of an inch, as determined by ultrasonic measurement, or when the animals had been on feed for a total maximum period of 220 days.

The animals were group weighed by pens after 30 days on feed and then at 28 day intervals until March 23, 1976. Beginning at this point the steers were weighed weekly until all animals were removed from the feedlot. The animals were fed "ad libitum" and daily observations were made on the amount of feed intake by each pen.

At the conclusion of the feeding trials carcass data including yield and quality grade were assembled. In addition, a consumer acceptance survey was carried out to determine if there were significant differences in the acceptability of the beef resulting from different feeding regimes.

Experimental Inadequacies

Designing an experiment, the results of which will lend themselves to economic analysis, is an important step in applied research. Design is often a difficult task, but one deserving considerable attention since inferences derived from improperly or inadequately generated data can only at best be weak.

This particular experiment was designed with very little thought about the economic analysis which would follow. Although one objective in the proposal for this project was to "ascertain the economics of differences associated with feeding regimes," it appears that the experiment was designed primarily to determine and evaluate differences in carcass characteristic resulting from different feeding regimes. An adequate economic evaluation of various feeding regimes would require that certain experimental procedures be changed.

The most important determinations that need to be made in order to maximize net revenue in a feedlot situation are: what ration to feed and for how long? Necessary information includes data which allow estimation of a production function from which marginal rates of substitution of various feeds can be derived, as well as a periodic appraisal of the animals to determine at what point in the feeding process changes in quality occur. If new information is desired, experimentation should also take place in ranges outside of currently accepted practices.

The current experiment provided data which allow estimation of a production function, but one with little statistical significance. Had the animals been weighed more often a better regression equation possibly could have been fit simply due to the increased number of observations. An increased number of replications of each treatment would increase the degrees of freedom available for hypothesis testing and give more significance to such tests. Since an animal's weight depends greatly upon rumen fill at the time of weighing, more accurate observation of weight could be obtained by weighing the animals on each of two successive days and using the average of the two observed weights as the experimental observation.

Isoquants showing the marginal rates of substitution of various feeds could not be estimated from the current data because of the nature of the three experimental treatments. Specification of feed isoquants would require that a minimum of three separate rations be fed. Accurate specification of isoquants would require that more than three separate rations be fed covering the range between the physiological minimum amount of roughage (about 10%) and 100% roughage. Although the current experiment included three feeding treatments, these treatments only included rations with concentrate levels of between 50% and 85%. This is the range that is most likely to be utilized according to current feedlot practices, but it tells us nothing of the possibilities of feeding lower than 50% concentrate rations. The three treatments also were set up in such a manner that only during a 61 day period in the middle of the experiment were three different rations fed simultaneously. Since the animals on the three rations during this period had been treated differently prior to the period, little can be said about roughage-concentrate trade offs even during the time when three separate rations were being fed. One method of experimentation which would allow estimation of roughage-grain isoquants would be to place all animals in a feedlot situation and feed them a starting ration for a given length of time so that they would become accustomed to some grain consumption. At the conclusion of this adjustment period animals should be randomly assigned to at least six treatments varying in concentrate levels from zero to 90%, with as many replications as possible. Once an animal is assigned to a particular ration it should remain on that ration for the remainder of the feeding period.

The length of the feeding period can be determined in many possible ways, but some criterion for termination of feeding must be chosen which requires all of the animals in a given pen to be fed for the same length of time, since the pen must necessarily be the experimental unit in trials of this nature. This experiment allowed animals to be removed from any pen a few at a time over a period of 35 days, rendering any observations taken after the first group of animals was removed useless.

The average weight of the animals upon termination of relevant data gathering was 947.5 pounds. This weight eliminates examination of the possibility that the economic optimum weight of animal to produce is greater than 950 pounds. Experimentation outside of the range of currently accepted practices is desirable.

The transition of an animal from feeder calf to live beef is a production process which involves not only additions to weight, but also changes in carcass composition. These carcass characteristics are just as important as final weight in the determination of the market value of the product. An economic analysis of the optimum feeding period must therefore include not only information about weight gain, but also information about carcass characteristics, the most important of which are quality grade and yield grade. An adequate experiment would provide observations on weight gain as well as periodic appraisals of the grade of animals. The current experiment included no observations on grade until the end of the feeding period. Therefore, it cannot be determined at what point in the feeding process the animals made the transition from a product of one value to a product of a different value.

Production Function Estimates

In order to estimate a production function for any production process one must have some preconceived notion of what are the important inputs and output. In the beef production process the transformation is made from a light weight animal of given quality to an animal of heavier weight and perhaps of a different quality. The appropriate dependent variable in a beef production function then appears to be weight gained. Changes in the quality of beef that occur during the feeding process are reflected in the value of the animal and need not be a part of the production function itself.

Although many fixed and variable factors of production are involved in cattle feeding, the main determinants of weight gain appear to be the amount and type of feed fed, the length of the feeding period, and the weather conditions during feeding. For this reason these factors were utilized in various ways as independent variables in estimation of alternative beef cattle production functions. Several different algebraic forms of equations were estimated from the data generated in the experiments described above, using the technique of ordinary least squares regression.

Basic Equations

An equation of the quadratic form was estimated and is presented below:

$$G = -3.37085 + 14.76367C - .10515C^2 - 2.15051R + .02490CR - .49842T \quad (1)$$

where G is pounds of beef gain, C is pounds of concentrates, R is pounds of roughage and T is the deviation from normal temperature during each observation period. The coefficient of determination, standard errors and "t" statistics for equation (1) are presented in Table 2. The quadratic form was chosen because of its ability to portray the diminishing returns which are suspected to exist during the relevant portion of a feeding period. Although the coefficient of determination for this equation is quite high, only C and C^2 have estimated coefficients which are statistically significant at the 90% level or better. The particular computer program that was used for this analysis does regression in a stepwise manner. Therefore, those independent variables with the highest simple correlation with the dependent variable enter first into the regression equation. Concentrate was the variable which entered on the first step of this regression. The coefficient of determination after step one was .96878, indicating that the addition of the other variables in subsequent steps added little to the overall explanatory power of the regression equation. This phenomenon probably occurred because of multicollinearity, or a strong correlation between the independent variables. The simple correlation coefficient between roughage and concentrates is 0.698. This correlation between roughage and concentrates is one which is unavoidable in an experiment such as this, because for any amount of concentrates consumed by a pen of animals on a

Table 2. Coefficient of determination, standard errors and "t" values for equation 1.

R^2	Independent variable	Standard error of regression coefficient	"t" value
.98459	C	1.18023	12.509
	C^2	0.02272	4.627
	R	1.41429	1.521
	R^2	0.03861	0.249
	CR	0.05214	0.478
	T	0.65480	0.761

particular ration, there is a corresponding given quantity of roughage which will be consumed.

Autocorrelation, or an interdependence among successive values of the disturbance term was also present, as evidenced by a Durbin-Watson statistic of 0.66176, a value below the critical value of 1.39. Autocorrelation is to be expected when the data consist of successive observations on any one lot of steers. Autocorrelation is a violation of one of the basic assumptions of the regression model and results in greater than minimum variance estimators of the regression coefficients. The results are "t" ratios, R^2 and F statistics that are biased upwards rendering invalid our statistical hypothesis tests.

There are methods which may be used to correct for autocorrelation. The procedure selected here is one described by Kelejian and Oates (1974, p. 195). When equation 1 is corrected for autocorrelation the resulting equation is:

$$\begin{aligned} G = \underset{(1.844)}{27.17538} + \underset{(4.391)}{9.85075C} + \underset{(0.025)}{.05065R} - \underset{(1.323)}{.04308C^2} + \\ \underset{(0.394)}{.02424R^2} - \underset{(0.477)}{.03663CR} + \underset{(0.125)}{.03946T} \end{aligned} \tag{2}$$

where the variables are as described for the previous equation and the numbers in parentheses are the relevant "t" values for the estimated coefficients. The Durbin-Watson statistic for this equation is 2.21492, a value less than the critical value of 2.30 indicating no autocorrelation, but the R^2 value decreased to 0.57585 and the significance level of both C and C^2 decreased.

The explanatory power and significance levels of the above production function estimates are less than completely satisfactory.

Other algebraic forms of the production function were estimated using the same variables. These forms included square-root and exponential functions. None of these functions fit the data quite as well as does the quadratic form, and all estimates are plagued with multicollinearity, autocorrelation and low significance of estimated regression coefficients. Erroneous specification of the important independent variables is indicated by the consistent lack of significance found. Temperature deviations seem to have no effect on gain, and although feed must be included as an explanatory variable perhaps the experimental design is such that the breakdown into roughage and concentrates is incorrect.

The California Net Energy System as developed by Lofgreen and Garrett (1968) provides an alternative to the traditional breakdown of feeds into roughage and concentrates. Since energy is the primary feed ingredient which contributes to weight gain it seems reasonable to express feed values in terms of energy when discussing contributions to gain. The appropriate energy measure for gain estimation is net energy, which consists of the energy left in the digestion process after all losses such as undigestable feed residue, urine, gases and heat are removed. Net energy must be further divided into net energy for maintenance (NE_m) and net energy for gain (NE_g). The division accounts for the differences in efficiency of digestion that occur depending upon whether energy is used to meet the animal's maintenance needs or for weight gain (National Academy of Sciences 1976).

In order to determine if some relationship does indeed exist between the net energy for gain value of a ration and the weight gained by animals on that ration, the feed data from this experiment were converted to NE_g values and plotted graphically against gain (Figure 5). Such a relationship appears to exist and least squares regression was used to estimate the function describing it.

Functional forms estimated include linear, quadratic, square-root, exponential and semilog. Only the most satisfactory of these forms, the quadratic and exponential are discussed here.

The quadratic form estimate of the production function is:

$$\underset{}{G = -5.01280} \underset{(13.400)}{+ 15.88774N} \underset{(5.373)}{- 0.12398N^2} \quad (3)$$

$$(0.361)$$

where G refers to pounds of weight gained, N refers to M Cal. of NE_g, and the values in parentheses are the corresponding "t" statistics. The Durbin-Watson statistic for this equation is 1.709, a value greater than the critical value of 1.700 indicating a lack of autocorrelation. The coefficient of determination for equation (3) is .946. The coefficients of both N and N^2 are significantly different from zero at a one percent level of significance, and the signs of the coefficients are as expected.

From the production function estimated in equation (3) can be derived an expression for marginal physical product:

$$\frac{dG}{dN} = 15.88774 - 0.24796N \quad (4)$$

Setting equation (4) equal to zero and solving for N gives the quantity of net energy for gain which maximizes total physical product. This value is equal to 64,072 MCal., and corresponds to a gain of 504 pounds or a total maximum weight of 947 pounds. However, this value is inconsistent with logic. Animals fed beyond a weight of around 950 pounds

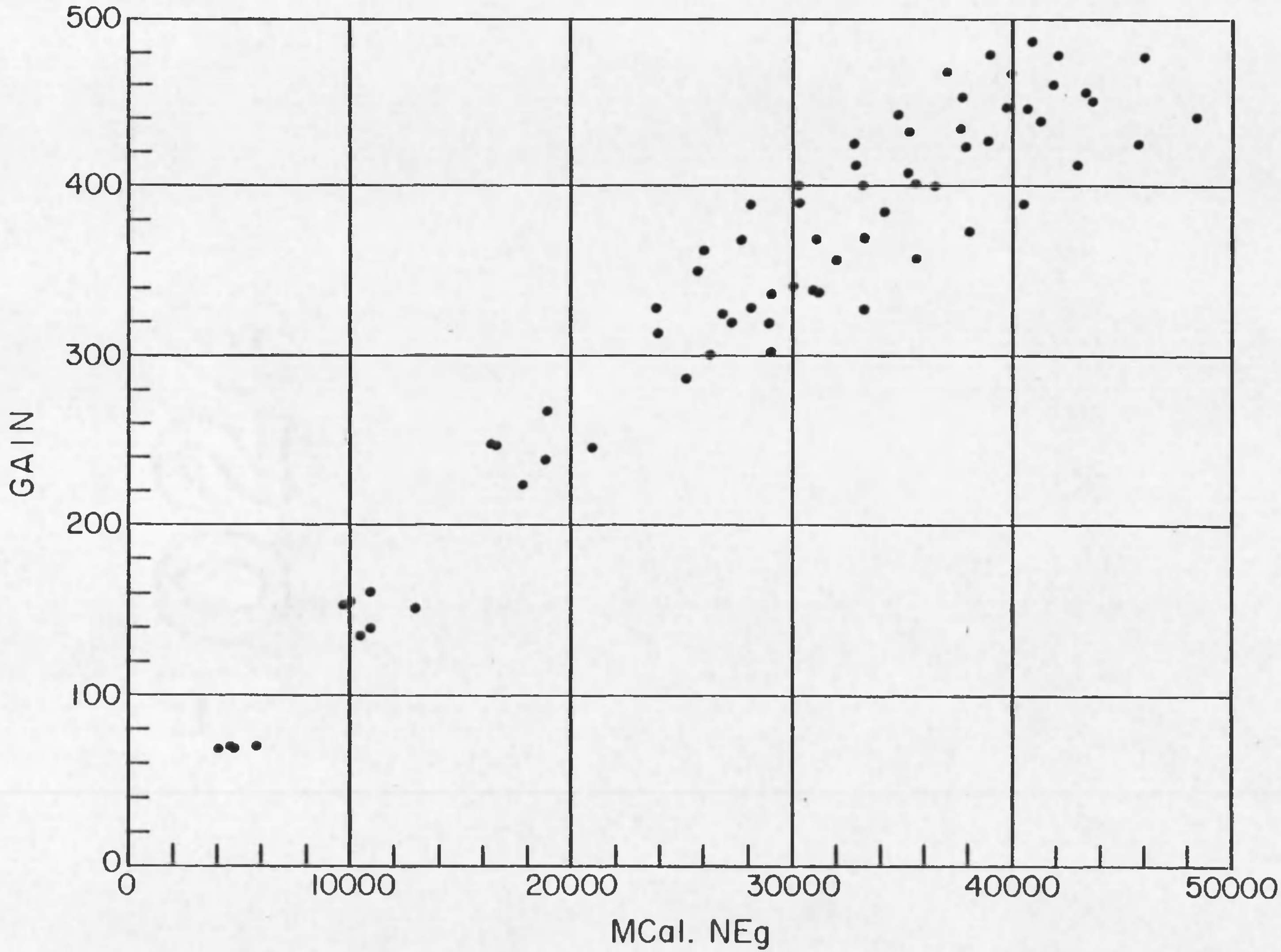


Figure 5. Plot of gain vs. NE_g.

will not begin to lose weight. While the quadratic function fits well within the limited range of the data, it is rejected on the basis of this logical inconsistency.

Another equation estimated was of the form:

$$G = aN^{b}e^{u} \qquad (5)$$

where G and N are as defined above, e is the base of the system of natural logarithms, "u" is a disturbance term and "a" and "b" are the parameters to estimate. To estimate the nonlinear relationship, it is necessary to transform it into a linear form using the log transformation. Taking the log of each side of (5) results in:

$$\ln G = \ln a + b\ln N + u \qquad (6)$$

where ln is the natural logarithm of the variable. Estimation of this equation using the experimental data gives:

$$\underset{}{\ln G} = \underset{(16.139)}{-2.82300} + \underset{(48.818)}{0.84175\ln N} \qquad (7)$$

where the numbers of parentheses are "t" values indicating that the estimated parameters are different from zero at a one percent level of significance. The coefficient of determination for this equation is 0.971, the F statistic 2383.231, and the Durbin-Watson statistic is 1.742, indicating that autocorrelation is not a problem. To put the production function in its original form it is necessary to take the antilog of equation (7). Doing so one obtains:

$$G = 0.059427N^{0.84175} \qquad (8)$$

where a "b" value that is positive and less than one indicates diminishing returns to the variable input as expected. The estimator of "a" also is positive as expected. However, when the antilog of ln a is taken to obtain an estimate of "a," a bias is introduced into the equation since $E(a) \neq e^{E(\ln a)} = e^{\ln a} = a$ (Kelejian and Oates 1974, p. 98).

The magnitude and direction of this bias at the mean can be calculated by substituting the mean values of gain and NE_g into the estimated production function and solving for "a." If there were no bias the resulting value would be the same as the regression estimate of "a." If bias exists it is of the magnitude and direction indicated by the difference between "a" as calculated above and the regression estimate of "a." From equation (8) "a" is seen to be 0.059427. The mean value of $G(\bar{G})$ is 332.78 and $\bar{N}$ = 28,833.0. Using these values and solving equation (9) for "a" gives a value of 0.058620.

$$332.78 = a(28833.0)^{0.84175} \qquad (9)$$

The difference, or calculated bias, is 0.000807, a value not significantly different from zero. Thus, bias of "a" is not an important problem in this application.

Implications of the Estimated Exponential Production Function

Conventional isoquants cannot be derived from the estimated production function. Since isoquants show the marginal rate of substitution of one input for another it is necessary to have at least two variable inputs in a production function if isoquants are to be derived directly from that function. This production function contains only one variable input, NE_g. In addition, the data from this experiment cover only a small range of the possible roughage to concentrate ratios, with few observations within that range. This problem renders it impossible to estimate isoquants from the data even if a production function containing variables for at least two types of feed were acceptable.

An expression for marginal physical product can be obtained from equation (8) by taking the derivative of gain with respect to NE_g as in equation (10).

$$\frac{dG}{dN} = .050023N^{-0.15825} \tag{10}$$

This function is decreasing at a decreasing rate, and approaches but never reaches zero. This relationship implies that the total physical product function increases at a decreasing rate but never reaches a maximum. Although it seems unrealistic that cattle will continue gaining weight if fed indefinitely, it does seem reasonable that they will continue to gain for some period beyond the range of this experiment, which this function allows. Figure 6 shows the estimated beef cattle production function, and Figure 7 shows its corresponding marginal product function.

The elasticity of production is obtained directly from equation (9). This elasticity is constant and equal to the estimated "b" value as demonstrated in equation (11).

$$E_p = \frac{MPP}{APP} = (baN^{(b-1)}) \frac{N}{G} = \frac{baN^b}{N} \cdot \frac{N}{G} = \frac{bG}{N} \cdot \frac{N}{G} = b \tag{11}$$

The elasticity of production is 0.84175, indicating decreasing marginal productivity, and that production is taking place in stage II where net revenue maximizing principles can be applied.

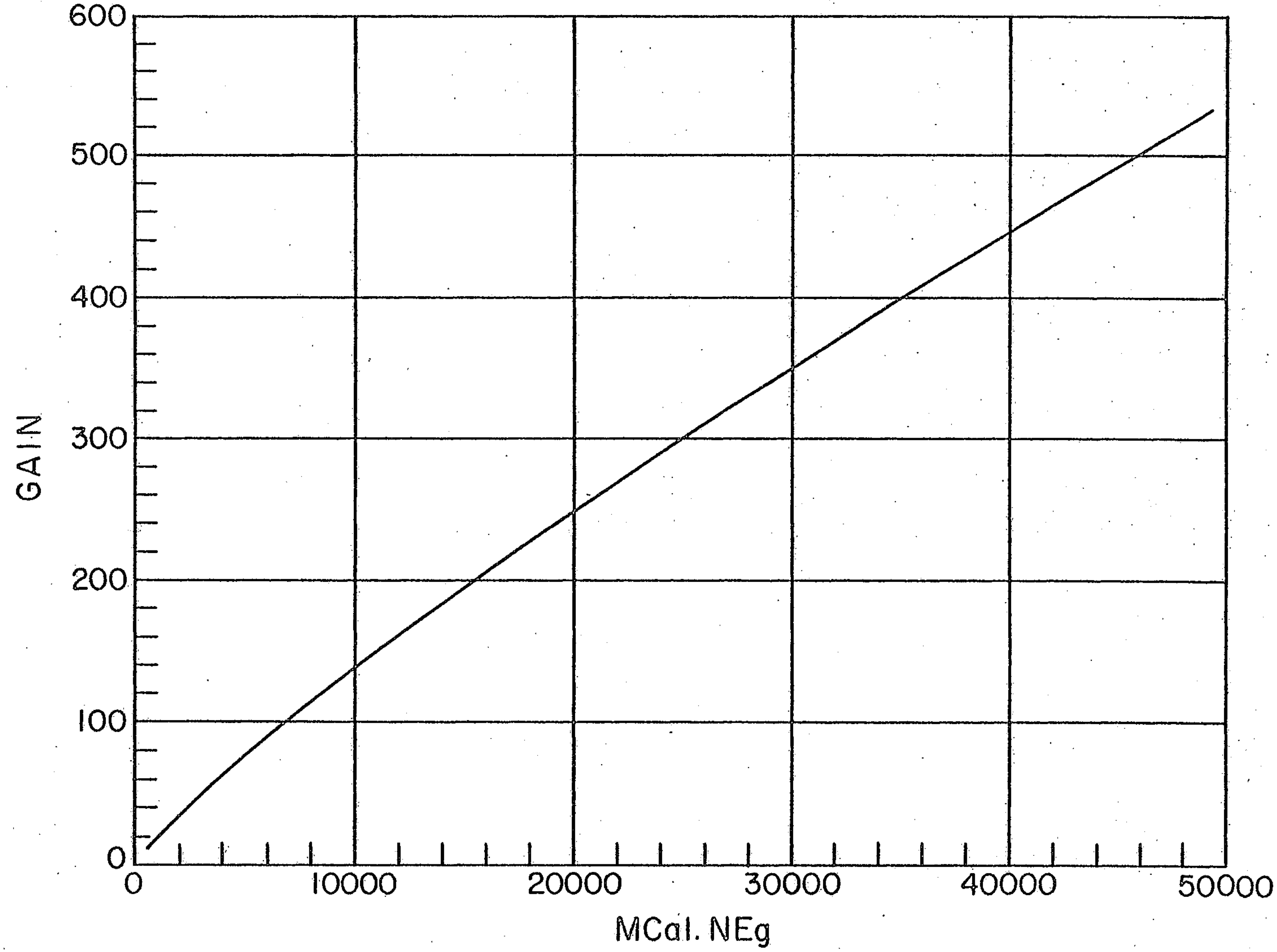


Figure 6. Total physical product.

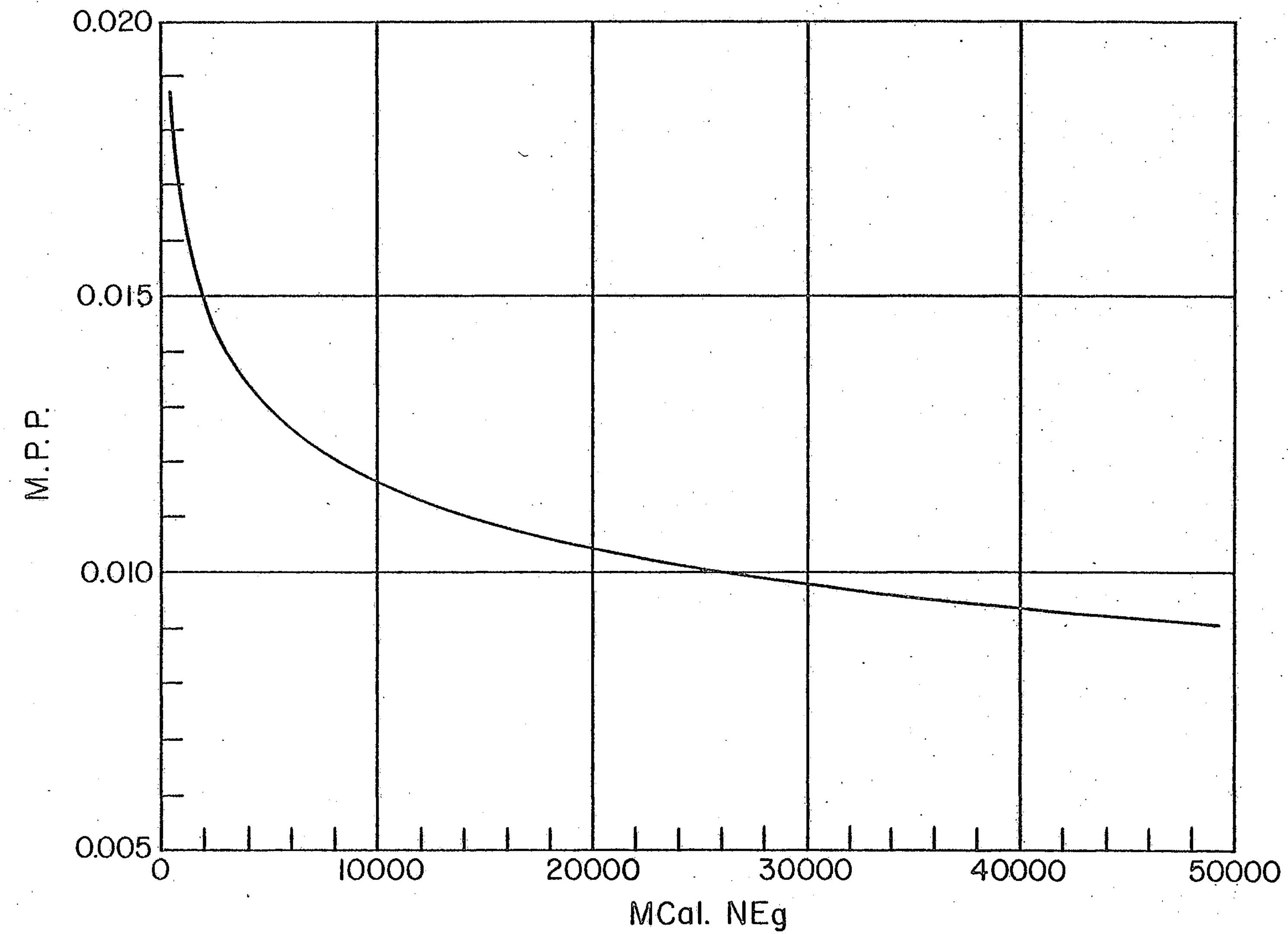


Figure 7. Marginal physical product.

Time Equations

As shown above, one equation can be used to show the relationship between gain and net energy for gain for all of the experimental treatments. However, this equation is not adequate to determine economic optima because the rate at which energy is consumed for feeds varying in concentrate level is different. This difference in the rate of energy consumption causes a corresponding difference in rates of gain. Rate of gain is important in the decision making process particularly when the objective is revenue maximization over time.

The relationship between time and intake of net energy for gain was estimated for each treatment using least squares regression. Various functional forms were tried with the exponential form yielding the most satisfactory results. The estimated equations are presented in equations 12 through 14 for the low, medium, and high concentrate treatments respectively:

$$E_\ell = 0.07111T^{1.26201} \tag{12}$$

$$E_m = 0.06291T^{1.26952} \tag{13}$$

$$E_h = 0.04894T^{1.31161} \tag{14}$$

In the above equations, E refers to intake of net energy for gain and T is time in days. Each of the three estimated equations has coefficients that are highly significant at the one percent level, coefficients of determination greater than 0.99, and F values greater than 3,000. These tests indicate that the overall explanatory power of each of the equations is quite high.

These estimated energy values for each treatment over time were converted to the appropriate amount of feed using conversions of 52.53 MCal. NE_g per cwt. of feed for rations 1 and 2, 48.39 MCal. NE_g per cwt. of feed for ration 3, and 60.14 MCal. NE_g per cwt. of feed for ration 4. Weights utilized were generated through equation (8) using energy values as calculated above. These results are listed in the first three columns of Tables 6, 7, and 8 (pp. 61-66).

The physical relationships estimated in this chapter are summarized in Figure 8. Figure 8b shows the relationship between time and consumption of net energy for gain for the low, medium and high concentrate treatments. At any point in time (for example t_1) during the feeding period, animals on the low concentrate treatment will have consumed the largest amount of net energy for gain (L), and animals on the high concentrate treatment the smallest amount (H). These net energy for gain values may then be transferred to Figure 8a where the gain associated with each of the three treatments at time t is shown. The highest net energy for gain consumption, and correspondingly the highest gain per period of time occur as a result of feeding the low concentrate treatment.

Conceptual Issues Relating to Physical Results

Heady et al. (1963) and Brokken et al. (1976) are among those who have shown that for a given feeding period the maximum level of gain is attained with the heaviest concentrate ration. Heady et al. (1963, p. 883) states "the time required to produce a given level of gain, for

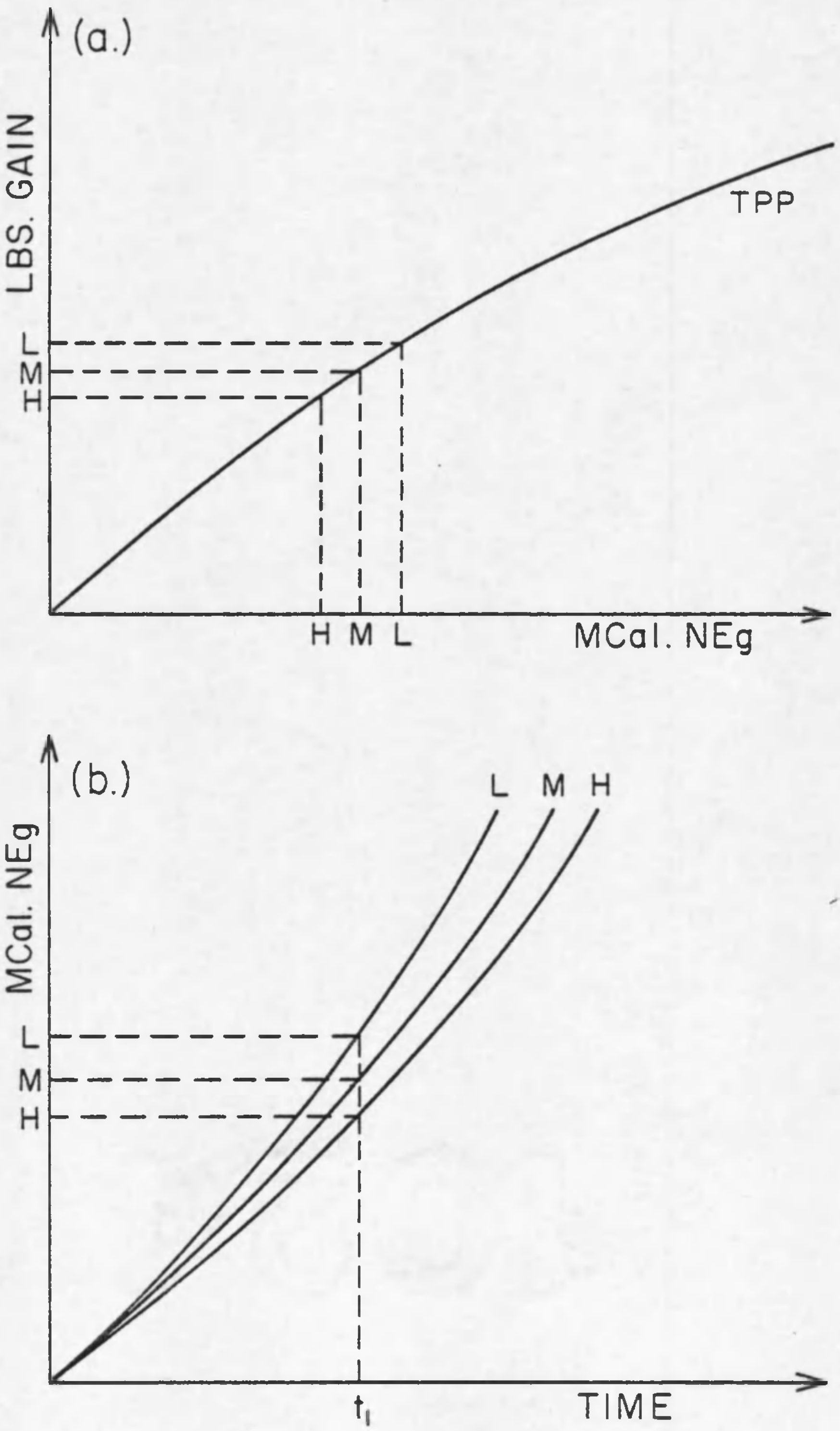


Figure 8. Summary of estimated physical relationships.

the rations both with and without stilbesterol, decreases as the proportion of corn in the ration increases."

The work of Brokken et al. (1976) shows an increasing rate of gain as energy concentration increases. Figure 9 shows the relationships between energy concentration and dry matter, digestible energy and net energy intake. In the region to the right of point A, rumen fill has ceased to limit intake and further increases in energy concentration result in a decline in dry matter intake. Although dry matter intake is declining with further increases in energy concentration, digestible energy intake remains approximately constant. Since it is known that net energy as a proportion of digestible energy increases as the energy concentration increases, the net energy intake curve in Figure 9 is implied. If net energy intake increases with energy concentration, then it is further implied that the rate of gain will be higher from higher concentrate rations. This same conclusion was reached by Montgomery and Baumgardt (1965), Dinius and Baumgardt (1969) and Dinius et al. (1976).

These results are in direct conflict with the findings of the current analysis as depicted in Figure 8. Although the majority of evidence presented in previous studies indicates that the most rapid gain is to be expected when feeding a high concentrate ration, the optimization analysis presented in the following chapter is based upon the physical relationships derived from the current experiment. Economic implications of this conflict will also be discussed in the following chapter.

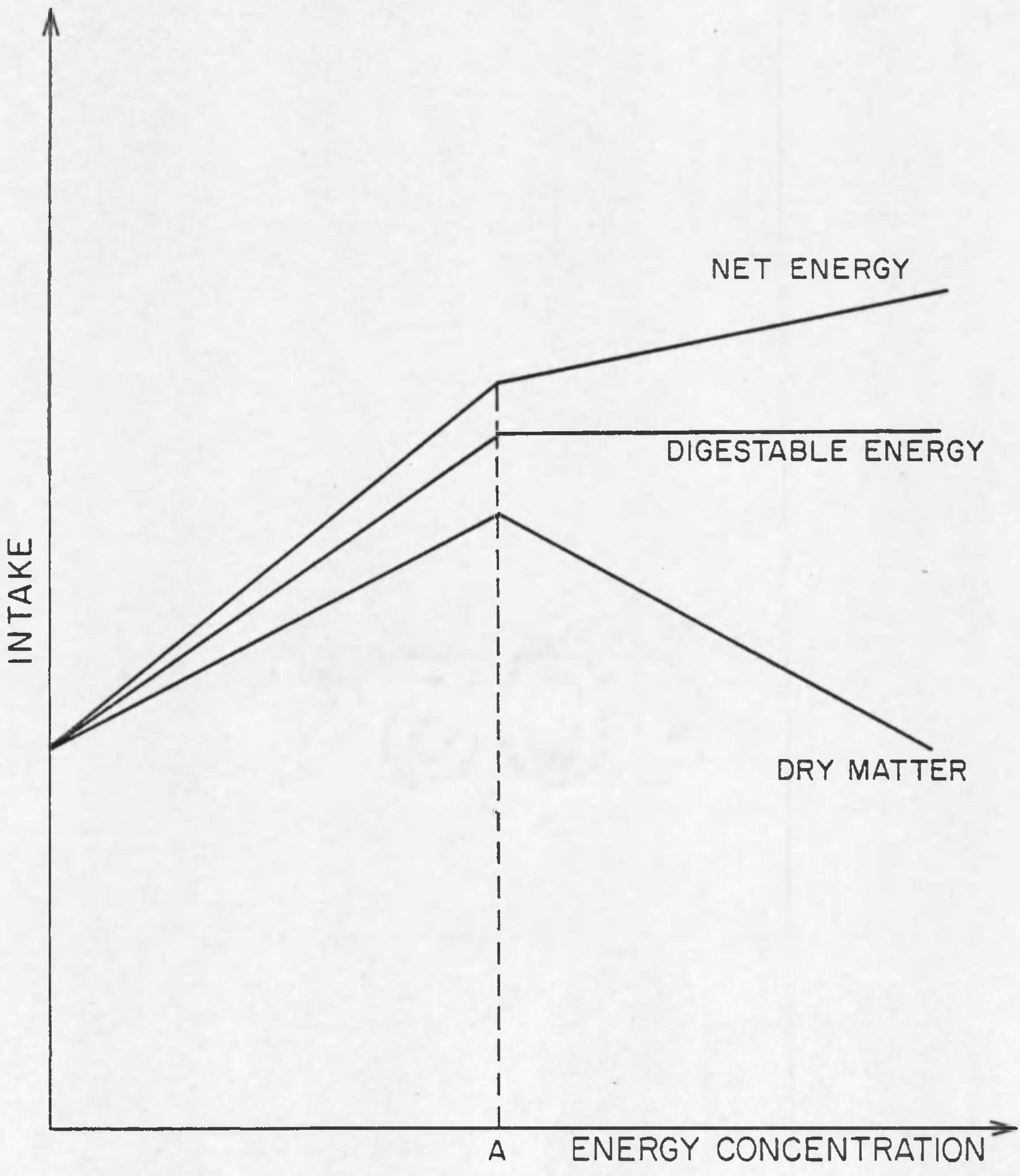


Figure 9. Feed and energy intake regulation in relation to dietary energy concentration.

Source: Brokken et al. (1976).

CHAPTER V

ECONOMIC OPTIMA

The two estimated exponential production functions relating gain to NE_g and relating NE_g to time, together with cost and price data, enable us to determine the economic optimum feeding method under various circumstances and from different points of view. This chapter explores the decisions appropriate to the objectives of net revenue maximization, either from a single lot of cattle, or over a period of one year, considering the question of when to sell one lot of animals and replace it with another. Both of the objectives are examined from the point of view of a custom feedlot owner, of a person owning cattle that are being custom fed, and of a feedlot owner who owns the animals he is feeding. The analysis is based upon cost and price data which existed at the time of the experiment, but repercussions of possible price changes are also examined.

Cost and Price Data

Value data necessary to determine economic optima in a feedlot situation include nonfeed variable operating costs, feed costs, cattle prices and information regarding charges made by a custom feedlot owner to his client. Although substantial fixed costs exist within the cattle feeding industry, short run production decisions are based upon variable costs and a discussion of fixed costs is not within the scope of this study.

Feedlots in Arizona have developed an accounting system based on the costs associated with each ton of feed fed (Menzie et al. 1973, p. 8). For this reason the description and analysis of costs in this chapter are based on costs per ton of feed fed.

Nonfeed variable costs are those costs, excluding feed, which change depending on the number of cattle being fed. These costs include labor, interest on operating capital, power and fuel, veterinary and medical supplies, administration, consultant fees, maintenance and repairs, and miscellaneous expenditures. These costs, for various sizes of operation, are presented in Table 3.

Feed costs utilized in this study are those reported by the cooperating feedlot as actually being paid for feed utilized in the experiment (Table 4). Individual ration costs based on these feed ingredient costs are presented in Table 5.

Livestock prices were obtained from a weekly summary of feedlot and range sales in Phoenix as published during the week of January 13 by the U. S. Department of Agriculture (1977). The animals are assumed to have a value equal to the price of mixed good and choice feeder steers at the outset of the experiment and until they reach an approximate weight of 650 pounds. This price is $35.00 per cwt. Animals heavier than 650 pounds are treated for pricing purposes as fed steers, but until they reach an approximate weight of 840 pounds are discounted $2 per cwt. This discount is based on a cattle buyer's practice of paying $2 per cwt. less than the market price for animals which will yield a carcass weighing less than 500 pounds. Over fat animals are also discounted, but none of the animals in the current experiment reached

Table 3. Average nonfeed variable costs per ton of feed by size of operation, 1975.[a]

Item	10,000 to 20,000 head	20,000 to 30,000 head	Over 30,000 head
	- - - - - $/ton of feed fed - - - - - -		
Labor	4.47	3.37	3.69
Interest	2.00	1.97	1.28
Power and fuel	1.33	1.19	.69
Vet and medical supplies	1.57	1.52	1.49
Administrative staff and supplies	1.12	1.77	1.55
Consultant fees	.23	.31	.75
Maintenance and repairs	1.69	1.57	1.54
Other	.23	.26	.74
TOTAL VARIABLE COSTS	12.87	12.24	11.99

a. Updated from 1971 data using relevant index numbers by U. S. Department of Agriculture (1975).

Source: Menzie et al. 1973, p. 9.

Table 4. Feed ingredient costs per ton.

Ingredient	Dollars/Ton
Corn	103.50
Alfalfa	64.00
Beet Solubles	64.00
Fat	294.00
Premix	149.50

Source: Marchello (1976)

Table 5. Cost per ton of experimental rations.

Ration Number	Dollars/Ton
1	89.41
2	89.41
3	81.51
4	99.90

Source: Marchello (1976)

that stage. Ideally periodic observations of quality grade would have been made throughout the experiment so that the points at which grade changes and accompanying changes in value occurred could be determined, but since these observations were not made, the prices utilized are those associated with the grade of the animals upon termination of the experiment. The animals on the low concentrate treatment graded good and are priced at $37.25 per cwt. Steers on the medium concentrate treatment graded mostly good, end choice, and are assigned a value of $38.25 per cwt. The grade of those animals fed the highest level of concentrates was mixed good and choice, with an associated price of $39.00 per cwt.[1]

Additional costs which are relevant in a custom feeding situation include charges other than feed that are made by the feedlot to the owner of the cattle. Interviews with personnel at several Arizona feedlots indicated that in most cases cattle owners are charged for the feed fed to their animals plus a constant dollar markup on each ton of feed fed. While the question of the optimum markup in various situations could be the focus of an entire study, this study assumes a markup of $16 per ton, a figure representative of current Arizona feedlot practices. Additional charges are made for services such as castration, dehorning, vaccination and branding, but these fees are charged only if the service is necessary for a particular animal, and only cover the feedlot cost of performing the service.

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1. Lots of cattle are typically graded Choice (> 70% Choice), Good to mostly Choice (60-70% Choice), mixed Good and Choice (30-60% Choice), mostly good, end Choice (10-30% Choice), or Good (< 10% Choice).

Theoretical Approach

Chapter II outlined the traditional methods which may be used to determine economic optima. However, due to the nature of the empirical results of this particular experiment, some departure must be made from conventional methods.

Since isoquants cannot be derived from the empirical data, marginal rates of substitution of various feeds cannot be estimated. Therefore, a determination of the optimum combination of feed inputs cannot be made. However, one can determine which of the three experimental treatments is optimum under various circumstances, without an examination of other possible feedstuff combinations.

Economic theory suggests that profits will be maximized for one lot of cattle when total revenue exceeds total cost by the greatest amount. This condition normally corresponds to the point at which marginal cost equals marginal revenue. However, discontinuities introduced into these functions due to the nature of market prices in the beef cattle industry cause the continuous marginal approach to be invalid. At certain points in the production process, as grade and weight change, the price per cwt. of the animal changes. This price change is not only on additional gains beyond the point of change, but on the entire weight of the animal. As a result, the marginal revenue functions derived from a continuous MPP function have large peaks, and a departure from the conventional marginal method of analysis becomes necessary.

Figure 10 shows the discontinuous marginal revenue function and the marginal cost function associated with the experimental high concentrate treatment. The decline in marginal cost between the thirteenth

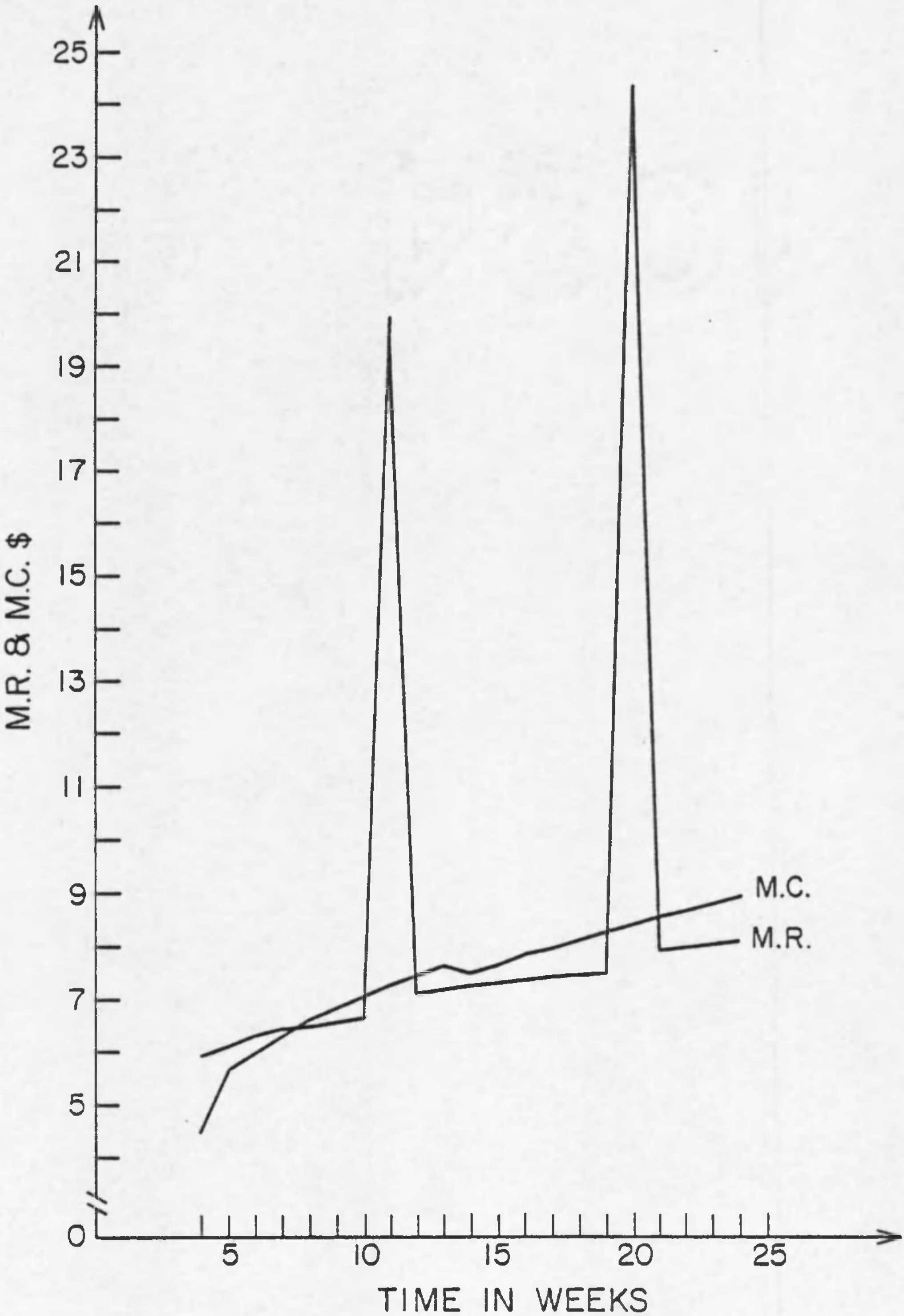

Figure 10. Marginal revenue and marginal cost functions for the high concentrate treatment.

and fourteenth weeks occurred as a result of a shift to a higher concentrate ration. Although the unit cost of the second ration was higher, less of this ration was consumed per unit of time which more than offset the increase in unit price. The marginal cost and marginal revenue functions for the other two experimental treatments are of the same general shape although the actual values are different.

Although the total revenue and cost functions for each of the three experimental treatments contain the same discontinuities as the marginal functions, their utilization makes determination of economic optima possible. Total variable costs and total revenue were determined for each of the three feeding regimes, and those of the high concentrate treatment are presented in Figure 11. Again the corresponding functions for the other two treatments are of the same general configuration. Net revenue is determined from this total cost and revenue information and is displayed in Figure 12. A comparison of net revenue values shows the profit maximizing production point for this single lot of cattle.

Chapter II presented the conceptual method of maximizing net revenue over time for a continuous feedlot operation. This method consists of replacing one lot of cattle with another when marginal net revenue from the present lot equals expected maximum average net revenue from the next lot. Figure 13 shows the average and marginal net revenue functions for the high concentrate treatment. These functions are plagued with the same discontinuities as the previously discussed functions. Marginal net revenue is at no point equal to maximum average net revenue, and again a departure from the standard conceptual approach is

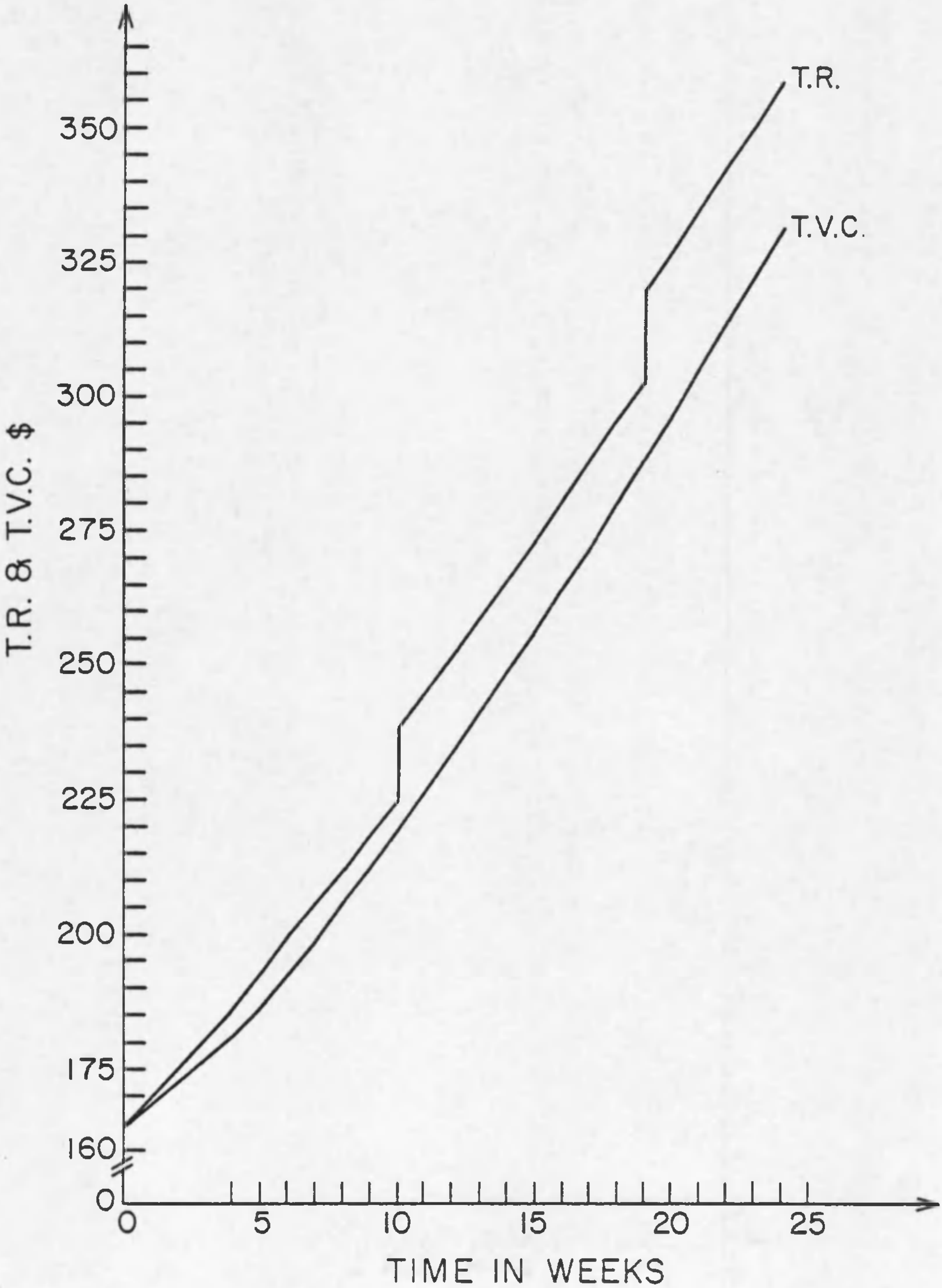

Figure 11. Total variable costs and total revenue for the high concentrate treatment. -- Based on Table 8, see p. 65.

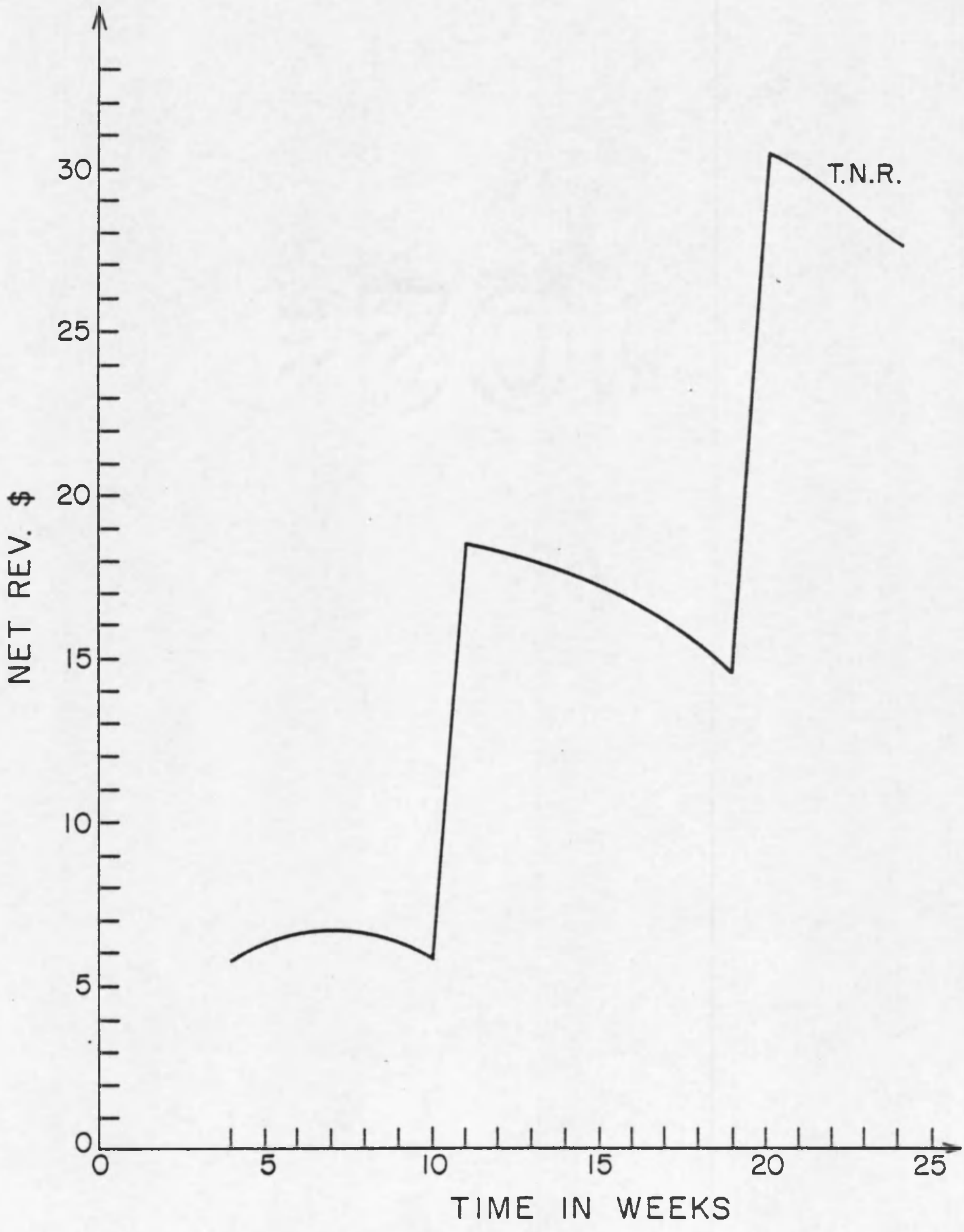

Figure 12. Net revenue for the high concentrate treatment. -- Based on Table 8, see p. 65.

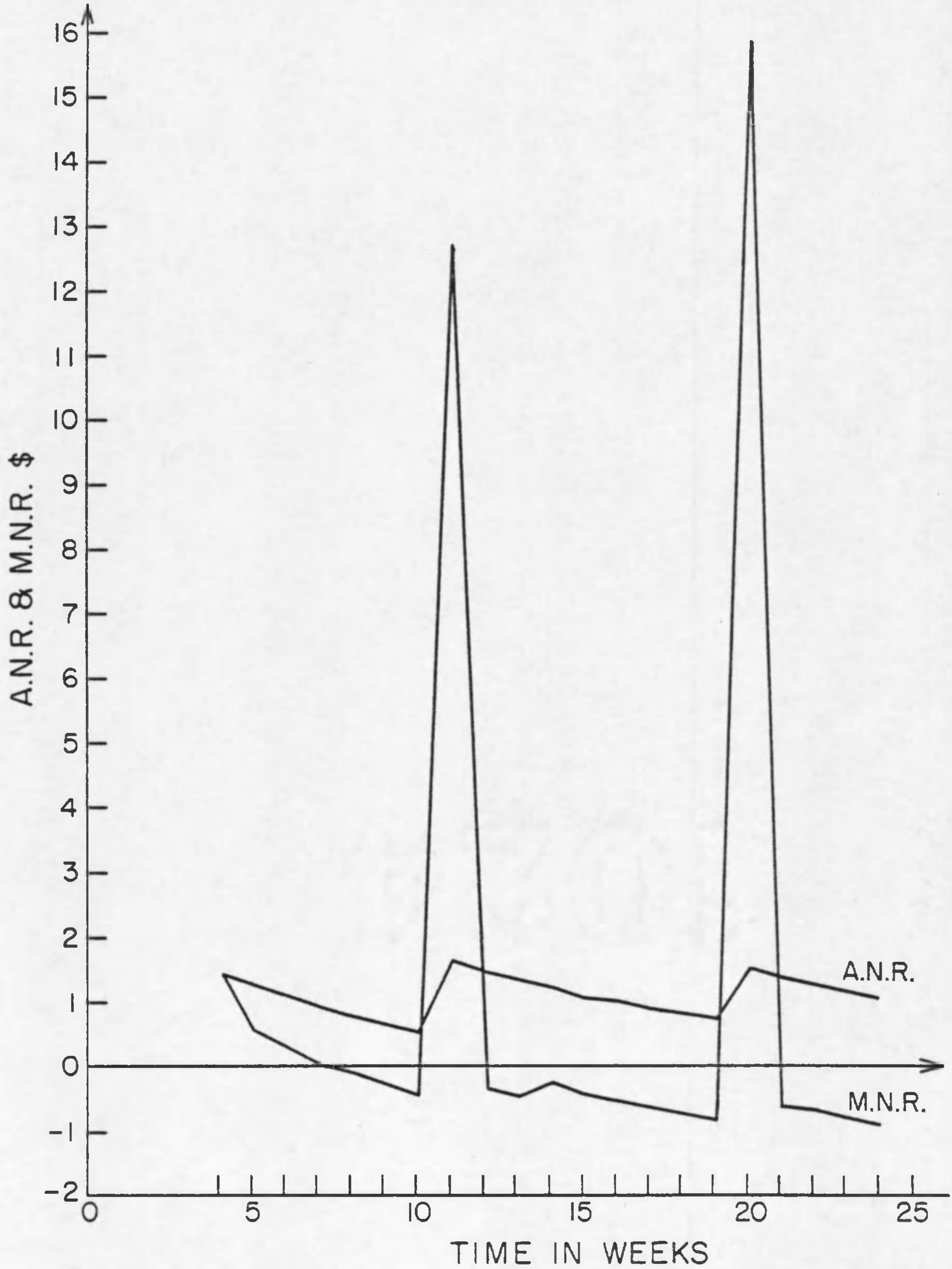

Figure 13. Average and marginal net revenue functions for the high concentrate treatment. -- Based on Table 8, see p. 65.

necessary. Optimum replacement time must be calculated by comparing the average net revenues per unit of time which would result from replacement at each of the points at which the market price of the animal changes. The maximum is selected. In Figure 13 it appears that average net revenues per week are highest and approximately equal at 11 and 20 weeks of feeding. Thus, either time would be an optimum replacement date. Figure 13 shows average net revenue to be highest at 11 weeks. In reality the 11 week time would probably be too early and may appear as optimum here only because of inaccuracies in the price-quality assumptions on which no actual observations were available. It is also possible that another average net revenue local maximum could appear at a time beyond the range of the observed data.

Computation of average net revenue values which will occur at various points in time, if the present lot of cattle continues to be fed, must be based upon price expectations. Calculation of expected average net revenue values from any anticipated future lots must also take price expectations into account. Thus, maximization of the average net revenue for each individual lot will maximize yearly net revenue if price expectations are accurate.

The above analysis was developed to reflect current market practices. At the present time most feedlot animals are graded and sold on a per lot basis. However, it has been suggested that animals be sold and then individually graded after slaughter in an effort to more accurately reflect the true value of the final product. If the animals were sold on an individual yield and grade basis, the resulting revenue functions would not be subject to the previously discussed discontinuities.

However, if the cattle owner sold his animals on an individual yield and grade basis, he would have no knowledge of the price he would receive for his animals until after they are sold. He therefore would not be able to estimate a revenue function and would not be able to make production decisions based upon economic criteria. Rather, he would have to rely on decision rules based upon ex post analyses.

Economic Optima -- The Viewpoint of the Custom Feedlot Owner

The elements which contribute to the total revenue of a custom feedlot owner are feed sales and the markup on feed. Total variable costs to the feedlot owner include the cost of feed plus nonfeed variable costs as outlined in Table 3. Net revenue above variable cost is total revenue minus total variable cost. Since revenue from feed sales and the cost of feed offset one another, net revenue above variable cost per ton of feed can be expressed as the markup per ton of feed minus nonfeed variable costs per ton of feed. As long as this value is positive the feedlot owner will maximize his profits or minimize his losses (by making a contribution to fixed costs) by keeping cattle in his lot.

According to current practices, the representative Arizona feedlot charges a markup of $16.00 on every ton of feed sold. This markup minus total nonfeed variable costs of $12.87 per ton of feed yields a net revenue above variable costs of $3.13 per ton of feed for a feedlot with 10,000 to 20,000 head capacity. Total nonfeed variable costs for a feedlot with 20,000 to 30,000 head capacity are $12.24 per ton of feed, resulting in a net revenue above variable costs of $3.76 per ton of feed.

Feedlots with a capacity of over 30,000 head have a total nonfeed variable cost of $11.99 per ton of feed which, when subtracted from $16, yields a net revenue above variable costs of $4.01 per ton of feed.

It is clear that since net revenue above variable costs increases linearly with the quantity of feed sold, it is the primary interest of the feedlot owner to sell as much feed as possible regardless of the ration. Such sales are probably best accomplished by keeping the lot as nearly full as possible at all times, that is, by showing a record of maximizing the profits of the owners of the cattle being fed. However, there is a basic conflict of interest generated by charging a constant collar markup on the tonnage of feed fed.

The most feed per unit of time will be sold by feeding the low concentrate treatment. However, net revenue to the cattle owner will be substantially decreased if the low rather than the high concentrate treatment is utilized. Tables 6, 7, and 8 (column 9) show the net revenue per head which will be realized by the cattle owner in a custom feeding situation. The low concentrate treatment yields a maximum net revenue of $13.61 per head after 128 days while the high concentrate treatment gives a maximum net revenue of $30.57 per head after 142 days, a difference of $16.96 per head. It is clearly to the advantage of the cattle owner to have his cattle fed the high concentrate ration. As long as animals are in the feedlot, the gain to the feedlot owner from feeding the low concentrate treatment for 128 days is $4.74 per head. If feeding is continued for 142 days the gain to the feedlot owner is $5.58 per head and this gain increases with time.

Table 6. Costs and returns for the low concentrate treatment on a custom feeding basis.

Feeding Period (days)	Net Energy Intake a/ (MCal)	Feed per Head b/ (tons)	Total Cost per Head c/ ($)	Marginal Cost d/ ($)	Average Weight per Head e/ (lbs.)	Total Revenue per Head f/ ($)	Marginal Revenue g/ ($)	Total Net Revenue h/ ($)	Marginal Net Revenue i/ ($)	Average Net Revenue j/ ($)
0	0	0	169.75	--	485.0	169.75	--	0	--	--
30	5200.827	0.20626	191.46	5.44	564.8	197.68	6.98	6.19	1.54	1.55
37	6776.679	0.26876	198.08	6.59	584.7	204.65	6.97	6.57	0.38	1.31
44	8433.044	0.07131	205.03	6.95	604.9	211.70	7.05	6.67	0.10	1.11
51	10160.178	0.14567	212.28	7.25	625.2	218.82	7.12	6.54	-0.13	0.93
58	11950.729	0.22276	219.80	7.52	645.7	226.01	7.19	6.21	-0.33	0.78
65	13798.930	0.30233	227.56	7.76	666.4	234.92	8.91	7.36	1.15	0.82
72	15700.115	0.38418	235.54	7.98	687.2	242.25	7.33	6.71	-0.65	0.67
79	17650.417	0.46815	243.74	8.19	708.2	249.64	7.39	5.91	-0.80	0.45
86	19646.583	0.55409	252.11	8.38	729.2	257.07	7.43	4.96	-0.95	0.41
93	21685.818	0.64188	260.67	8.56	750.4	264.53	7.46	3.86	-1.10	0.30
100	23765.701	0.73143	269.40	8.73	771.7	272.03	7.50	2.63	-1.23	0.19
107	25884.112	0.82263	278.29	8.89	793.1	279.56	7.53	1.27	-1.36	0.08
114	28039.169	0.91541	287.34	9.05	814.5	287.12	7.56	-0.22	-1.49	-0.01
121	30229.198	1.00970	296.54	9.20	836.1	294.71	7.59	-1.83	-1.61	-0.11
128	32452.691	1.10543	305.87	9.33	857.7	319.48	24.77	13.61	15.44	0.76
135	34708.285	1.20254	315.34	9.47	879.4	327.56	8.08	12.22	-1.39	0.64
142	36994.748	1.30098	324.94	9.60	901.1	335.67	8.11	10.73	-1.49	0.54
149	39310.939	1.40070	334.66	9.72	922.9	343.80	8,13	9.14	-1.59	0.44
156	41655.831	1.50165	344.51	9.85	944.8	351.95	8.15	7.44	-1.70	0.34
163	44028.463	1.60380	354.47	9.96	966.8	360.12	8.17	5.65	-1.79	0.25
170	46427.948	1.70711	364.54	10.07	988.8	368.32	8.20	3.74	-1.87	0.16

Table 6. (continued)

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a. $E = .07111t^{1.26201}$

where E = net energy intake; t = time

b. Cumulative amount of each ration with a change in ration after 37 days.

c. Based upon ration costs given in Table 5.

d. $MC = \frac{\Delta TVC}{\Delta t}$

e. Calculated from equation (8) using energy values calculated as in footnote a.

f. Price changes occur after the 58th and 121st days. Prices were \$35.00, \$35.25 and \$37.25 per cwt.

g. $MR = \frac{\Delta TR}{\Delta t}$

h. TNR = TR - TVC

i. MNR = MR - MC

j. $ANR = \frac{TNR}{t}$

Table 7. Costs and returns for the medium concentrate treatment on a custom feeding basis.

Feeding Period (days)	Net Energy Intake a/ (MCal)	Feed per Head b/ ($)	Total Cost per Head c/ ($)	Marginal Cost d/ ($)	Average Weight per Head e/ (lbs.)	Total Revenue per Head f/ ($)	Marginal Revenue g/ ($)	Total Net Revenue h/ ($)	Marginal Net Revenue i/ ($)	Average Net Revenue j/ ($)
0	0	0	174.48	--	498.5	174.48	--	0	--	--
30	4720.137	0.18720	194.21	4.93	572.0	200.21	6.43	6.00	1.50	1.50
37	6160.034	0.24431	200.23	6.02	590.5	206.68	6.47	6.45	0.45	1.29
44	7675.660	0.06525	206.59	6.26	609.2	213.23	6.55	6.64	0.19	1.11
51	9257.936	0.13337	2.3.24	6.65	628.2	219.85	6.62	6.61	-0.03	0.94
58	10900.007	0.20407	220.13	6.89	647.3	226.54	6.69	6.41	-0.20	0.80
65	12596.486	0.27711	227.25	7.12	666.5	241.61	15.07	14.36	7.95	1.60
72	14343.013	0.35240	234.58	7.33	685.9	248.65	7.04	14.07	-0.29	1.41
79	16135.974	0.42949	242.11	7.53	705.5	255.73	7.08	13.62	-0.45	1.24
86	17972.319	0.50855	249.82	7.71	725.1	262.86	7.13	13.04	-0.58	1.09
93	19849.434	0.58937	257.79	7.88	744.9	270.02	7.16	12.32	-0.72	0.95
100	21765.049	0.07597	265.71	8.01	764.8	277.22	7.20	11.51	-0.81	0.82
107	23717.174	0.15229	273.87	8.16	784.7	284.46	7.24	10.59	-0.92	0.71
114	25704.048	0.23219	282.18	8.31	804.8	291.73	7.27	9.55	-1.04	0.60
121	27724.095	0.31231	290.62	8.44	824.9	299.03	7.20	8.41	-1.14	0.49
128	29775.898	0.39368	299.20	8.58	845.1	323.26	24.23	24.06	15.65	1.34
135	31858.181	0.47627	307.90	8.70	865.4	331.02	7.76	23.21	-0.94	1.22
142	33969.783	0.56001	316.73	8.83	885.8	338.81	7.79	22.08	-1.04	1.10
149	36109.632	0.64488	325.68	8.95	906.2	346.63	7.82	20.95	-1.13	1.00
156	38276.762	0.73083	334.74	9.06	926.7	354.47	7.84	19.73	-1.22	0.90
163	40470.267	0.07599	343.55	8.81	947.3	362.34	7.87	18.79	-0.94	0.82
170	42689.314	0.15286	352.41	8.86	967.9	370.23	7.89	17.82	-0.97	0.74

Table 7. (continued)

a. $E = .06291t^{1.26952}$

where E = net energy intake; t = time.

b. Cumulative amount of each ration with ration changes after 37, 93, and 156 days.

c. Based upon ration costs given in Table 5.

d. $MC = \frac{\Delta TVC}{\Delta t}$

e. Calculated from equation (8) using energy values calculated as in footnote a.

f. Price changes occurred after the 58th and 121st days. Prices were $35.00, $36.25, and $38.25 per cwt.

g. $MR = \frac{\Delta TR}{\Delta t}$

h. TNR = TR - TVC

i. MNR = MR - MC

j. $ANR = \frac{TR}{t}$

Table 8. Costs and returns for the high concentrate treatment on a custom feeding basis.

Feeding Period (days)	Net Energy Intake a/ (MCal)	Feed per Head b/ (tons)	Total Cost per Head c/ ($)	Marginal Cost d/ ($)	Average Weight per Head e/ (lbs.)	Total Revenue per Head f/ ($)	Marginal Revenue g/ ($)	Total Net Revenue h/ ($)	Marginal Net Revenue i/ ($)	Average Net Revenue j/
0	0	0	163.10	--	466.0	163.10	--	0	--	--
30	4237.122	0.16804	180.81	4.42	533.2	186.60	5.88	5.79	1.45	1.45
37	5578.700	0.22125	186.42	5.61	550.7	192.73	6.13	6.31	.52	1.26
44	7002.714	0.27771	192.37	5.95	568.5	198.97	6.24	6.60	.29	1.10
51	8498.261	0.33704	298.63	626	586.6	205.32	6.35	6.69	.09	.96
58	10059.902	0.39897	205.16	6.53	605.0	211.77	6.45	6.61	-.08	.83
65	11681.516	0.46329	211.94	6.78	623.7	218.29	6.52	6.35	-.26	.71
72	13358.565	0.52980	218.95	7.01	642.5	224.89	6.60	5.94	-.41	.59
79	15087.267	0.59836	226.17	7.22	661.6	244.79	19.90	18.62	12.68	1.69
86	16864.421	0.66884	233.60	7.43	680.8	251.90	7.11	18.30	-.32	1.53
93	18687.269	0.74113	241.22	7.62	700.2	259.07	7.17	17.85	-.45	1.37
100	20553.412	0.06465	248.71	7.49	719.7	266.30	7.23	17.59	-.26	1.26
107	22460.736	0.13072	256.37	7.66	739.4	273.58	7.28	17.21	-.38	1.15
114	24407.365	0.19815	264.19	7.82	759.2	280.91	7.33	16.72	-.49	1.05
121	26391.622	0.26689	272.15	7.96	779.2	288.29	7.38	16.14	-.58	.95
128	28411.988	0.33688	280.26	8.11	799.2	295.71	7.42	15.45	-.69	.86
135	30467.093	0.40807	288.52	8.26	819.4	303.17	7.46	14.65	-.80	.77
142	32555.687	0.48042	296.90	8.38	839.7	327.47	24.30	30.57	15.92	1.53
149	34676.620	0.55389	305.42	8.52	860.1	335.42	7.95	30.00	-.57	1.43
156	36828.844	0.62845	314.06	8.64	880.5	343.41	7.99	29.35	-.65	1.33
163	39011.380	0.70406	322.82	8.76	901.1	351.44	8.03	28.62	-.73	1.24
170	41223.326	0.78068	331.70	8.88	921.8	359.50	8.06	27.80	-.82	1.16

Table 8. (continued)

a. $E = .04894t^{1.31161}$

where E = net energy intake; t = time.

b. Cumulative amount of each ration with a ration change after 93 days.

c. Based upon ration costs given in Table 5.

d. $MC = \frac{\Delta TVC}{\Delta t}$

e. Calculated from equation (8) using energy values calculated as in footnote a.

f. Price changes occurred after the 72nd and 135th days. Prices were $35.00, $37.00 and $39.00 per cwt.

g. $MR = \frac{\Delta TR}{\Delta t}$

h. TNR = TR - TVC

i. MNR = MR - MC

j. $ANR = \frac{TR}{t}$

But while the feedlot owner might increase his net revenue by feeding the low concentrate treatment, his customer will be dissatisfied and in the future will have his cattle fed elsewhere. In order to keep his lot as nearly full as possible, the feedlot owner must keep his current customers satisfied and attract new customers by showing a record of maximizing their profits. Having an empty lot would be much more costly than the short term gain from feeding the low concentrate ration.

Economic Optima -- The Viewpoint of the Cattle Owner in a Custom Feeding Situation

A person owning cattle and having them custom fed receives all of his revenue from the sales of his fed cattle. His total costs include the purchase of feeder cattle, and the charges made by the feedlot for feed and services provided. Costs and returns to a person whose cattle are being custom fed are presented for the low, medium, and high concentrate treatments in Tables 6, 7, and 8.

The maximum net revenue that can be obtained from any of the three experimental treatments is \$30.57 per head (see Table 8, column 9). This maximum results from feeding a lot of cattle on the high concentrate treatment for 142 days (column 1), at which time the animals reach an average weight of 840 pounds (column 6). A comparison of the net revenue values presented in Tables 6, 7, and 8 indicates that if cattle are to be fed at all, the high concentrate feeding regime is superior.

It is important to examine the sharp increases in net revenue which occur with a change in selling price per pound. Because of the limited nature of the current data only two such increases are observed for each experimental treatment. In reality there is a change in product value not only at the weights utilized here, but also every time the average grade of a lot changes, which could occur as many as seven times during the production process. Little can be said in this study about the other nonrecorded price increases, but the profit maximizing length of time to feed will occur at one of the points where there is a change in grade. Each time a grade and price change occurs a decision must be made to either sell the animals or to continue feeding them. If the decision is to continue feeding, the animals must be fed until the next increase in quality grade, unless cattle prices are dropping so rapidly that it is expected that by the time the animals reach the next highest grade, the price per cwt. for that grade will be lower than the current price for the current grade.

A cattle owner who is having cattle fed, and who intends to replace that lot with a new lot, is concerned with determinating the optimum replacement time. His objective is to maximize his net revenue over a given period of time rather than the net revenue from a single lot. For the purposes of this study it is assumed that the cattle owner wishes to maximize his net revenue over a period of one year, although longer periods could be analyzed using the same methods if some discount rate for time preference were included.

The points at which sharp increases in average net revenue occur are those which require examination to determine the optimal replacement time. Because of the severe discontinuities present in functions describing cattle feeding costs and returns, calculations must be made of the average net revenue per week which would result from feeding the animals to the point where each of the local maxima of the total net revenue function for each ration are reached. A comparison of the resulting average net revenue per week values and a choice of the largest yields the optimal replacement time.

Indications from the current data are that the maximum net revenue over time will be realized by feeding the high concentrate treatment. Data from Table 8 indicates that the optimum replacement time is after 11 weeks of feeding. The time required to maximize net revenue from a single lot was seen above to be 20 weeks. Although these times are somewhat arbitrary because of the lack of actual observations on the time and magnitude of grade induced price changes, they show that the time required to maximize net revenue from a single lot does not necessarily coincide with the time required to maximize net revenue over time.

Economic Optima -- The Viewpoint of the Feedlot Owner Feeding his own Cattle

The feedlot owner feeding his own cattle receives all of his revenue from the sale of fed cattle. Total variable costs include the purchase of feeder cattle, feed costs, and nonfeed variable costs as outlined in Table 3 for various sizes of operation. Although fixed costs exist, they are not important to the short-run decision making process. If total revenue is greater than total variable costs the firm will maximize profits or minimize losses by producing fed cattle. Any revenue remaining after the payment of variable costs can be applied to fixed costs, which must be paid regardless of whether production takes place.

Total revenue values for each of the three experimental treatments are the same for a feedlot owner feeding his own cattle as they are for a cattle owner having his cattle custom fed (Tables 6, 7, and 8). Two of the components of variable cost, feeder cattle purchase and feed costs, are also the same. The only difference between the costs associated with this situation and those of the custom situation discussed in the previous section is that custom feeding costs included a markup on feed, while the noncustom feeder faces the nonfeed variable costs (Table 3). Since both the markup and nonfeed variable costs are constant values expressed on a per ton of feed basis, the current analysis becomes identical to that utilized in the previous section. Total variable cost figures are somewhat lower and net revenue values slightly higher because nonfeed variable costs are lower than the markup of $16 per ton. However, the points in time at which local maxima and minima occur in the total net revenue function are identical. The optimal production decisions, therefore, are also identical. Whenever net revenue per head values are positive as they are in this experiment, it is in the interest of the feedlot owner to keep his lot as nearly full as possible at all times.

Impacts of Possible Price Changes

The empirical solutions discussed above are optimal only if market cattle prices and input costs are the same as those utilized here. The framework and method of analysis, however, remains valid regardless of changes in price. It is important, particularly with markets as subject to change as those for feed and cattle, to examine the consequences of possible price changes.

Yearly grain to hay price ratios in Arizona since 1968 have varied between a minimum of 1.43 in 1976 and a maximum of 2.02 in 1974 (Table 9). At the time of this experiment the corresponding ratio was 1.62. The high concentrate feeding regime proved to be the best given this price ratio, but it is possible that a lower concentrate treatment would become optimal if the grain to hay price ratio changed drastically. In order to test this hypothesis the price of corn was increased to $128 per ton with all other prices remaining constant. The resulting grain to hay price ratio is 2:1, and the optimization analysis was repeated.

The results of the analysis indicate that although all net revenue values decline, the highest net revenue is still received if the high concentrate treatment is followed. A possible reason for this phenomenon is that there is a substantial amount of grain contained even in the low concentrate treatment. When grain prices increase, the price of the high concentrate ration increases more than the price of the low, but the change in ration price ratios is not great enough to offset the performance advantages associated with the high concentrate treatment. It is possible that a higher roughage ration than the highest in this study would have become optimal with the above change in relative prices, but with no information about marginal rates of substitution this hypothesis cannot be tested.

Large changes in cattle prices or overall feed costs may cause termination of feeding at some point in time other than when product value changes, if net revenue maximization from one lot is the objective. This situation is illustrated using a hypothetical example.

Table 9. Yearly average grain to hay price ratios, 1968-76.

Year	Average Sorghum Grain Price ($/ton)	Average Alfalfa Hay Price ($/ton)	Grain to Hay Price Ratio
1968	41.83	26.13	1.601
1969	46.18	27.29	1.692
1970	47.22	32.29	1.462
1971	51.48	33.54	1.535
1972	52.58	35.04	1.501
1973	81.75	42.17	1.939
1974	114.38	56.75	2.016
1975	107.42	58.46	1.837
1976	99.75	69.58	1.434

Sources: Arizona Crop and Livestock Reporting Service (1976) and U. S. Department of Agriculture (1976).

The general shapes of a marginal revenue and a marginal cost function for cattle feeding are illustrated in Figure 14. The large peaks in the marginal revenue function occur every time the market price of the animals increases because of a change in quality grade. The dip between points B and C occurs as a result of a decline in the value of animals that become over fat. If feed and cattle prices are such that the marginal cost function crosses the marginal revenue function at a point between the last increase in product value and a decline in product value (between points A and B in Figure 14), net revenue will be maximized by terminating the feeding period at the point in time where marginal revenue equals marginal cost (point D). This case causes an exception to the decision rule developed above, consisting of comparing total net revenue values associated with each change in quality grade and selecting the largest. If net revenue maximization over time is the objective, replacement should take place when average net revenue per unit of time is at the global maximum as in the previous analysis.

If the cattle market is such that feeder cattle prices are higher than fed cattle prices, then the analysis must change slightly. As the animals reach heavier weights their market price decreases until they reach a quality grade of good. Beyond this point further increases in quality grade will cause increases in market price. Thus, the shape of the marginal revenue function is different than that previously analyzed. Figure 15 shows a hypothetical marginal revenue function and a marginal cost function associated with the situation in which feeder cattle prices are higher than fed cattle prices. At the points in time when product value decreases there are large valleys in the marginal revenue function.

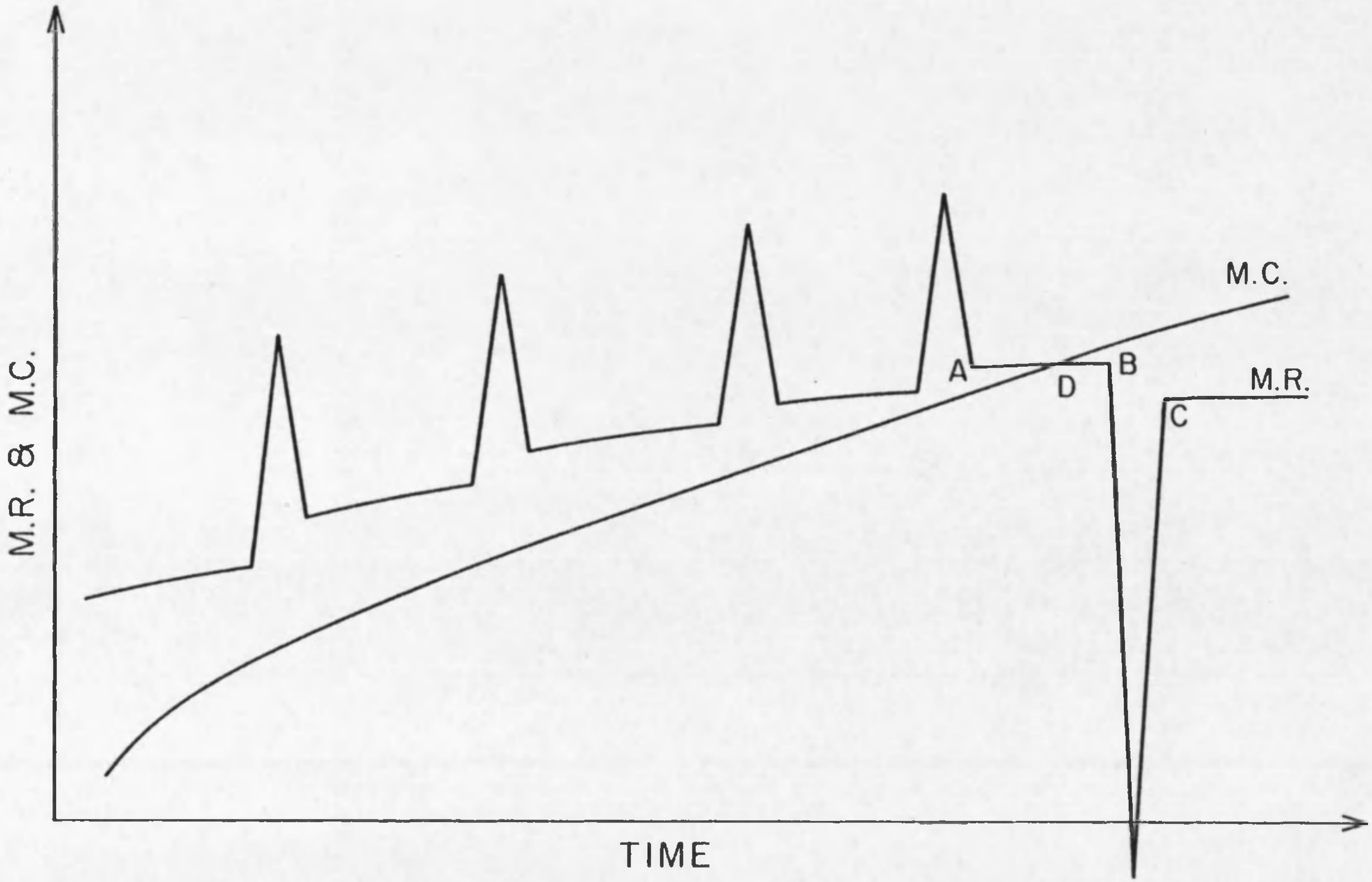

Figure 14. Hypothetical marginal revenue and marginal cost functions.

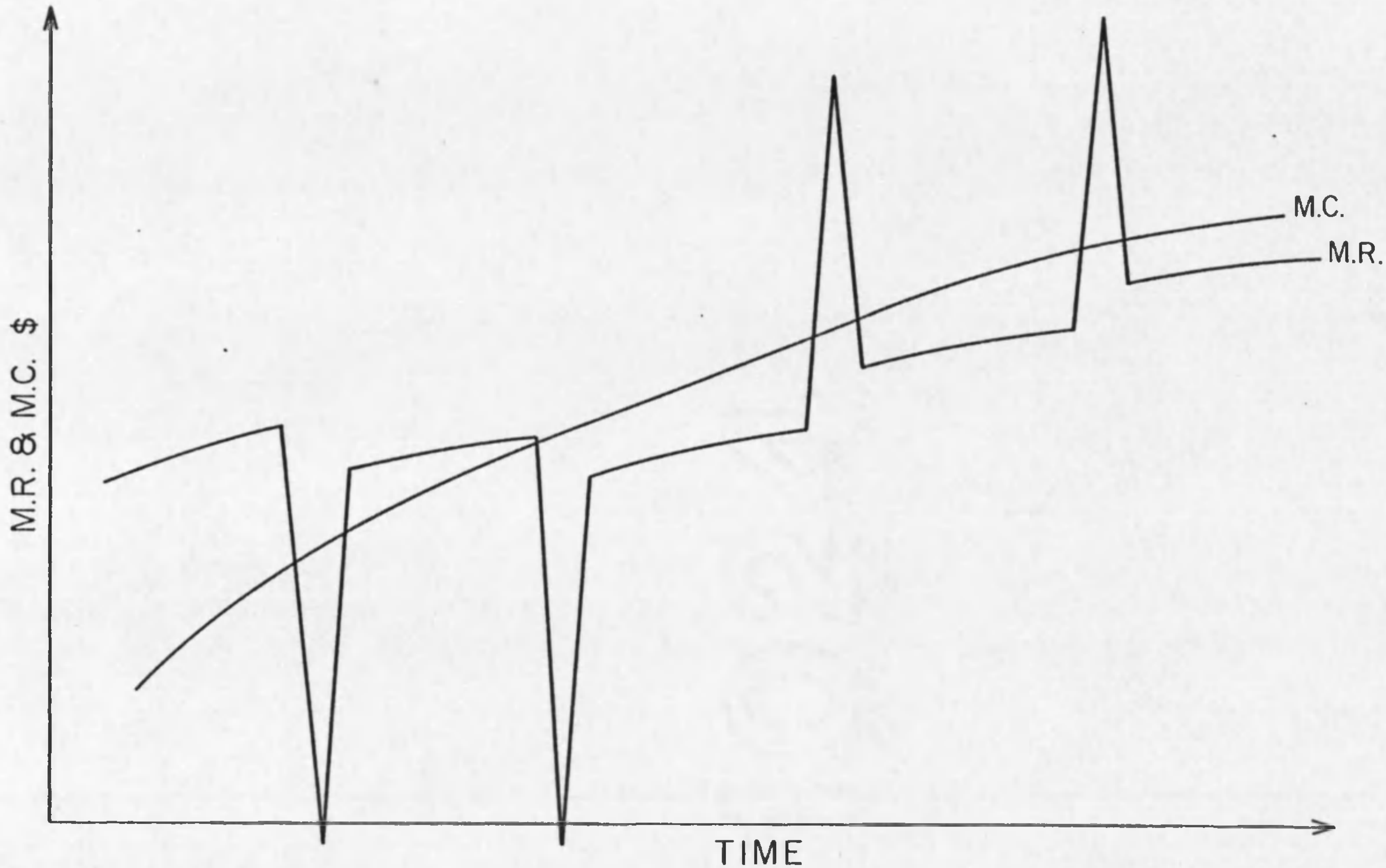

Figure 15. Hypothetical marginal revenue and marginal cost functions associated with feeder cattle prices being higher than fed cattle prices.

At these points incremental additions to cost from the continuation of feeding are substantially larger than additions to revenue. Only after the animal begins to reflect changes which increase its market price do the increases in revenue begin to offset increases in cost at the margin. It is implied, therefore, that if animals are to be fed at all, it is to the advantage of the cattle feeder to feed animals that are as heavy as possible as feeders since heavier animals may have already declined somewhat in price prior to their purchase. In addition, the animals must be carried completely through a period in which marginal revenue is less than marginal cost, and long enough past that period to take advantage of any price increases substantial enough to offset previous losses. The implication is that heavier animals should be produced when feeder cattle prices are higher than fat cattle prices since additions to total weight contribute more to revenue than do product price increases.

Additional Conceptual Issues Relating to Optimization Results

Chapter IV showed that the most rapid rate of gain, and therefore the highest level of gain per unit of time occurs as a result of feeding the low concentrate treatment. However, the high concentrate treatment proved to be the optimum in all cases within the optimization analysis. These results occurring simultaneously imply that the animals on the low concentrate treatment could have been fed at a rate somewhat less than ad libitum, reducing cost while maintaining the same rate of gain as for the animals on the high concentrate treatment.

Zulberti et al. (1973) and Wilson (1976) have proposed that if feeding is to take place at all, ad libitum feeding systems are always the optimum method. Their analyses are based upon the concept of a daily production function, and no interaction among successive daily gain functions are considered. They state that as daily intake of feed of a given quality increases, weight gain per unit of feed also increases. This condition implies that as daily feed intake increases, the daily average physical product increases until the voluntary appetite restriction is reached. Applying economic theory to a situation of increasing average physical product they conclude that the greatest return over cost of the input will be obtained with the greatest amount possible of the input (i.e., ad libitum feeding).

Figure 16 shows theoretical daily production functions for the three treatments included in this study with their corresponding average physical product functions. The only empirically obtained points are those occurring at the appetite constraint for each ration (points H, M, L, A, B, and C). The shape of the functions is based on the assumption that as daily intake of feed of a given quality increases, weight gain per pound of feed also increases.

Since the high concentrate treatment is the optimum, and the low concentrate treatment is consumed most rapidly and provides the fastest gain, it is possible that by feeding the low concentrate treatment at a rate somewhat less than ad libitum, costs could be reduced while maintaining the same rate of gain as provided by the high concentrate treatment. Within the limited framework provided by Zulberti et al. (1973) and Wilson (1976), and shown in Figure 16, however, it can be seen that if such a procedure were followed the result would be production at a point (D) less than the maximum obtainable average physical product

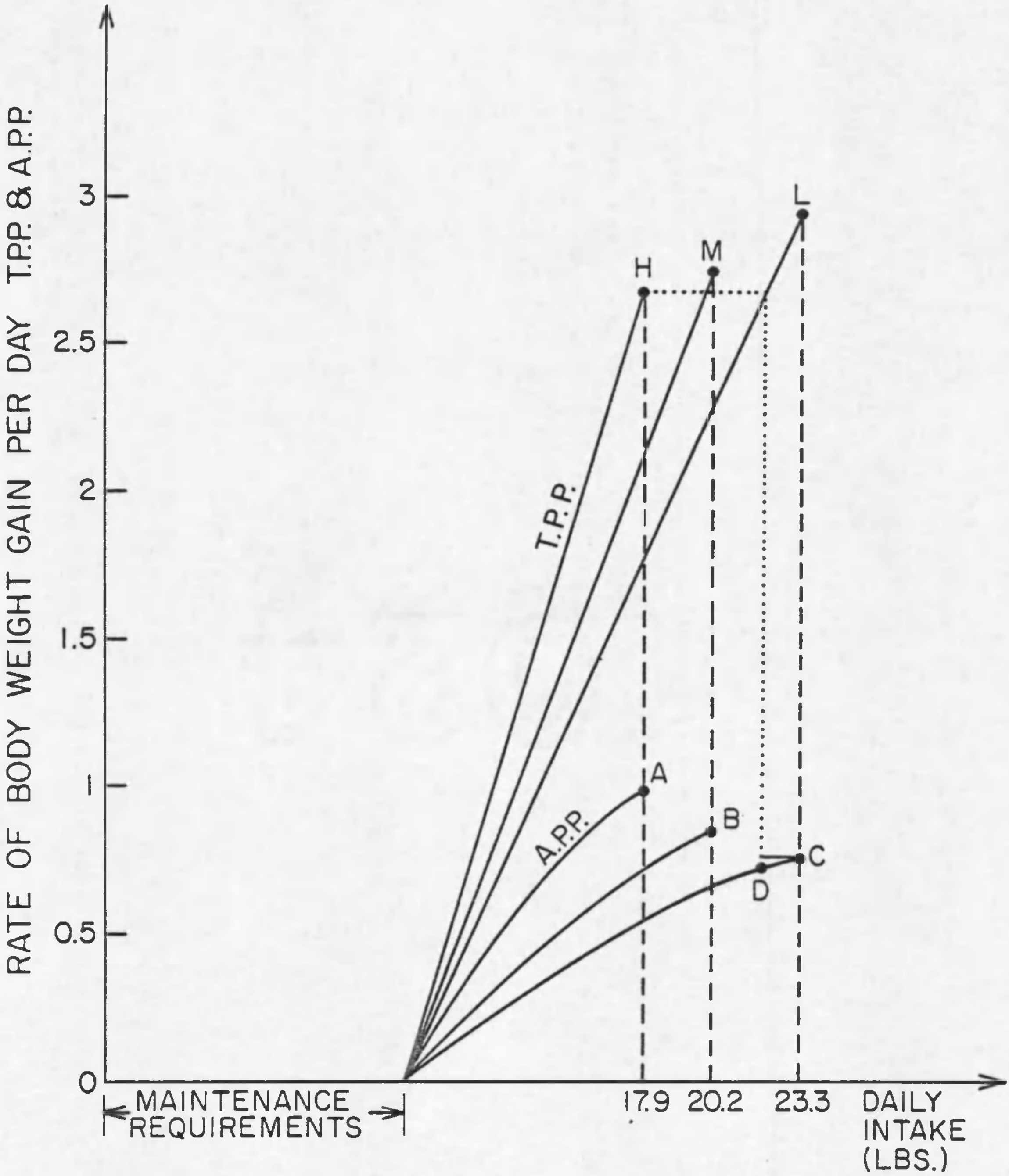

Figure 16. Theoretical daily production functions with corresponding average product functions for three experimental treatments.

(point C) in stage I. Therefore, following Zulberti et al. (1973) and Wilson's (1976) logic, optimality of ad libitum feeding systems is indicated.

But, since feeding periods are typically much longer than a day, it seems appropriate to analyze the ad libitum feeding question within a framework which can accommodate feeding over time. Figure 17 shows such a framework, consisting of the total physical product function estimated in Chapter IV, and the corresponding average physical product function. These functions are based on an ad libitum feeding system.

Since energy intake is a linear function of feed intake, and weight gain per pound of feed increases as daily intake of feed of a given quality increases, it can be assumed that weight gain per MCal. of energy increases as daily intake of feed of a given quality increases. Therefore, a decrease in net energy consumption which occurs as a result of less than ad libitum feeding is not a movement to the left on the ad libitum TPP curve but a movement to some point (i.e., point A) on a lower TPP function.

Within this framework it can be seen that a reduction in the quantity of the low concentrate treatment fed per day, to a point where the gain from this treatment is equal to the gain from the high concentrate treatment fed ad libitum, causes a reduction in average product per unit of input (from point B to C), but the optimality of such a move depends upon ration costs. If such a move reduces ration cost per unit of time and an animal of equal quality grade is produced from both treatments, a reduction in feed per day and the low concentrate treatment are indicated as being optimal.

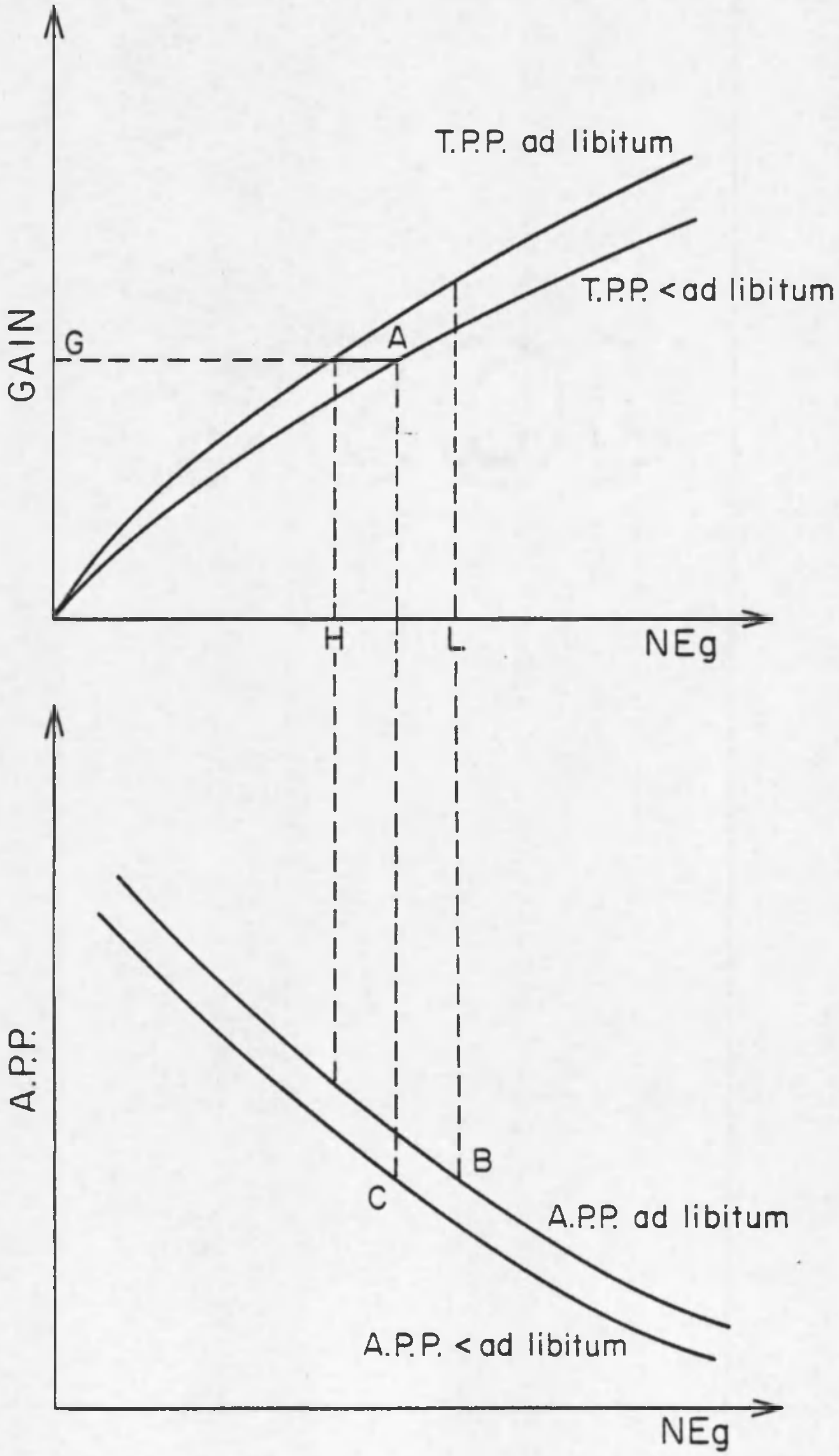

Figure 17. Total physical product and corresponding average physical product functions.

An empirical analysis of the consequences of less than ad libitum feeding could not be carried out utilizing the current experimental data. A lower quality grade animal was, however, produced from the low concentrate treatment, and consequently a reduced total revenue was received from animals fed the low concentrate treatment to a weight equal to the weight of the high concentrate treatment animals. An exact determination of the consequences of less than ad libitum feeding is beyond the scope of this study. The results of this study, however, indicate that ad libitum feeding systems are not necessarily the only optimal feeding method.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Although many studies have examined the nature of beef-cattle production functions and the meaning of these functions in decisions involving optimization based upon economic criteria, many unanswered questions remain. There is no general consensus among those involved with livestock production studies as to the form of beef cattle production functions. Consequently, differences of opinion exist about optimum production methods.

The first objective of this study was to estimate a production function for cattle in Arizona feedlots including a determination of the rates at which forage and grain substitute in the beef-fattening process, a determination of the rate at which feeds are transformed into beef gains from different forage-grain rations, a determination of the time required to produce different levels of gain for different rations, and a determination of carcass grade produced from various rations.

A determination of the marginal rate of substitution of forage for grain was not possible because of the experimental design.

Multiple regression analysis was utilized to estimate a growth response function from the experimental data. Several alternative algebraic forms were used to estimate this function, with the exponential form in which weight gain is a function of net energy for gain providing the best results. An elasticity of production value of 0.8

indicates that beef gains increase at a decreasing rate as net energy for gain is increased.

Equations for each of the three experimental treatments, expressing the consumption of net energy for gain as a function of time, were also estimated. An exponential form which increases at an increasing rate gave the best results. These equations were used, in conjunction with the estimated production function, to predict the levels of gain which would be produced at various points in time for the three experimental treatments. The time required to produce a given level of gain increases as the concentrate level of the treatment increases. Also, for a given feeding period the maximum level of gain is attained with the low concentrate treatment. These results imply that the low concentrate treatment could possibly be fed at a rate somewhat less than ad libitum, thereby reducing costs while maintaining the same rate of gain as that associated with the high concentrate treatment.

The relationship between carcass grade and ration fed was determined at the end of the feeding period. Animals fed the high concentrate treatment achieved higher quality grades than did those fed the lower concentrate treatments. No subjective grade observations were made during the feeding period so the points at which the animals on each treatment changed quality grade could not be determined.

The second and final objective of this work was to estimate, under different price conditions, the combinations of feed, gain, carcass grade, and the number of lots per year that would maximize yearly net revenue. This objective was examined from the points of view of a feedlot owner feeding his own cattle, a custom feedlot owner, and a cattle owner having his animals custom fed. In each case the optimal solution is contrasted with the optimum which would occur if the objective were to maximize net revenue from one lot of cattle.

Using the relationship between net energy and time derived under the previous objective, and information about the energy concentration of each ration, the relationship between time and the amount of feed consumed was derived for each ration. Feed costs were determined and combined with the appropriate nonfeed variable costs to determine total variable costs per head. Weight gain information derived under the first objective was combined with the starting weight of the animals to give total weight at succeeding points in time. This total weight information, when multiplied by market price, gives the total revenue which would be received by selling the animals at any point during the production process. This alternative total cost and total revenue information allows a determination of the optimal production process.

Under the price conditions existing at the time of this experiment, (a grain to hay price ratio of 1.6:1) the high concentrate treatment should be utilized to maximize net revenue. Even if grain prices increase to the point where the grain to hay price ratio is as much as 2:1, the high concentrate treatment remains optimal.

A custom feedlot owner receives all of his revenue from the markup he charges for the service of feeding someone's cattle. This markup is charged on a per ton of feed basis. The custom feedlot owner, therefore, maximizes net revenue above variable cost by selling as much feed as possible. This condition implies keeping his lot as nearly full as possible, which is best accomplished by showing a record of maximizing the profits of his past and current customers.

A departure from conventional marginal analysis is necessary to determine maximum net revenue for a cattle owner having his animals custom fed, or for a feedlot owner feeding his own cattle. This departure is required because as cattle change in quality grade during the feeding process, their market price also changes. These price changes cause steps to occur in the total revenue function, with corresponding discontinuities in the marginal revenue function. Net revenue is maximized by terminating the feeding period at one of the points in time where these discontinuities occur. Net revenue from one lot of cattle is maximized by computing the net revenue value at each peak and selecting the largest, while the optimum replacement time occurs when average net revenue is at the global maximum.

In the feeding experiment, not all of the points at which price changes could take place were recorded. Also, further price changes could have occurred had the feeding period been extended. The significance, therefore, of the empirical net revenue values and feeding period lengths reported in the text is minimal. The framework and method of analysis developed here, however, has validity as a decision making tool, particularly if better information than that generated through this experiment were available. The study has broken through the conceptual block of economic analysis generated by the pervasive influence on economists' minds of "textbook type," mathematically continuous cost and revenue functions.

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