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An Interregional Competition Study of Utah Agriculture Using the Linear Programming Technique

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AN INTERREGIONAL COMPETITION STUDY OF UTAH AGRICULTURE

USING THE LINEAR PROGRAMMING TECHNIQUE

by

Douglas Lee Andersen

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ii

LIST OF TABLES v

LIST OF FIGURES vii

ABSTRACT viii

INTRODUCTION 1

- Nature of the study 3
- Objectives 4

REVIEW OF LITERATURE AND THEORETICAL DISCUSSION 5

- Literature review 5
- Comparative advantage 6
- Linear programming 9

METHOD OF PROCEDURE 12

- Achieving objectives 12
- Regionalization and enterprise definition 14
- Linear programming model development 19
- Assumptions 28

DATA DEVELOPMENT 31

RESULTS AND ANALYSIS 53

- Region 1 59
- Region 2 70
- Region 3 72
- Region 4 75
- Region 5 77
- Region 6 79
- Region 7 82
- Region 8 84
- Resource shadow prices 86
- Post optimization 88
- Analysis 99

CONCLUSIONS AND RECOMMENDATIONS 102

- Conclusions 102
- Policy implications 107
- Recommendations 111

TABLE OF CONTENTS (Continued)

Page

LITERATURE CITED 114

APPENDIX 118

LIST OF TABLES

Table		Page
1	Nutrients furnished by feeds for animals	32
2	Nutrients required to produce one unit of each livestock activity	33
3	Costs of producing crop activities	36
4	Output of the crop activities	37
5	Net nonfeed production costs per unit and primary product output of the livestock enterprises	39
6	Available land and range resources by region	43
7	Upper bounds of acreages available for sugar beet production by regions	45
8	Normalized price of agricultural products in the consumption regions	46
9	Crop enterprise production in the optimal solution	54
10	Livestock enterprises produced and feeds fed in the optimal solution	55
11	Amounts of feeds purchased by the production regions in the optimal solution	66
12	Shadow prices and reduced costs of the land resources by land class and region	87
13	Parameterized feed prices to region 1	89
14	Feeds purchased from interstate regions at parameterized prices	90
15	Number of units of animal enterprises produced at parameterized feed prices	91
16	Number of units of the fed beef, turkey, and dairy enterprises at decreasing product prices	94
17	Production of the swine and range sheep enterprises as amounts of product output per production unit change	96

LIST OF TABLES (Continued)

Table		Page
18	Number of units of animal enterprises produced and amounts of feed available from the interstate supply regions in each parameterization step	98
19	Mileages used in calculating transportation costs	119
20	Product consumption constraints in intrastate regions . . .	120
21	Exogeneous feed requirements	121
22	Updated prices of agricultural products in Utah	122

LIST OF FIGURES

Figure		Page
1	Intrastate regions, counties, and center points	16
2	Interstate consumption regions and center points	17
3	Condensed graphic illustration of the linear programming matrix of one production region	23
4	Marketing pattern for background feeders sold by the intrastate production regions to the interstate consumption regions in the optimal solution	60
5	Marketing pattern for wheat sold by the intrastate production regions to the interstate consumption regions in the optimal solution	61
6	Marketing pattern for milk sold by the intrastate production regions to the interstate consumption regions in the optimal solution	62
7	Marketing pattern for fed beef sold by the intrastate production regions to the interstate consumption regions in the optimal solution	63
8	Marketing pattern for turkey sold by the intrastate production regions to the interstate consumption regions in the optimal solution	64
9	Marketing pattern for pork sold by the intrastate production regions to the interstate consumption regions in the optimal solution	65

ABSTRACT

An Interregional Competition Study of Utah Agriculture

Using the Linear Programming Technique

by

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The purposes of this paper were to inventory the available agricultural production resources in Utah, to determine how those resources could be allocated most efficiently, and to provide information to aid the crop and livestock producing sectors in Utah in making informed production and marketing decisions.

Utah was divided into eight agricultural production and product consumption regions and the rest of the country was regionalized into product supply and market areas. Input and output coefficients, production costs, and market prices for the major Utah crop and livestock production enterprises and their products were developed. A linear program was then used to determine how resources could most profitably be allocated among regions and production enterprises. The optimal marketing pattern for agricultural commodities produced in Utah was also generated. A sensitivity analysis was utilized to ascertain the stability of the optimal production and marketing patterns.

(130 pages)

INTRODUCTION

Utah's agricultural sector is significantly dependent upon the livestock industry. In 1971, 80.3 percent of the cash receipts by Utah farmers came from livestock and livestock products. A brief examination of the state's agricultural production records reveals important and changing trends in the types of livestock and crop products produced, trends which will undoubtedly continue to evolve. These changing trends occur because of product marketing, production, and consumption influences which are transferred through the market system to the individual agricultural producer. Using his available resources, he responds to changes in product and factor market prices so as to maximize his profits. A careful analysis of present trends and their probable changes can assist producers individually in maximizing profits and the state's producers collectively to maximize agricultural net income.

Since in the United States most people currently have sufficient food to eat, the total demand for pounds of food domestically is almost completely dependent upon the size of the population. But trends for the type, quality, variety, and form of food products demanded are a function of income, tastes, preferences, and relative food product prices. The livestock industry, then, is influenced both by the size and location of the population and by consumer demand trends.

The most important changes in the livestock production processes have been specialization and increasing size of individual production units to capture economies of scale. These two things as well as the cost and availability of essential production inputs will continue to be major determinants of the types of livestock produced in Utah. The changing agricultural trends in Utah are illustrated by the following facts. The number of farms in the state has declined almost every year since 1936, and there were only 12,600 farms in Utah in 1973. The average number of acres per farm has continually increased during this period, with the average farm size reaching a record high 1,032 acres in 1973. The number of farmers in the state has followed the downward trend indicated by the decreasing number of farms. While acreage of wheat produced in the state has fluctuated over the years, there have been no real trend changes. Barley acreage is also remaining fairly constant, as is alfalfa hay acreage. But, production of minor crops such as oats, sugar beets, and potatoes has been decreasing while relatively large increases in corn silage production have occurred.

The number of beef cattle in the state has slowly been increasing since 1940, but the number of cattle on feed has had a decreasing trend since 1966. The number of milk cows on farms in Utah has remained relatively stable since 1966, but total milk production has continually increased. The egg industry has become highly specialized on a few farms. Egg production has remained steady over the past few years, but broiler production has become almost nonexistent. The trend in turkey production has been slowly increasing, hog production has remained relatively stable over the past several years, and sheep production in the state is continuing a long downward trend (Utah Agricultural Statistics, 1973).

In 1970, milk, turkey, beef, and lamb and mutton were produced in Utah in excess of consumption requirements in the state, but Utah was a net importer of pork, chicken, and eggs. Keeping in mind the above mentioned factors which are influencing the livestock industry, two observations can be made. First, Utah is very dependent in both supply and demand relationships to areas outside of the state for livestock products. Second, depending on relative enterprise productivity and on factor and product prices, producers in the state may be able to profitably increase livestock production both to supply local consumption requirements and to further develop outside markets for products.

Nature of the study

In livestock production, one of the most important intermediate products is feed and, in many cases, that feed is bulky and expensive to transfer. Livestock production costs depend greatly on the availability of local feeds and the livestock sector is thus closely linked to the crop-producing sector. Since many final agricultural products are also bulky, it seems that where local resources are available, producers in a region have an advantage to meet demand in that region and other nearby regions. In seeking to maximize profits, farmers may buy or sell intermediate and final crop and livestock products from and to other regions. Thus, the agricultural industry faces interregional and intraregional considerations in competing for available production inputs and for output markets. The comparative advantage position of local producers in these areas becomes very important.

All of these factors are having an effect on livestock and crop producers in Utah, and the effects vary in the different production regions within the state. Utah's producers will react according to the different economic forces which affect them in their area. Their reactions will include moving into and out of specific production enterprises and even entering or leaving production entirely. If wrong production decisions are made resources will be misallocated, at least temporarily, and the producer will lose possible benefits.

Within the context of Utah's changing agricultural economy, the purposes of this study are to inventory available agricultural production resources in Utah, to determine how those resources can be allocated most efficiently, and to provide this information to Utah's livestock and crop sectors to aid them in making informed production and marketing decisions.

Objectives

The specific objectives of this thesis are:

1. To determine which crop and livestock production enterprises are most profitable in each area of the state, and to show the extent to which those enterprises can be expanded profitably;
2. To show which market areas are most profitable for the agricultural products which are produced in the different areas of the state, and to determine the optimal product transportation pattern for those products;
3. To examine the stability of regional and enterprise competitive positions in response to changes in input/output coefficients and in product and factor market price conditions; and,
4. To present selected policy implications and recommendations as indicated by the results of the study including suggestions for agricultural producers, policy makers, and future researchers.

REVIEW OF LITERATURE AND THEORETICAL DISCUSSION

Literature review

Interregional analysis of crop and livestock production using linear programming has been a popular and useful tool of agricultural economists for more than 20 years. Fox (1953) developed an early spatial equilibrium model of the U.S. livestock-feed economy. Heady has used sophisticated models to analyze agricultural production regionally in the entire country and has shown optimal national production and transportation patterns for livestock products (cf. Brokken and Heady, 1968). Many studies have used similar techniques, including several studies emphasizing the western United States as a region. Each work has its own area of emphasis; a certain region of the country, livestock products in general, crop products in general, specific crop or livestock products, or more recently, the interrelated nature of the livestock and crop sectors. Grimshaw (1972) focused on the Pacific Northwest region and livestock products as they are related to feed inputs. Basically, he concluded that a region has an advantage in producing the livestock products consumed in that region until locally produced feed grains are used up. After that, regional advantages in production costs, output prices, or transportation rates greatly influence the regional location and allocation of livestock enterprises and products.

Gray (1972) used the basic techniques developed by Grimshaw to analyze the livestock industry as related to available feeds. He emphasized Utah as a region and worked to establish the competitive position of Utah livestock producers. He elaborated statistically on the data used to examine the livestock-feed economy. His general conclusion was that the comparative advantage to produce a livestock product belongs to the consumption region if local feeds are available. He also concluded that based on feed costs for the years of his study (1970 and 1971) Utah producers had a comparative advantage to produce all of the milk, broilers, and eggs consumed in the state as well as to compete favorably in supplying the California market with some milk and eggs. He also concluded that limited quantities of beef, pork, and turkeys could be produced competitively in Utah for local consumption, with special expansion opportunities in the pork production industry.

Although the study by Brokken and Heady (1968) was national in scope and emphasized no particular region, it provided important theoretical guides for this study. It illustrated the division of production and consumption regions and used both crop and livestock producing activities as well as activities transferring feeds from crop supplies to nutrients used in livestock production. Transportation activities for all products were also allowed. Studies by Anderson et al. (1973) and Keith, Andersen, and Clyde (1973) emphasized interregional use of the water resource in Utah and provided useful information on Utah crop enterprises and on interregional linear programming analysis.

Comparative advantage

While many economic principles are directly involved in an interregional competition study of this nature, the basic one of importance here is that of comparative advantage as it relates to resource allocation, both between enterprises and between regions.

The principle of comparative advantage has been used to examine trade possibilities between separate countries and regions with different resource endowments and production abilities (e.g., Ohlin, 1933). For example, because of these differences suppose Region A can produce 100 units of wheat or 75 units of corn with a given amount of resources. Region B can produce only 75 units of wheat or 70 units of corn with the same amount of resources. Thus, Region B can produce only 0.75 as much wheat or 0.93 as much corn as A with the same amount of resources, and so suffers an absolute disadvantage in producing both products. But, its disadvantage is least with corn, so in corn production it has a comparative advantage. If both regions need to have both products, it will be advantageous for the regions to specialize in production, A producing wheat and B producing corn, and then trade products between regions. If the resources being used are transferable without cost, then all resources would be transferred to Region A and all production would occur there. If costs of transfer were incurred, resource reallocation would occur to the point where transfer costs just negate the absolute advantage of Region A. Transferable resources in agricultural production include labor, capital, and water. If the resources being used are not transferable (e.g., land), production of a product will occur in the region which enjoys a comparative advantage in producing that product.

Heady (1952, p. 661) points out that the principle of comparative advantage as outlined above assumes a constant marginal rate of substitution between products within a region (linear production possibility curves), whereas regions generally have changing rates of product substitution. An implication of this assumption is that each region will produce only a single product, the product that provides the region with the greatest comparative advantage. So, marginal rates of product substitution are an important qualifying variable to be considered with comparative advantage.

Heady discusses two other variables which ought to be associated with the comparative advantage principle. First is the existence of complementary and supplementary enterprises in agriculture. Second is the need to include the relative price ratios along with the substitution ratios of the products being produced (Heady, 1952, pp. 661, 662).

In a linear program, changing marginal rates of substitution can be partially dealt with by imposing constraints on the amounts of each product that can be produced or consumed in the intrastate regions at the given prices. This limits the area where the marginal rates of substitution are assumed to be constant. Some complementary and supplementary effects of agricultural enterprises can be included in the analysis by permitting several feeds to be grown, and then allowing them to either be sold or to be used in meeting production requirements of any of several livestock enterprises. Relative price ratios of products can be included directly in the analysis if output prices for each product in each region are specified.

The principle of comparative advantage as applied in this study will show how resources are allocated among enterprises. Transferable resources will be transferred to regions where the comparative advantage of using them (net of transfer costs) is greatest. Since total enterprise production is also ultimately constrained by regional consumption limits, transferable enterprises will be "allocated" to regions where they have the greatest comparative advantages in production. The comparative advantages of regions within Utah in producing crop and livestock products for local and out of state markets will also be examined.

Linear programming

The value of linear programming in analyzing the agricultural sector, from individual farm planning problems to national interregional competition studies has been demonstrated during the past 20 years. A detailed discussion of linear programming methods and their application to interregional studies will not be made here, but a brief explanation of the basic logic as it applies to this study is necessary. For a more complete explanation of linear programming and its application to agriculture and interregional analysis, the reader is referred to Heady (1954), Dorfman, Sammuelson, and Solow (1958), Beneke and Winterboer (1973), and Heady and Candler (1973).

Linear programming is a tool used in minimizing or maximizing a specific objective given various methods of meeting that objective subject to specified limiting restraints. Obtaining the objective involves minimizing or maximizing a linear function called the objective function. In most agricultural problems, the objective function is to either minimize costs or maximize profits. That objective may be obtained by engaging in the proper combination of available activities. Agricultural activities may include the production, buying, selling, and transfer of agricultural products for which the proper input/output coefficients, costs, and prices must be included. To complete the linear programming problem, these available activities are subject to certain constraints or limitations, which are included in the model as linear inequalities. In agricultural problems, those constraints may be the available amounts of land, labor, capital, or other resources.

Heady and Candler (1973, pp. 17, 18) list the basic assumptions used in linear programming. These assumptions must be met or closely approximated in order for the program to provide a precise and meaningful solution.

1. The first assumption is that of linearity and additivity. This assumption indicates that no interaction effects exist between activities or resources so that when two activities are used their total product is equal to the sum of their individual products, and when resources are used in several enterprises their total use is equal to the sum of their use in each enterprise. This assumption also disallows increasing returns to scale since the same input/output coefficients are used for any number of units of activity produced.
2. Linear programming assumes divisibility in that all inputs can be used or all products produced in fractional units.
3. Finiteness is assumed. The optimal solution is derived from only the finite number of possible activites which are defined and input into the program.
4. The final assumption is that of single-value expectations. It is assumed that the input data (amounts of resources available, input/output coefficients, costs, and prices) are known with certainty.

Although these assumptions often do not completely hold for agricultural problems and data, they approximate real world conditions closely enough to allow the linear programming technique to provide highly valuable and useful information. The most restrictive assumption is the first, but its rigidness can be partially offset by defining more than one activity for each production enterprise to approximate increasing returns to scale or diminishing marginal physical product to inputs.

Some interaction effects can also be included in a linear programming model by defining one enterprise which has joint products as an output. This addition of complementary effects further reduces the restrictions imposed by the first assumption.

A small linear programming problem could also be solved by simple mathematic, geometric, or budgeting methods. The great value and efficiency of using a computerized linear program is manifest when large numbers of activities and constraints are included to solve a complex problem. Without this computerized method, those large problems would be virtually impossible to solve.

METHOD OF PROCEDURE

Achieving objectives

This study is an extension and compilation of many similar or related projects. It combines ideas developed in several separate studies and utilizes some information developed for and resulting from those studies. In order to focus on Utah agriculture, the state was divided into analytically useful agricultural production areas and product consumption areas (intrastate regions). To facilitate the delineation of intrastate production regions data needed to be obtained concerning the amount, type, and location of the state's basic agricultural resource, productive land. Factors analyzed in describing production regions included logical physical divisions of the land resource, current enterprise production patterns, accessibility to product markets, and already existing regional divisions. The size and location of the population were the main factors considered in defining consumption regions. Outside of Utah, the rest of the continental United States was divided into agricultural product supply and demand areas (interstate supply and interstate consumption regions).

The determination of which specific crop and livestock enterprises to include as activities in this study was made by considering the value at present of specific enterprise production in Utah and by determining if the amount of the enterprise produced has been increasing, decreasing, or remaining constant over the years. Other points evaluated were enterprise expansion opportunities and the interdependent role of crop and livestock enterprises. Once the regions were outlined, production costs and the necessary input/output data for each of the specified crop and livestock enterprises in each region had to be determined. Market prices for all products in all consumption regions and product transportation costs between regions had to be obtained. It was determined that a trend price for each product would be more useful than current or average prices. Even though agricultural prices fluctuate constantly, the relative price ratios between regions, enterprises, and inputs and outputs are the important relationships. The use of trend prices in a study of this nature gives a more stable account of those relationships.

Since this was an interregional competition study involving several production and consumption regions and several agricultural enterprises, it was decided that it could best be analyzed by using the computerized linear programming technique. The programming model was built so that given the basic available resources each region could produce both crop and livestock products. Crop products which were produced could either be sold or transferred to feed for use in livestock production. Livestock products could be sold to any consumption region.

A profit-maximizing linear program was used, and the objective was defined as the maximization of profits to Utah agricultural producers. Each region's most profitable activities were determined by the input production costs, enterprise input and output coefficients, available resources, and market prices for outputs. Activities were bounded by logical physical and production constraints. By the use of this approach, the first objectives of this study were met as the competitive position of each intrastate production region in producing crop and livestock products for itself, other intrastate regions, and specific interstate consumption regions was shown. The competitive position of enterprises in using available regional resources was determined, and the ability of regional producers to compete in local and outside product markets was outlined. Information was provided to determine the regional product transportation pattern, and with the use of available modifiers to the basic programming model, the desired sensitivity analysis was obtained.

The last objective was met by the use and analysis of all of the information obtained from the linear programming model. A complete prediction of the exact production decisions which regional agricultural producers ought to take could not be provided by any analysis of the model's output, but it is expected that real trends were illuminated, and the relative benefits of regional increases or decreases in specific enterprise production pointed out.

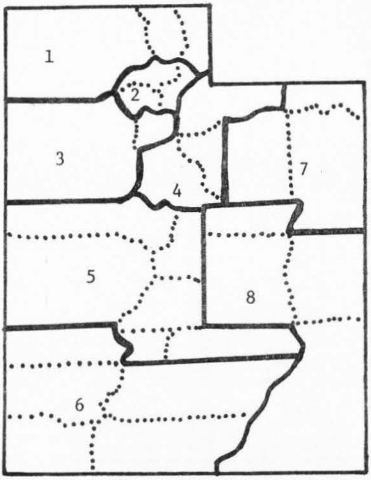
Almost all of the data was obtained from secondary sources. Most came from publications of the United States and Utah State Departments of Agriculture, from publications of the Utah State Agricultural Experiment Station and Extension Service, and from other Utah State University publications. What information needed to be obtained from primary sources came from personal contact with those sources.

Regionalization and enterprise definition

A significant problem to be dealt with was that of the delineation of production and consumption regions. Actual conditions are more closely approximated if the number of regions included in the model is large, but the number of regions had to be limited in order to provide a manageable model for which to prepare data and with which to obtain economic computer analysis. It would have been most desirable to regionalize along natural boundaries, transportation rate contours, or enterprise-specific boundaries (such as milk sheds), but since each production region had to include all production enterprises, and since the large amounts of data which had to be collected were most readily available on a county or state basis, regional boundaries were made to follow those political lines. It was decided that the intrastate boundaries would serve for both the production and consumption regions, so that criteria relating to both needed to be included in the delineation decision. It was decided to divide the state into the eight regions which have been designated as the official state multi-county planning regions, as shown in Figure 1. This delineation is precisely the same as that used by the Four Corners Regional Commission to designate subregions of the four corners region (Minshall et al., 1971).

The interstate consumption regions are shown in Figure 2. Population size and proximity to the Utah production regions were the main criteria used in outlining these regions. Again, the number of these regions established had to be limited.

The interstate supply regions for the intermediate products available for purchase by the intrastate production areas needed to be defined next. Traditional sources of supply, amounts of products produced in the supply areas, product prices, and transportation prices for the products from the supply areas to the production areas were the criteria used in establishing these regions. It was decided that intrastate regions could obtain intermediate products from three different

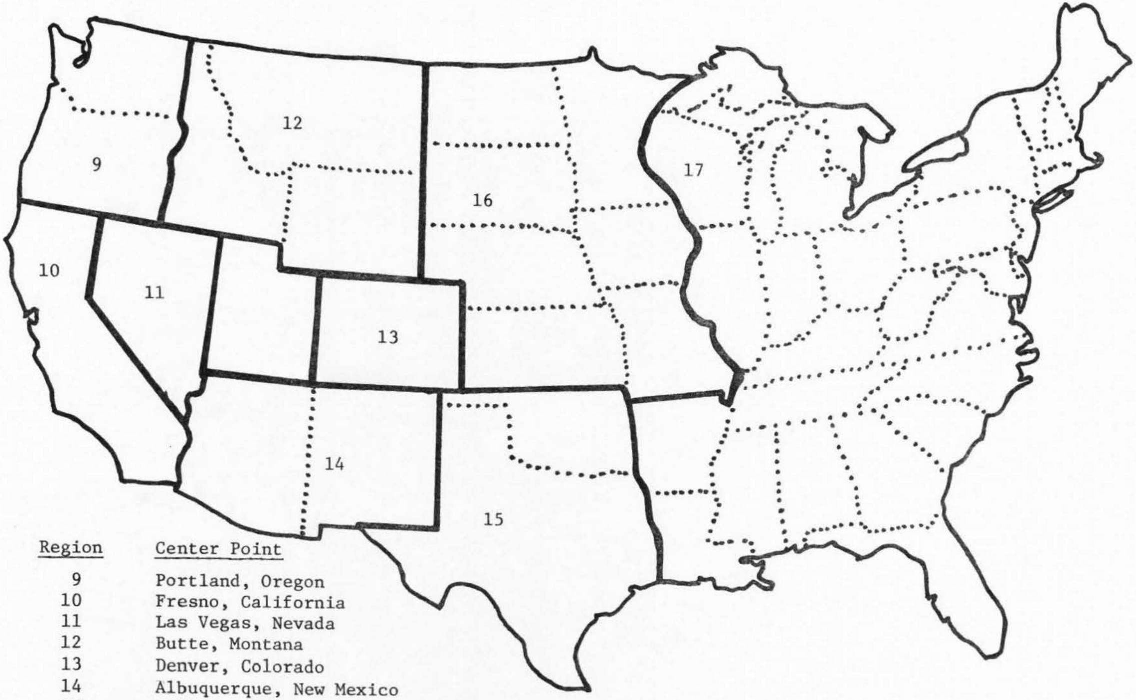


Region	Center Point
1	Logan
2	Ogden
3	Salt Lake
4	Provo
5	Richfield
6	Cedar City
7	Vernal
8	Green River

Region 1	Region 2	Region 3	Region 4
Box Elder	Davis	Salt Lake	Summit
Cache	Morgan	Tooele	Utah
Rich	Weber		Wasatch

Region 5	Region 6	Region 7	Region 8
Juab	Beaver	Daggett	Carbon
Millard	Garfield	Duchesne	Emery
Piute	Iron	Uintah	Grand
Sanpete	Kane		San Juan
Sevier	Washington		
Wayne			

Figure 1. Intrastate regions, counties, and center points.



Region	Center Point
9	Portland, Oregon
10	Fresno, California
11	Las Vegas, Nevada
12	Butte, Montana
13	Denver, Colorado
14	Albuquerque, New Mexico
15	Dallas, Texas
16	Omaha, Nebraska
17	Chicago, Illinois

Figure 2. Interstate consumption regions and center points.

interstate supply areas for each product. The main region was an area close to Utah and was the traditional supply source for the product. The secondary supply region for each product had the same geographical definition as did the first supply region. But, it was assumed that transportation costs from the secondary supply region to the intrastate regions were 1.5 times higher than transportation costs from the main supply region. The final interstate supply region for each product was generally a large area where large quantities of the intermediate product were available. These areas were quite distant from the intrastate regions, so transportation costs, and thus total product costs to the intrastate regions were high. Upper bounds were placed on the amounts of each intermediate product available in each supply region.

The interstate supply regions for each product were defined as follows: Idaho and Montana were the main supply areas for wheat, barley, and oats. The final supply area for these products included the central and eastern portions of the country. The main supply area for corn included Nebraska and Kansas, while the central part of the country was defined as the final supply region for corn. Idaho and Wyoming made up the main supply area for alfalfa hay. The Pacific Northwest and Montana were the areas included in the final alfalfa hay supply region. Only one general supply region was defined for backgrounder and feeder calves. That region included the states of Nevada, Idaho, Colorado, Texas, and Oklahoma.

In order to provide a single mileage figure upon which to calculate transportation costs, a single center point for each region had to be established. These centers were designated on the basis of population size, location within the region and relative to other regions, and proximity to major highways and railroads. The regional centers are shown in Figures 1 and 2.

One of the stated assumptions in linear programming models is finiteness, meaning that only a finite number of activities can be defined and used in the program. The decision as to which crop and livestock producing enterprises to include in this study was based on the criteria set forth in the first of this chapter, and on the availability of data concerning the enterprises. The crop-producing enterprises which were used include: alfalfa hay, barley, dry land wheat, sugar beets, irrigated pasture, corn silage, public cattle range, private cattle range, public sheep range, and private sheep range. The livestock production enterprises which were used include: beef cow/calf, background beef feeding, finish beef feeding, range sheep, turkeys, farrow-to-finish swine, and dairy. These specific crop and livestock producing enterprises accounted for 86.0 percent of the cash receipts by farmers in Utah in 1971.

Linear programming model development

The linear programming model used in this study utilizes the Tempo MPS/MPS programming system. It was decided that the overall objective function would be to maximize net returns to Utah agricultural producers assuming that they produced only the enterprises which are defined. Algebraically, the objective function is to maximize the following linear equation:

$$\sum_{k=1}^{18}\sum_{r=1}^{17} ({}_kA_r)({}_kB_r) - \sum_{k=1}^{18}\sum_{r=1}^{8} ({}_kC_r)({}_kD_r) - \sum_{u=1}^{8}\sum_{r=1}^{8} ({}_uE_r)({}_uF_r) -$$

$$\sum_{k=1}^{18}\sum_{r=1}^{8}\sum_{m=1}^{17} ({}_kG_{rm})({}_kH_{rm}) - \sum_{u=1}^{8}\sum_{r=1}^{8}\sum_{i=1}^{3} ({}_uI_{ir})({}_uJ_{ir})$$

where k = all products produced by the enterprise activities in the intrastate regions. There are 18 different products which can be produced.

r = all production and consumption regions. Regions 1 through 8 are the intrastate production/consumption regions, and regions 9 through 17 are the interstate consumption regions.

u = all intermediate products purchased by the production regions. There are eight intermediate products available for purchase.

m = the region of destination (consumption region) in the transportation of products produced and sold by the intrastate regions.

i = the interstate regions which sell intermediate products to the production regions. There are three interstate supply regions for each product.

${}_kA_r$ = the number of units of product k sold in region r.

${}_kB_r$ = the price per unit of product k sold in region r.

${}_kC_r$ = the number of units of product k produced in region r.

${}_kD_r$ = the cost per unit of producing product k in region r.

${}_uE_r$ = the number of units of intermediate product u purchased by region r.

${}_uF_r$ = the cost per unit of intermediate product u purchased by region r.

${}_kG_{rm}$ = the number of units of product k transported from production region r to consumption region m.

${}_kH_{rm}$ = the per unit cost of transporting product k from production region r to consumption region m.

${}_uI_{ir}$ = the number of units of intermediate product u transported from interstate supply region i to production region r.

${}_uJ_{ir}$ = the per unit cost of transporting intermediate product u from interstate supply region i to production region r.

Verbally, the equation is to maximize the following value: the total income from products produced in the intrastate regions and sold in the consumption regions, minus the costs of producing the enterprise products in the intrastate regions, minus the costs of the producing regions purchasing intermediate products to be further used in production, minus the costs of transporting products from the production regions to the consumption regions, minus the costs of transporting intermediate products from the interstate supply regions to the intrastate production regions.

Having described the objective function, the other two essential elements of the linear programming model (activities and constraints) can now be discussed. Essentially, the model was divided into eight individual segments, one for each intrastate region, and the activities and constraints are of the same basic pattern in each region. A simplified version of the matrix of one region as developed in the model is shown in Figure 3. This figure illustrates how the activities and constraints enter the model. The matrix symbols have the following meanings:

c = the cost of engaging in one unit of the activity.

p = the selling price net of transfer costs per unit of product sold.

t = the transportation costs of getting one unit of product from the selling to the buying region.

d = the data coefficient corresponding to the column and row where it is placed.

b = the constraint value. The final value of the row must be greater than or equal to, less than or equal to, or equal to this number, depending on how the row is defined.

1 = shows that one unit of the activity either adds or subtracts one unit of product to the corresponding row.

0 = shows that the activity has no effect on the row. All matrix elements which are not specified are assumed to be zero.

The essential parts of the linear programming model, then, are the columns (activities), rows (constraint names), and right hand side (RHS), or constraint values. In addition a bounds section may be included, and was in this model, to put lower or upper bounds, or both, on selected activities. The function of these different matrix elements as shown in Figure 3 will now be described.

Crop production activities were defined for each of the selected crop enterprises in each region. Irrigated land was divided into five soil classes, soil types 1 through 4 and types poorer than class 4, and separate activities were defined for alfalfa, barley, corn silage, and

Activities

Constraints	Crop Production	Livestock Production	Feed Transfer	Sell Intermediate Crops Products[a]	Sell Intermediate Livestock Products[a]	Sell Final Crop Products	Sell Final Livestock Products	Buy Intermediate Crops from Interstate Supply Regions	Buy Intermediate Livestock from Interstate Supply Regions	RHS
Objective Function	-c	-c	0	-t	-t	+p	+p	-c	-c	
Regional Profit Account	-c	-c	0	+p	+p	+p	+p	-c	-c	≥0
Land Account	-1									≥-b
Crop Account	+d		-1	-1		-1		+1		≥0
Livestock Products Account		+d			-1		-1		+1	≥0
Feed Account		-d	+d							≥0
Crop Product Consumption Account						+1				≤b
Livestock Product Consumption Account							+1			≤b
Crop Interstate Supply Region Account								-1		≥-b
Livestock Interstate Supply Region Account									-1	≥-b
Crop Account for Another Production Region				+1						≥0
Livestock Account for Another Production Region					+1					≥0

c = activity costs
p = product selling price net of transfer costs
t = transportation costs
d = specific data coefficient
b = constraint value
For a more complete explanation of matrix symbols see page 22.

[a]These activities as shown here occur between intrastate production regions.

Figure 3. Condensed graphic illustration of the linear programming matrix of one production region.

sugar beet production on each soil class in each region, where applicable. Irrigated pasture was the only crop activity defined for production on soil poorer than class 4, and it was assumed to be produced nowhere else. Wheat was the only defined dry land activity. The costs of producing each unit (acre or AUM)[1] of crop activity was subtracted from the objective function and the regional profit row. An acre of land was subtracted from the appropriate land class account for the region, and the amount of output was added to the crop account for each unit of activity produced. As will be discussed later, upper and lower bounds were placed on crop production activities to approximate rotation limitations and to avoid production beyond practical limitations.

Livestock production activities were defined for each of the selected livestock enterprises in each region, and upper bounds were placed on the amounts of each activity that could be produced in each region. A dairy construction activity was also defined so that dairy production could expand if profitable. The objective function and regional profit rows show the nonfeed costs of producing one unit of the livestock activity. The amount of feed needed to produce that activity is subtracted from the feed row, and the amount of livestock product output is shown in the livestock account row.

Livestock feed requirements for production are specified on the basis of metabolizable energy and digestible protein, a procedure initiated in linear programming by Grimshaw (1972). This basis of converting feed to livestock products is used because it provides a good estimate of the amount of feed eaten by livestock which is actually

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[1] AUM means animal unit month.

converted to useful product, and because good, recently published data is available for metabolizable energy and digestible protein. Feed transfer activities are defined in each region to transfer a unit of each specific crop product to megacalories (Mcal) of metabolizable energy (ME) and pounds of digestible protein (DP) for use by each specific livestock enterprise. This can be seen in the matrix in Figure 3 where a unit of crop is taken from the crop account and transferred to the feed account. The feed coefficients as made available by this transfer and as used in livestock production are expressed in terms of ME and DP. No costs are associated with this transfer.

The sale of intermediate crop or livestock products between production regions subtracts the costs of transporting those products between those regions from the objective function. The selling region adds the selling price to its profit row and the buying region (although not shown in the matrix) subtracts the price plus transfer costs from its profit row. One unit of the product sold is subtracted from the selling region and added to the buying region's product account. The sales of intermediate products from production regions to interstate consumption regions are not shown in the matrix as those activities are handled in the same way as the sale of final products.

The sales of all final crop and livestock products to all consumption regions are next defined for each production region. These activities add the selling price (net of transportation costs) to the objective function and regional profit row. A unit of the product sold is taken from the selling region's account row and added to the buying region's product consumption row.

Activities are defined for the production regions to buy intermediate crop and livestock products from interstate supply regions. These products are then used by the intrastate regions to produce final products. Activities provide for each production region to buy feed wheat, barley, alfalfa, corn grain, oats, soybean oil meal, beef calves, or background beef feeders. The product buying price plus the transportation costs are subtracted from the objective function and from the production region's profit row. The unit of intermediate product is taken from the interstate supply row and added to the intrastate product account.

The RHS shows the values that are put on the constraints. In this model, rows are either limited by a numerical value or are simply constrained to be greater than or equal to zero. The objective function row is not constrained since the purpose of the program is to maximize its value. Each land account is constrained to be less than or equal to the number of acres of the specific class of land available for use in that region. The crop and livestock product consumption accounts in the intrastate regions are limited to insure that only the amounts of products which can be consumed in a region are sold to that region. The interstate crop and livestock supply rows are constrained so that they can only sell a fixed percentage of the amounts of those products that they produce themselves to the intrastate production regions.

Constraining the regional profit rows to be positive insures the nonoccurrence of the unrealistic condition of having one region produce at a loss to provide inputs for another production region simply because such a pattern would maximize total state-wide profits. The positive constraint on crop and livestock accounts in the production regions provides that only those products which are produced or purchased are available to be further used or sold. The positive feed row constraint allows livestock production activities to use only those feeds which are properly transferred from the crop accounts into ME and DP units specific to the livestock enterprise.

The linear programming technique was used to find the optimal solution (the highest obtainable net revenue to the state agricultural producers) using the model as set up. The main objectives of this study are reached by analysis of the output data provided. The range and post-optimal parameterization procedures were used to provide the necessary sensitivity analysis. In the linear programming output, the range procedure provides information such as how much production costs for an activity could vary without changing the amount of that activity produced. The amounts of activity which would result if costs decreased one unit below or increased one unit above that price range are also shown. Parameterization is a means of changing specific variables in the matrix in discrete steps to allow observation of changes in the optimal solution as those variable changes occur. For instance, production costs of an enterprise could be increased in $1.00 steps and the changes in the optimal solution at each step shown. Costs, prices, input/output coefficients, or constraint values could all be changed (parameterized) either upward or downward in any size step and as many steps as are desired, and the resulting solution changes in each step would be output.

Assumptions

There are several limiting and qualifying assumptions which must be made in order to make the model manageable and to make the proper accumulation and manipulation of data possible. Those related directly to the linear programming model have already been discussed, and several others relating to procedural methods have been mentioned. Those dealing directly with the development of specific pieces of data will be discussed in the following chapter. This section will outline the other assumptions made.

1. The only livestock and crop enterprises included in the model are those which have already been defined. An exogeneous feed requirement is established for the use of nondefined livestock enterprises, but those enterprises are not included as profit-generating production activities.
2. The feeds available for livestock use in a production region are those produced in the region, plus those purchased from other regions, minus those sold to other regions, minus those needed by the exogeneous livestock. Ten percent of the total wheat produced in a region is assumed available as a feed.
3. It is assumed that transportation between regions occurs only between regional center points, an assumption necessary to determine transportation rates. There are no transportation costs for products moving within the regions themselves.
4. The prices used for agricultural products in the model are "normalized" prices obtained by using a least squares regression on prices for the years 1960 through 1973. The normalized

price used was the price in the fourteenth time period of the regression. Prices are the average state yearly prices received by farmers for products as reported by the Statistical Reporting Service (U.S. Department of Agriculture, 1960-1972, 1973-1974). For multi-state regions, the regional price is an average of the individual state prices.

5. If a product is produced in a region, it is assumed that it is further used or sold first in that region. If further use is not profitable, or if consumption constraints are reached in that region, surplus products may be sold to other regions.
6. In order to make transportation activities occur in a logical sequence, the following assumptions were used: a production region selling a final product receives the price for that product in the region of destination net of transport costs; a production region selling an intermediate product to another production region receives the total normalized price, while the buying region pays the normalized price plus transport costs; if the intermediate product is sold to an interstate consumption region, it is handled in the same manner as a final product; a production region buying an intermediate product from an interstate supply region pays the normalized price in the interstate region plus transport costs.
7. The crop production costs used in the matrix are total production costs as developed from budget data. The livestock production cost coefficients are total nonfeed costs, with the model determining which feeds will be fed at the specified costs. Therefore, all determinable costs are included, and

profits are returns to enterprise management and invested capital.

8. In order for livestock to attain the assumed daily rates of gain or yearly production totals used in calculating nutrient requirements, it is assumed that the ration of dairy cows will include at least 20 percent concentrates, the ration of background beef feeders will include a minimum of 25 percent concentrates, and finish beef feeders will be fed at least an 80 percent concentrate ration.

9. It is assumed that all products produced in an intrastate region may be transported to other regions with the exceptions of corn silage and pasture, which must be used in the region of production. Range which is available in one region may be "transported" in that another region may transport animals to use the range in the first region.

10. It is assumed that any number of units of product can be sold by the production regions to the interstate consumption regions at the established price. Subject to the consumption constraints, this assumption is also used for the intrastate consumption regions.

DATA DEVELOPMENT

The accumulation of the proper data for this thesis was an extremely lengthy and involved process. This chapter will present the final data used and outline the methods and sources used in obtaining it.

Table 1 presents the coefficients which were used in the feed transfer activities to transfer the feeds used from a weight basis to a nutrient (ME and DP) basis. Transfers are specific for kind of feed and animal class. The figure of 410 pounds of total digestible nutrients (TDN) per AUM used in figuring pasture nutrients was obtained from the study by Brokken and Heady (1968, p. 8).

In Table 2, the nutrient requirements per unit of livestock activity are presented on the ME and DP basis. It is important to understand how one unit of each livestock activity was defined for purposes of this study. The basic unit of the beef cow/calf enterprise is one beef cow producing in a one year cycle. Total nutrient requirements included nutrients for the cow throughout the year both while nursing and while dry and pregnant, a percentage of the nutrients required to maintain herd bulls, and a percentage of the nutrients required to maintain herd replacement heifers.

The basic unit in the background beef feeding activity is one beef calf fed from 400 pounds to 650 pounds (250 pounds gain). It is assumed that the average daily gain of these animals is 1.65 pounds, and that 55 percent are steers and 45 percent are heifers.

One unit of fed beef activity is composed of feeding one beef feeder from 650 to 1050 pounds (400 pounds gain). The assumed average

Table 1. Nutrients furnished by feeds for animals[a]

Animal Class		Barley	Alfalfa	Wheat	Corn Silage	Corn Grain	Oats	Pasture	Soybean Oil Meal	Cattle Range	Sheep Range
Beef Cattle	ME	121.2	84.1	129.9	45.9	128.3	111.0	700.0	125.5	600.0	
	DP	8.7	11.4	8.5	1.9	6.5	8.8	44.1	37.3	32.5	
Turkeys[b]	ME	120.0		140.0		155.0	115.0		110.0		
	P	11.6		10.8		8.8	11.9		43.8		
Dairy Cattle	ME	125.1	82.9	133.8	46.6	135.4	113.9		130.2		
	DP	8.7	11.4	8.5	1.9	6.5	8.8		37.3		
Swine	ME	130.5		154.9		148.6	121.0		135.9		
	DP	8.2		9.9		7.0	9.9		39.4		
Sheep	ME	125.5	85.6	129.9	45.3	138.2	109.5	700.0	122.5		533.0
	DP	9.2	13.0	8.5	1.8	6.9	9.2	44.1	39.4		26.5

[a]Megacalories of metabolizable energy (ME) and pounds of digestible protein (DP) furnished per hundredweight of harvested feed or per animal unit month (AUM) of pasture and range on an "as fed" basis.

[b]Total protein for turkeys.

Source: Calculated using United States-Canadian Tables of Feed Composition (National Academy of Sciences, 1969) for the harvested feeds. Pasture nutrients per AUM figured assuming 410 lb. TDN/AUM (TDN = total digestible nutrients) with pasture plants averaging 25% dry matter and 2.7% DP on an as-fed basis. Range nutrients per AUM calculated from the average monthly nutrient requirements of the animals using the range.

Table 2. Nutrients required to produce one unit of each livestock activity[a]

Nutrient	Animal Class						
	Cow/Calf	Back-grounders	Fed Beef	Turkeys	Dairy	Swine	Sheep
Metabolizable Energy (Mcal)	7,204.402	1,849.722	3,442.51	104.6391	11,153.62	16,603.194	1,279.75
Digestible Protein (Pounds)	389.9726	117.6419	242.1742	13.2066	843.5392	1,515.9125	62.987

[a]For the definition of a unit of each livestock activity see pages 31 and 34.

Source: Calculated using Nutrient Requirements of Domestic Animals (National Academy of Sciences, 1968, 1970, 1971).

daily gain of the steers is 2.87 pounds and of the heifers 2.65 and 2.43 pounds. It is assumed that 65 percent of the feeders are steers and 35 percent are heifers.

The basic turkey production unit is feeding a turkey from the time it hatches to an average market weight of 22.5 pounds (29 pounds for toms and 16 pounds for hens). It is assumed that 50 percent of the turkeys raised for market are toms and 50 percent are hens.

The production unit of the dairy activity is one mature dairy cow producing in a yearly cycle. It is assumed that the cow lactates for 305 days and is dry for 60 days. Nutrient requirements were calculated for a cow producing an average of 11,500 pounds of milk yearly.

One sow producing in a yearly cycle is the basic swine activity unit. Requirements include nutrients for the sow during pregnancy and during lactation, for a percentage of the herd boars, for a percentage of the open and nonproducing sows in the herd, for a percentage of the required herd replacement guilts, and for feeding the offspring produced by the sow from birth to a market weight of 220 pounds.

The basic range sheep activity unit is one ewe producing in a yearly cycle. Nutrient requirements include maintaining the ewe during the gestation, lactation, and nonlactating periods. Requirements to maintain a percentage of the herd replacement lambs and the herd rams are also included.

Since each activity experiences some percentage of death loss during production, the actual total amount of nutrients used in an activity is greater than the simple sum of the amounts used by the individual units to produce the final product. To account for this, the average death loss in each of the enterprise activities was determined and the different amounts of loss during the production cycles approximated. A percentage of the nutrients used by the animals which were lost during the production cycle was added to the nutrient requirement total of each activity unit which produced final output.

Table 3 shows the costs per acre of producing field crops and the costs per AUM of producing range. The average product output of the crop activities per acre of land is shown in Table 4. As noted, the field crop data was calculated from Anderson et al. (1973), who obtained most of their information from crop budgets produced from the "Greenbelt" studies and published in Davis, Christensen, and Richards (1972). The costs as presented include all production costs except management costs and opportunity costs of invested capital. All labor costs are included at the rate of $2.00 per hour. A cost of $4.00 per acre for water was included for all irrigated crop activities, and it is assumed that sufficient water is available at that price to irrigate all presently irrigated land. It is assumed that alfalfa is grown in rotation with a "nurse crop" activity. This rotation consists of planting a nurse crop of barley with new alfalfa the first year, and only barley is harvested that year. The alfalfa produces for the next five years before it must be replanted again with a nurse crop. To approximate this condition, the total costs and yields of the one year of nurse crop and alfalfa activity and the five years of alfalfa activity are calculated and divided by six to give a yearly rotation cost and yield figure. To approximate the summer fallowing procedure that is practiced in dry land wheat production, it was assumed that all wheat land was available for use each year, but the costs and yields were divided in half. It is assumed that corn silage and sugar beets are not grown on class 4 land, and that

Table 3. Costs of producing crop activities

Crop Enterprise	Unit	Region 1	2	3	4	5	6	7	8
Alfalfa rotation on soil 1	Acre	$62.87	$65.80	$65.54	$65.07	$61.75	$74.27	$ ---	$64.57
Alfalfa rotation on soil 2	Acre	58.62	60.62	61.33	60.82	59.46	60.60	53.93	59.00
Alfalfa rotation on soil 3	Acre	52.12	54.07	55.37	52.48	54.46	55.28	49.39	54.75
Alfalfa rotation on soil 4	Acre	45.26	45.81	47.95	44.71	47.51	48.03	45.08	47.25
Barley on soil 1	Acre	63.00	64.50	64.64	65.50	64.30	65.00	---	64.50
Barley on soil 2	Acre	61.20	62.49	62.66	63.70	62.64	62.72	62.40	62.42
Barley on soil 3	Acre	59.10	60.44	60.62	61.36	60.78	60.86	60.45	60.59
Barley on soil 4	Acre	56.43	57.47	57.78	58.48	58.77	58.69	58.65	58.50
Corn silage on soil 1	Acre	121.78	126.68	128.68	128.68	122.00	121.50	---	117.35
Corn silage on soil 2	Acre	115.48	119.48	121.48	121.48	116.08	119.25	115.15	112.85
Corn silage on soil 3	Acre	107.38	112.05	114.05	114.05	108.20	110.25	108.40	105.65
Sugar beets on soil 1	Acre	232.36	238.74	240.74	233.30	---	---	---	---
Sugar beets on soil 2	Acre	225.56	230.92	232.92	226.50	---	---	---	---
Sugar beets on soil 3	Acre	216.72	219.70	221.70	218.00	---	---	---	---
Dry land wheat	Acre	10.07	10.07	10.06	10.08	9.88	11.38	10.08	10.98
Irrigated pasture	Acre	23.00	25.20	25.00	23.70	25.30	26.40	25.00	25.30
Public cattle range	AUM	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
Private cattle range	AUM	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53
Public sheep range	AUM	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17
Private sheep range	AUM	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60

Source: Field crop data calculated from information published in Anderson et al. (1973). Range data calculated from information in McArthur, Nielsen, and Andersen (1973, p. 24).

Table 4. Output of the crop activities[a]

Crop Enterprise	Product	Region 1	2	3	4	5	6	7	8
Alfalfa rotation on soil 1	Hay	82.5	88.3	83.2	88.3	75.0	105.0	---	82.5
	Barley	5.8	6.1	6.0	6.1	5.1	5.6	---	5.3
Alfalfa rotation on soil 2	Hay	72.5	76.5	73.3	78.3	69.8	71.7	60.0	69.3
	Barley	5.0	5.2	5.1	5.3	4.4	4.6	4.2	4.3
Alfalfa rotation on soil 3	Hay	57.0	60.8	59.2	58.3	58.0	59.0	49.3	59.3
	Barley	4.0	4.3	4.2	4.2	3.6	3.7	3.3	3.5
Alfalfa rotation on soil 4	Hay	40.8	41.3	41.7	40.0	41.3	41.7	39.2	41.3
	Barley	2.7	2.8	2.8	2.8	2.6	2.7	2.5	2.6
Barley on soil 1	Barley	44.2	46.1	45.6	46.1	40.3	43.2	---	41.3
Barley on soil 2	Barley	38.4	39.8	39.4	40.3	35.0	36.0	33.6	34.6
Barley on soil 3	Barley	31.7	33.1	32.6	32.6	29.3	29.8	27.4	28.8
Barley on soil 4	Barley	23.0	23.5	23.5	23.5	22.6	23.0	21.6	22.1
Corn silage on soil 1	Silage	454.0	470.0	470.0	470.0	440.0	440.0	---	412.0
Corn silage on soil 2	Silage	398.0	406.0	406.0	406.0	390.0	420.0	380.0	372.0
Corn silage on soil 3	Silage	326.0	340.0	340.0	340.0	320.0	340.0	320.0	308.0
Sugar beets on soil 1	Beets	418.0	452.0	452.0	420.0	---	---	---	---
Sugar beets on soil 2	Beets	378.0	406.0	406.0	380.0	---	---	---	---
Sugar beets on soil 3	Beets	326.0	340.0	340.0	330.0	---	---	---	---
Dry land wheat	Wheat	6.54	6.54	6.48	6.60	5.10	6.60	6.60	6.60
Irrigated pasture	Pasture	7.0	7.0	7.1	6.9	7.0	6.9	6.7	7.0

[a]Output is in hundredweight per acre. AUMs per acre for pasture.

Source: Calculated from information published in Anderson et al. (1973).

sugar beets can only be produced where significant amounts are currently produced (regions 1 through 4).

The range AUM costs as detailed by McArthur, Nielsen, and Andersen (1973, p. 24) were the basis for the range production costs. Since the AUM costs were shown for 1966, they were updated to 1973 using a production cost index calculated from cost indexes published in the annual summaries of Agricultural Prices (U.S. Department of Agriculture, 1960-1972, 1973-1974). Grazing fees used are an average of the current (1974) grazing fees charged by the Bureau of Land Management and the National Forest Service. All costs are included except management costs and the opportunity costs of capital and private land.

The net nonfeed production costs and primary product outputs for the livestock enterprises are listed in Table 5. Since nonfeed production costs are net of the value of secondary products, both primary and secondary product determination will be described here. The costs are developed from budgetary data in the sources listed. Since the years in which the budgets were obtained differ for the different enterprises, all costs were updated to the present using the production cost indexes described above. The costs shown include all costs except feed, management, and the opportunity costs of capital. Labor costs were included at the rate of $2.00 per hour.

The secondary products of the beef cow/calf activity included a percentage of the herd cull cows, heifers, and bulls. The assumed calving rate is 92 percent yearly, and an additional 2 percent die during the year leaving 0.9 calf per cow. Of this, 0.2 calf per cow is kept for yearly herd replacements to replace cows that are culled or die or are lost during the year. This leaves 0.7 calf per cow to be

Table 5. Net[a] nonfeed production costs per unit[b] and primary product output of the animal enterprises

Enterprise	Unit	Costs	Output per unit
Beef cow/calf	1 cow	$54.73	280.0 lbs. backgrounder calf (liveweight)
Beef background feeding	1 back-grounder	22.64	640.25 lbs. feeder calf (liveweight)
Finish beef feeding	1 feeder	19.56	1,034.25 lbs. fed beef (liveweight)
Turkey production	1 turkey	1.35	20.25 lbs. turkey (live-weight)
Dairy production	1 cow	266.30	11,500 lbs. milk
Dairy with construction	1 cow	426.30	11,500 lbs. milk
Swine production	1 sow	212.28	3,115.2 lbs. fed hog (liveweight)
Range sheep production	1 ewe	14.73	63.0 lbs. lamb (liveweight)

[a]Total nonfeed production costs for the production period minus the value of secondary products.

[b]For the complete definition of one unit of each animal enterprise see pages 31 and 34.

Source: Calculated from budgets and data in Christensen, Davis, and Richards (1973, pp. 43-46), Capener, Gorman, and Green (1973), Brown, Gorman, and Dawson (1973), Taylor et al. (1970, p. 77), Blackham (1973), Utah Agricultural Statistics (1973), U.S. Department of Agriculture (1960-1972, 1973-1974), and Successful Farming (Planting Issue, 1974, p. D8).

sold, and since it is assumed that a beef calf is raised to 400 pounds, the primary product of the enterprise is 2.8 hundredweight (cwt.) of beef calf per cow.

The beef backgrounding enterprise produces no secondary products. The assumed death rate of animals in this enterprise is 1.5 percent, so for every one unit of input (400 pound calf) this activity produces 0.985 unit of a 650 pound beef calf, or 6.4025 cwt., as the primary output.

Finish beef feeding produces no secondary products, and the assumed death rate of animals in this activity is also 1.5 percent. Therefore, for every 650 pound unit of animal input, 0.985 unit of a 1050 pound fed beef (10.3425 cwt.) is output.

The turkey enterprise produces no secondary products, and it is assumed that 10 percent of the turkeys fed die before marketing. For every poult input, then, 0.9 turkey is output, and since the average weight of turkeys produced is 22.5 pounds, this equals 0.2025 cwt.

The secondary products of the dairy enterprise include a percentage of the dairy calves produced (a 96 percent calving rate is assumed), and a percentage of the herd's cull dairy cows. The primary product of the producing milk cow is 11,500 pounds of milk per year.

The secondary products of the swine activity are percentages of the culled herd sows and boars. It is assumed that a sow produces 2.3 litters per year, bearing 10 live pigs per litter and raising 7 pigs per litter to weaning time. A herd is assumed to average 90 percent producing sows and 10 percent nonproducing sows. On the average, this means a sow produces 14.49 pigs per year. Since it is assumed that a sow must be replaced every three years, each sow must contribute 0.33

replacement gilt to the herd each year. This leaves 14.16 market hogs to be sold per year. Assuming a market weight of 220 pounds per hog, the primary swine enterprise output per sow is 31.152 cwt. of fed swine.

The secondary range sheep enterprise products include one 10.5 pound wool fleece per year per ewe, and a percentage of the cull herd ewes. It is assumed that a 92 percent lamb crop is saved until docking each year, and that 6 percent of those lambs die before marketing. Assuming that an annual herd replacement ratio of 17 percent is made up from lambs produced in the herd, 0.7 lamb per ewe remains to be sold. Since these range-fattened lambs average 90 pounds each, the primary output per ewe is 0.63 cwt. of lamb.

The dairy with construction enterprise is the same as the basic dairy activity except that the estimated costs per cow of constructing new facilities are added to the production costs. This allows for dairy to be produced in the model, if it is profitable, after the present facility limits are met.

It will be noted that the beef cow/calf, swine, and range sheep enterprises are defined to have internal replacement, that is, a portion of each year's offspring are retained in the herd to replace production animals that die or are sold. In order to avoid favoring the other enterprises, they too must provide for the replacement of the production unit. In the turkey and dairy enterprises, the current costs of buying replacement animals are included as part of the costs of production. That is, part of the turkey production cost is the cost of buying the poult, and since it is assumed that a dairy cow is replaced every three years, one-third of the cost of buying a dairy replacement heifer is included in the yearly dairy cow production cost. The positive constraints on the beef backgrounding and finish feeding rows insure that those activities are not produced unless the calf for backgrounding or feeder for finishing is first either purchased or produced. Thus, all livestock enterprises are placed on an equal replacement basis.

Table 6 lists the amount of each type of land in each region which can be used for production, as calculated from data in Anderson et al. (1973). Since irrigated pasture is the only crop grown on irrigated land poorer than class 4, the acreage of that type of land available in each region is input in the model as the upper bound for the pasture production activity in that region. The number of acres of land available for dry land wheat production is the total of the acres of hay, wheat, and barley presently grown on nonirrigated ground. This acreage is input as an upper bound on dry land wheat production by region.

The fact that Bureau of Land Management (BLM) and Forest Service (FS) grazing data is accumulated on a regional or forest basis, and that those regions are not delineated along county boundaries made the calculation of available AUMs of range by multi-county regions very difficult. Data published by the BLM and FS, as well as information received by telephone and mail communications with State BLM and FS officials, was used in estimating the total number of AUMs currently available in each production region. The number of acres of private, state, and Indian lands used for grazing in the state was obtained from Soil Conservation Service data (U.S. Department of Agriculture, SCS, 1972). Since the acres of land per AUM by region on the public land had been determined, it was assumed that those figures would be the same on the private lands and available AUMs of private range by region were calculated. The approximate percentages of AUMs used by sheep and cattle by region were

Table 6. Available land and range resources by region

Type of Land	Unit (times 1000)	Region 1	2	3	4	5	6	7	8
Class 1	Acres	16.4	29.4	7.8	10.0	0.4	3.5	0.0	1.6
Class 2	Acres	80.7	51.9	13.3	43.3	196.6	64.5	56.1	29.1
Class 3	Acres	87.8	27.1	31.0	87.8	98.8	43.8	83.0	32.1
Class 4	Acres	63.6	10.3	14.8	42.3	13.9	10.7	50.1	10.0
Poorer than class 4	Acres	18.5	5.3	4.1	10.5	14.4	0.9	28.6	14.6
Dry land	Acres	147.8	11.0	23.2	13.5	26.3	2.5	1.0	17.6
Public cattle range	AUMs	53.0	4.0	37.0	61.0	283.0	338.0	83.0	236.0
Private cattle range	AUMs	85.0	52.0	29.0	168.0	162.0	158.0	82.0	175.0
Public sheep range	AUMs	75.0	4.0	57.0	58.0	208.0	58.0	110.0	106.0
Private sheep range	AUMs	115.0	67.0	28.0	192.0	91.0	33.0	91.0	118.0

Source: Calculated from data published in Anderson et al. (1973) for land resources and from data from Cliff (1973), Nielsen (1973), and McArthur, Nielsen, and Andersen (1973, p. 58) for the range resources.

determined from BLM and FS data, and those percentages were applied to the total public and private range AUM figures to estimate the AUMs in each region and range type (public or private) which were available for sheep and which were available for cattle. The total AUMs for each range type in each region are input in the model as upper bounds on the range utilization activities.

Since sugar beet production has been declining over the past several years, and since only one processing plant remains open in the state, it is assumed that sugar beets can only be grown in the approximate current amount and location pattern. Therefore, they are assumed to be produced only in regions 1, 2, 3, and 4. The upper bounds of acres available for sugar beet production by region and soil class are shown in Table 7.

Table 8 summarizes the normalized (as explained) prices in the 17 consumption regions for the agricultural products produced in Utah. Since the prices used in normalizing are average state prices, the prices for regions 1 through 8 (the Utah regions) are the same. All prices are presented on a hundredweight basis since that is how they are handled in the model. The sugar beet price includes the average payment to farmers under the Sugar Act. It is assumed that all sugar beets are sold to the processing plant in the state. The milk price used in this study is the average price for all milk sold.

The question of which rates to use in determining product transportation costs between regions was a major one. Distance is a major factor in total transportation costs, but generally there are other determinants as well, such as road conditions and back-haul availability. The transportation rate problem is a major study in itself, and could

Table 7. Upper bounds of acreages available for sugar beet production by regions

	Region			
Soil class	1	2	3	4
1	1,700	2,000	700	400
2	5,900	2,600	800	1,800
3	7,000	1,600	1,900	1,900

Source: Calculated from data published in Anderson et al. (1973).

Table 8. Normalized price of agricultural products in the consumption regions[a]

Product	Region 1-8 Utah	9	10	11	12	13	14	15	16	17
Alfalfa	$1.66	$1.86	$1.94	$1.76	$1.58	$1.74	$1.84	$1.93	$1.24	$1.78
Barley	2.83	2.83	3.23	3.06	2.54	2.92	3.02	2.42	2.25	2.29
Wheat	2.88	3.30	3.07	2.92	2.80	2.68	2.88	2.95	2.85	2.80
Sugar beets	.98	---	---	---	---	---	---	---	---	---
Calves	42.20	41.00	40.10	42.40	44.81	44.90	42.05	43.30	43.11	43.07
Background calves	37.53	36.86	37.06	38.01	39.07	39.74	38.10	39.07	38.32	36.81
Fed beef	34.70	34.35	35.22	35.34	35.58	36.60	35.70	36.50	35.40	33.00
Turkeys	25.60	26.10	24.90	25.50	25.40	26.90	28.60	24.90	24.60	27.50
Milk	6.14	6.48	5.82	6.31	6.00	7.09	7.22	7.13	5.75	7.05
Hogs	25.90	27.45	27.37	26.70	26.43	27.40	27.75	27.00	27.31	27.25
Lambs	29.70	29.90	31.10	30.30	30.65	32.80	31.60	30.40	31.04	30.40

[a]Price in dollars per hundredweight. Liveweight for animals.

Source: Calculated from data published in Agricultural Prices (U.S. Department of Agriculture, 1960-1972, 1973-1974), and Utah Agricultural Statistics (1973).

not be handled in this thesis. It was determined that the use of available or readily calculable rate formulas for each product with mileage as the variable factor so as to be universally applicable to transportation between all regional centers would best suit the purposes of this study.

The formulas for calculating transportation costs of feed grains and live animals were developed from waybill and tariff data by Dietrich (1970), and used by Grimshaw (1972). The formula Dietrich developed for transporting live cattle by truck was used in this study to determine transportation costs for cattle, sheep, and hogs, and is as follows:

$$y = 0.10609156 + 0.001911109x + 0.004550354 \sqrt{x}$$

where y is the transportation cost in dollars per hundredweight and x is the number of miles between regions.

The formula for feed grain is:

$$y = 0.090628326 + 0.00049126094x$$

where y is the transportation cost in dollars per hundredweight and x is the number of miles between regions.

The rate formula for the transportation of bulk milk was derived from information provided in January, 1974 by Western General Dairies in Ogden, Utah, a firm which handles much of the intra- and interstate transportation of bulk milk produced in the state. They provided information about the actual current costs incurred in the transportation of bulk milk, and from that information the following formula was developed:

$$y = 0.14 + 0.0018x$$

where y is the transportation costs in dollars per hundredweight and x is the number of miles between regions.

It was determined that the best way to determine the transportation costs of baled alfalfa hay was to obtain information about the current rates being charged by hay transporters. Telephone contact was made with many people engaged in the hay transportation business in Utah and Idaho and data was gathered for costs of transporting hay between areas within Utah, from areas in Idaho to Utah, and from areas in Utah to Nevada. From this data the following general hay transportation formula was developed:

$$y = 0.25 + 0.0015x$$

where y is the transportation costs in dollars per hundredweight and x is the number of miles between regions.

Information provided by the Ogden Poultry Company in March, 1974 led to the development of the formula for transporting turkeys:

$$y = 0.0022x$$

where y is the transportation costs in dollars per hundredweight and x is the number of miles between regions.

Since sugar beets were transported only between the four regions where they were grown and the Garland processing plant, data for rates charged for transporting beets from the regional centers to the factory was obtained by telephone contact with the Union Pacific Railroad Company. An official at the factory in Garland indicated that the sugar company pays transportation costs up to $2.00 per ton, so only those costs above that amount were included in the matrix coefficients.

Since it was assumed in the model that one region could use the range that was produced in another region if that arrangement contributed to the most profitable solution, it was necessary to determine the "range transportation costs", that is, the costs of one region moving its animals to and from the available range of another region. In February, 1974, telephone contact was made with a few of the trucking companies in the state that haul animals to range sites, and data on their rate schedules was collected. Using the data they provided and an approximate average weight of cow/calf and ewe/lamb pairs, and assuming that animals which were trucked to a range site could utilize that range for four months on BLM range and five months on FS range, the following "range transportation formulas" were developed:

for cattle

$$y = 0.01542x$$

for sheep

$$y = 0.01127x$$

where y is the transportation cost in dollars per AUM of range used

and x is the number of miles between regions.

It should be noted that all animals are transported on a liveweight basis. This was done because the normalized prices used in the model, and thus the demand for the product in each region, is on a liveweight basis. This also avoids the problem of having to determine the availability and location of local slaughtering facilities. Although it is unrealistic to assume that some of the animals will be transported live over very great distances, that assumption makes transportation rates for all products on the same basis possible. It is expected that should all products be converted to a carcass basis for transportation purposes, the approximate relative rates between products and regions would be about the same as the liveweight basis.

The figures for the product consumption constraints used in the intrastate consumption regions were calculated from average per capita consumption figures for products as listed in the National Food Situation (U.S. Department of Agriculture, ERS, 1973, p. 15), and from regional population figures obtained from county population data as of January 1, 1973 published by the Rand McNally Corporation (1973a). Consumption figures for meats are converted to a liveweight basis. The wheat constraints were based on the consumption of wheat and wheat cereals, and milk consumption constraints included milk and milk products.

The objective function of the linear programming model is to maximize the profits of Utah agricultural producers by using the available resources to produce the defined activities. The program will choose the most profitable activities. Without any other constraints the most profitable activity and those activities which are auxiliary to the production of that most profitable activity will be the only activities produced. Since in crop production many activities will not yield consistently well unless grown in rotation with other crops, and since in both crop and livestock production institutional constraints are important, the use of additional constraints is necessary to insure that a realistically unobtainable solution is avoided.

Some of these constraints have already been mentioned, such as the limits on dairy production without a dairy construction enterprise, and the requirement that alfalfa must be brought into production with a nurse crop of barley, and replaced in the same way after five years of production. In addition, to insure that crops are grown in a rotational pattern, constraints were placed on the maximum and minimum amounts of each field crop which could be grown on each soil class in each region.

These constraints were based on current levels of production, importance to other activities, and production trends. The upper bounds on sugar beet, wheat, and pasture acreages have already been outlined, and no lower bounds were specified for those activities. In addition, it was assumed that a maximum of 75 percent and a minimum of 25 percent of the acreage of each soil class in each region could be used in the production of alfalfa hay. Barley production was constrained to use between 5 percent and 50 percent of each soil class in each region, and corn silage was constrained to be produced on between 2 percent and 40 percent of the class 1, 2, and 3 soils and not to be grown on class 4 soil in each region.

It was decided that each livestock enterprise should have an input upper bound on production activities in each region. Since hogs, turkeys, and fed beef are very dependent on feed grains, their activity bounds were based on the amount of feed grain that could be produced in the region where the livestock activity was being produced. The maximum amount of barley and feed wheat that could be produced in a region was calculated using the acreage and rotation constraints and regional yield data. The total amount of metabolizable energy available in this amount of grain was then calculated. It was assumed that each of the three mentioned livestock enterprises could use a maximum of 50 percent of the total amount of energy available in the feed grains, so the total available ME was divided by two and that figure was divided by the energy requirements of one unit of the livestock activity to give the approximate upper bound of that livestock activity in that region.

It was assumed that 1,500,000 range sheep activity units could be produced in the state. This total was divided regionally in the approximate same proportion as exists in present range sheep production. An assumed total of 1,000,000 units of beef cow/calf activity producible in the state was divided regionally in the same proportion as present production. It was assumed that the backgrounding enterprise would be bounded so that it could produce no more units of activity than were produced by the cow/calf enterprise. The dairy enterprise was constrained to the number of dairy cows currently produced in each region plus 15 percent. The dairy construction enterprise was constrained to two times the primary dairy constraint.

In all cases, these constraints allow more units of each enterprise activity to be produced than is currently being done. Although these constraints are rather arbitrary, they do constrain the model to a realistic solution while allowing the basic comparative advantage positions of the regions and enterprises to be shown.

As has been mentioned, a constraint was included in the model to insure that enough feed was produced to provide for animals which were exogeneous to the model. These exogeneous requirements were specified for feed grains and roughages. The animal activities which were included exogeneously were: heifers and heifer calves kept as dairy heifer replacements, sheep and lambs on feed, horses and mules, hens and pullets, chickens raised for replacements, and broilers produced. Estimates of the number of these animals and their requirements were derived from Savelli C. (1972).

RESULTS AND ANALYSIS

The results presented in this chapter are derived from the optimal solution to the linear programming model which was set up as described using the data that was prepared as outlined. Because of the large size of the model, it was quite expensive to obtain the optimal solution, so most of the sensitivity analysis was obtained by using the reduced cost and dual information provided by the primal computer output, and by using the ranging procedure on pertinent activities and constraints. Another run of the entire model using less restrictive upper bounds on livestock enterprise activities provided additional information on the comparative advantage of livestock enterprises in using available resources. Using parameterization procedures on a single region provided a valuable sensitivity analysis on enterprises in that region, and it is expected that the results obtained in that region would be generally applicable to enterprises in the other production regions.

Care should be taken to properly analyze the results of the model. All of the assumptions used in building the model need to be regarded in interpreting the output of the linear program. It is especially important to recognize that the optimal solution is a maximization of net revenue to agricultural producers in the entire state. Were each producing region to be analyzed separately and individual regional optimal solutions to be found, the results would be expected to differ somewhat from the overall solution.

The optimal crop enterprise production pattern by region is shown in Table 9. Table 10 presents the number of units of each livestock

Table 9. Crop enterprise production in the optimal solution

Crop Enterprise	Unit	Production region							
		1	2	3	4	5	6	7	8
Alfalfa rotation	Acres	78,025	32,250	20,425	56,425	80,900	34,682	59,825	20,700
Barley	Acres	100,609	56,422	25,255	86,050	150,281	43,430	73,735	26,980
Sugar beets	Acres	14,600	6,200	3,400	4,100	---	---	---	---
Dry land wheat	Acres	157,800	11,000	23,200	13,500	26,300	2,500	1,000	17,600
Irrigated pasture	Acres	18,500	5,300	4,100	10,500	14,400	900	28,600	14,600
Public cattle range used	AUMs	53,000	4,000	37,000	61,000	283,000	338,000	83,000	236,000
Private cattle range used	AUMs	85,000	52,000	29,000	168,000	162,000	158,000	82,000	175,000
Public sheep range used	AUMs	0	0	0	0	0	0	0	0
Private sheep range used	AUMs	0	0	0	0	0	0	0	0

Table 10. Livestock enterprises produced and feeds fed in the optimal solution

Region 1 Enterprises	Number produced (1,000 units)	Feeds fed (1,000 cwt. or 1,000 AUMs)[a] Barley	Alfalfa	SOM	Wheat	Corn Silage	Oats	Corn	Pasture	Public Range	Private Range
Turkeys	2,300.0	1,809		214							
Dairy	27.2	2,597	2,791			7,597					
Dairy (construction)	54.4										
Cow/calf	92.7		757			10,245			130	53	19
Background feeding	180.0	1,233	360			3,338					
Finish feeding	73.0	1,767	442								
Swine	15.0			173	909		700				
Sheep	0.0										
Region 2											
Turkeys	1,300.0	1,023		121							
Dairy	11.1	1,058	1,137			3,095					
Dairy (construction)	22.2										
Cow/calf	50.0		500			6,253			37		9
Background feeding	50.0	300	387			513					
Finish feeding	40.0	968	242								
Swine	9.0			133	848						
Sheep	0.0										

Table 10. (Continued)

Region 3 Enterprises	Number produced (1,000 units)	Feed fed (1,000 cwt. or 1,000 AUMs)[a]									
		Barley	Alfalfa	SOM	Wheat	Corn Silage	Oats	Corn	Pasture	Public Range	Private Range
Turkeys	650.0	511		61							
Dairy	5.4	512	550			1,497					
Dairy (construction)	10.7										
Cow/calf	40.0		371			4,652			29	10	29
Background feeding	40.0	266	132			667					
Finish feeding	20.0	484	121								
Swine	5.0			64	368		143				
Sheep	0.0										
Region 4											
Turkeys	1,700.0	1,337		158							
Dairy	14.0	1,333	1,433			3,901					
Dairy (construction)	27.9										
Cow/calf	90.0	743				9,480			72	61	106
Background feeding	70.9	402	704			503					
Finish feeding	53.0	728	314					529			
Swine	11.0			148	887		207				
Sheep	0.0										

Table 10. (Continued)

Region 5 Enterprises	Number produced (1,000 units)	Feeds fed (1,000 cwt. or 1,000 AUMs)[a]									
		Barley	Alfalfa	SOM	Wheat	Corn Silage	Oats	Corn	Pasture	Public Range	Private Range
Turkeys	2,900.0	2,281		270							
Dairy	9.1	873	939			2,555					
Dairy (construction)	18.3										
Cow/calf	220.0		1,991			24,411			101	215	162
Background feeding	204.0	1,208	1,689			1,935					
Finish feeding	89.0	2,154	539								
Swine	19.0			281	1,790						
Sheep	0.0										
Region 6											
Turkeys	1,150.0	905		107							
Dairy	7.0	666	716			1,949					
Dairy (construction)	14.0										
Cow/calf	138.0		1,147			13,523			6	296	158
Background feeding	96.6	661	193			1,791					
Finish feeding	35.0	352	206					471			
Swine	8.0			118	754						
Sheep	0.0										

Table 10. (Continued)

Region 7 Enterprises	Number produced (1,000 units)	Feeds fed (1,000 cwt. or 1,000 AUMs)[a]									
		Barley	Alfalfa	SOM	Wheat	Corn Silage	Oats	Corn	Pasture	Public Range	Private Range
Turkeys	1,500.0	1,180		140							
Dairy	5.9		792			1,298		523			
Dairy (construction)	11.8										
Cow/calf	139.2		1,140			15,392			192	28	82
Background feeding	160.0	544	644			2,461		481			
Finish feeding	46.0	463	271					619			
Swine	10.0			148	942						
Sheep	0.0										
Region 8											
Turkeys	650.0	511		61							
Dairy	1.2		164			268		108			
Dairy (construction)	2.4										
Cow/calf	93.6		522			7,210			102	205	175
Background feeding	78.0	495	417			1,070					
Finish feeding	20.0	201	118					269			
Swine	5.0			74	471						
Sheep	0.0										

[a]Hundredweight for barley, alfalfa, soybean oil meal (SOM), wheat, corn silage, oats, and corn. AUMs for pasture and range. Feed figures rounded to nearest thousand.

enterprise produced in each region and shows the kind and quantity of feeds used to produce each activity. Figures 4 through 9 outline the marketing pattern for the products which are produced and sold to the interstate regions by the intrastate production regions. The quantities within the parenthesis indicate the amounts of products which are exported from each production region. Table 11 presents the amounts of intermediate feeds which are purchased by each of the production regions in the optimal solution. A region by region analysis of the data in the tables and other relevant information from the output of the program is presented below. The livestock production costs referred to in this analysis are nonfeed production costs.

Region 1

The crop enterprise use of the land resource is shown in Table 9. Alfalfa is produced at the lower limits on class 1, 2, and 3 soils and at an intermediate level on class 4 soil. (The limits are the input upper and lower acreage bounds which have been explained.) Barley is produced at intermediate levels on class 1, 2, and 3 soils and at the upper limit on class 4 soil. Pasture, wheat, and sugar beets are produced at their upper limits while corn silage is produced at the upper limits on soil classes 1 and 2 and at an intermediate level on soil class 3. Public and private cattle range is utilized at the upper limits and no sheep range is used. If bounds were relaxed, an additional acre of class 1 soil would be used first by the sugar beet enterprise, next by barley, then corn silage, and lastly by alfalfa. An extra acre of class 2 land would follow the same priority list, while the class 3 soil would be used in this order: sugar beets, corn silage, barley, and

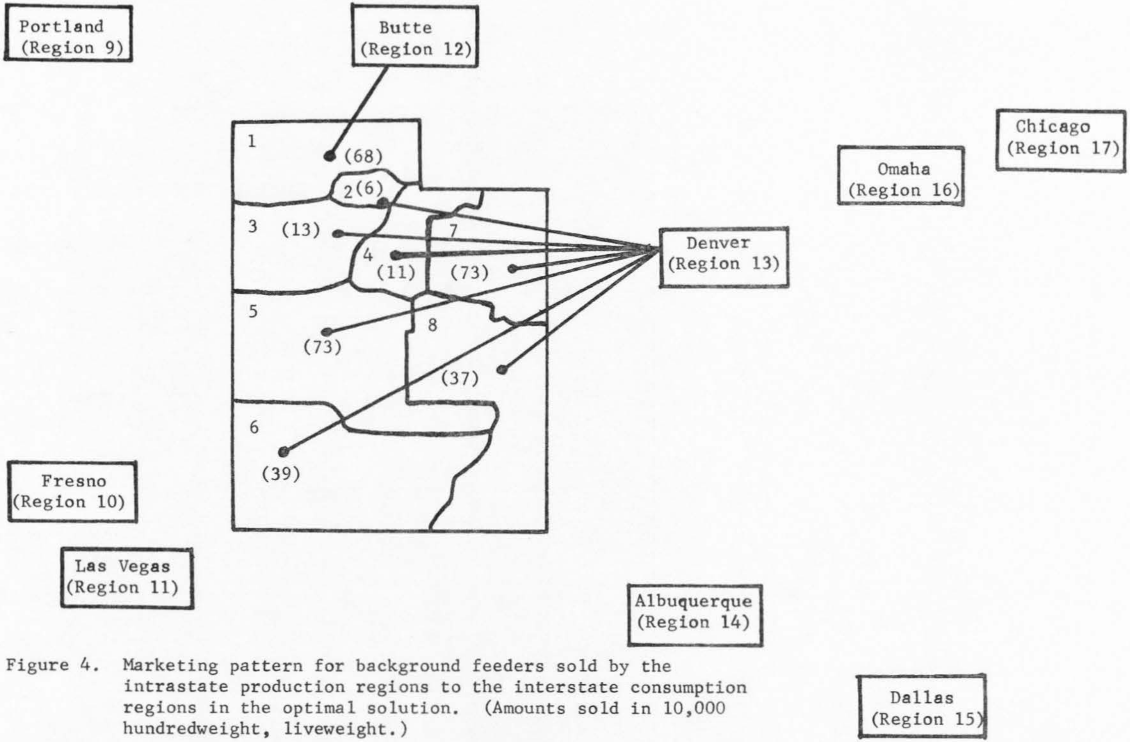

Figure 4. Marketing pattern for background feeders sold by the intrastate production regions to the interstate consumption regions in the optimal solution. (Amounts sold in 10,000 hundredweight, liveweight.)

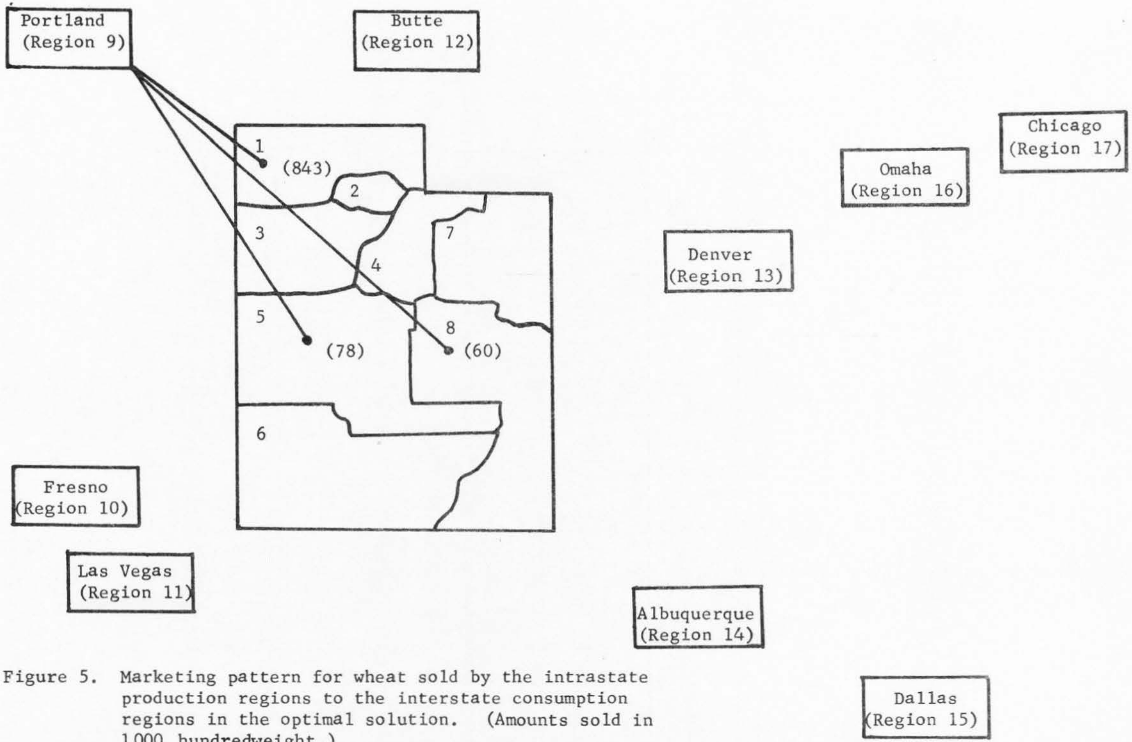

Figure 5. Marketing pattern for wheat sold by the intrastate production regions to the interstate consumption regions in the optimal solution. (Amounts sold in 1000 hundredweight.)

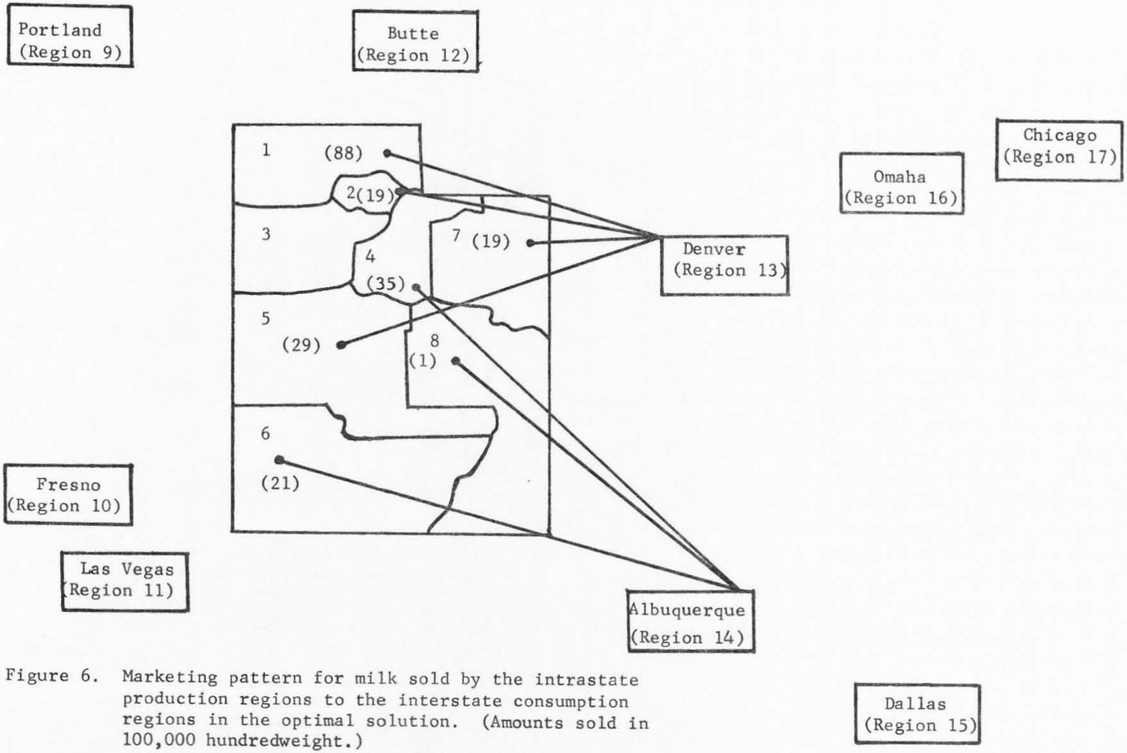

Figure 6. Marketing pattern for milk sold by the intrastate production regions to the interstate consumption regions in the optimal solution. (Amounts sold in 100,000 hundredweight.)

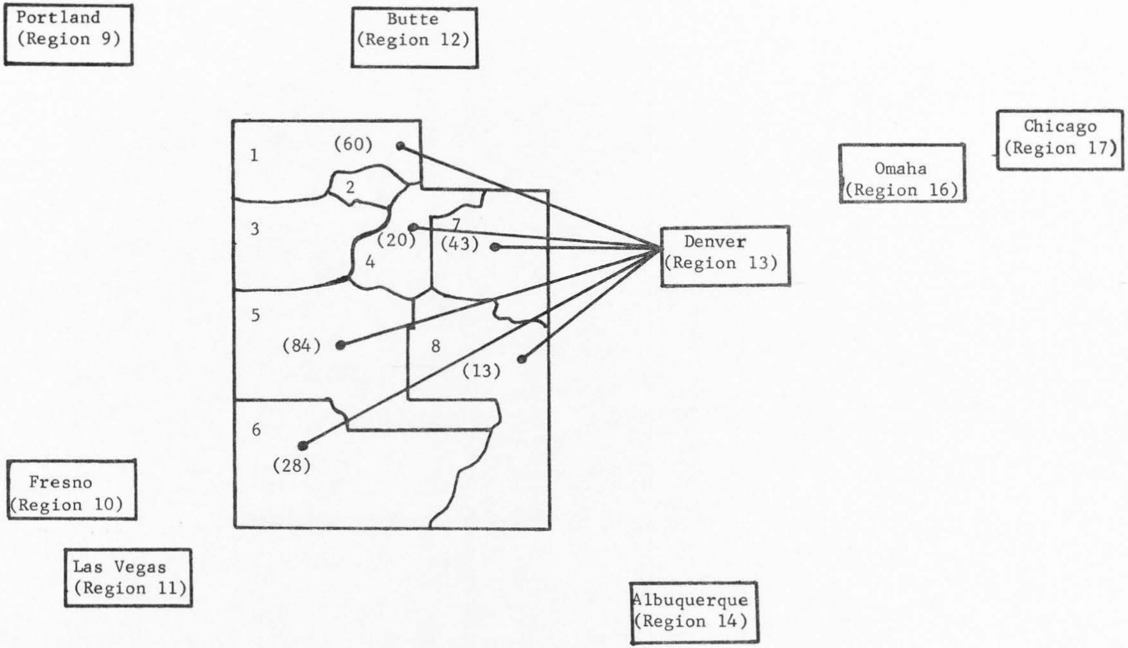

Figure 7. Marketing pattern for fed beef sold by the intrastate production regions to the interstate consumption regions in the optimal solution. (Amounts sold in 10,000 hundredweight, liveweight.)

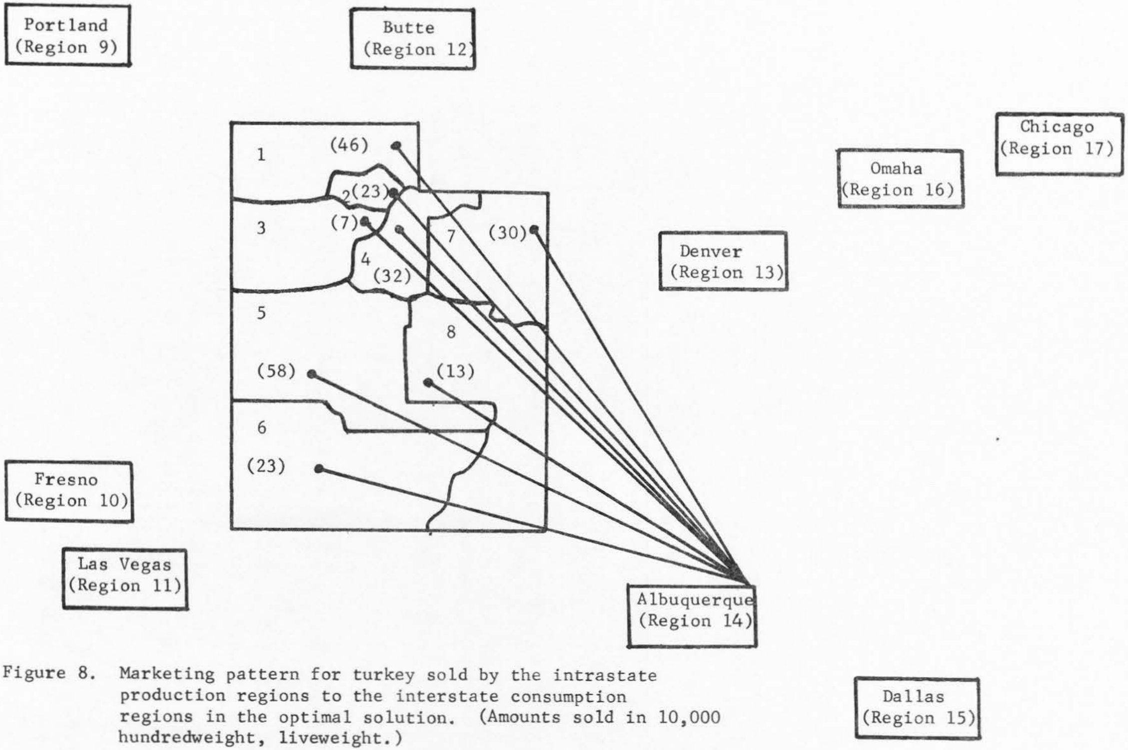

Figure 8. Marketing pattern for turkey sold by the intrastate production regions to the interstate consumption regions in the optimal solution. (Amounts sold in 10,000 hundredweight, liveweight.)

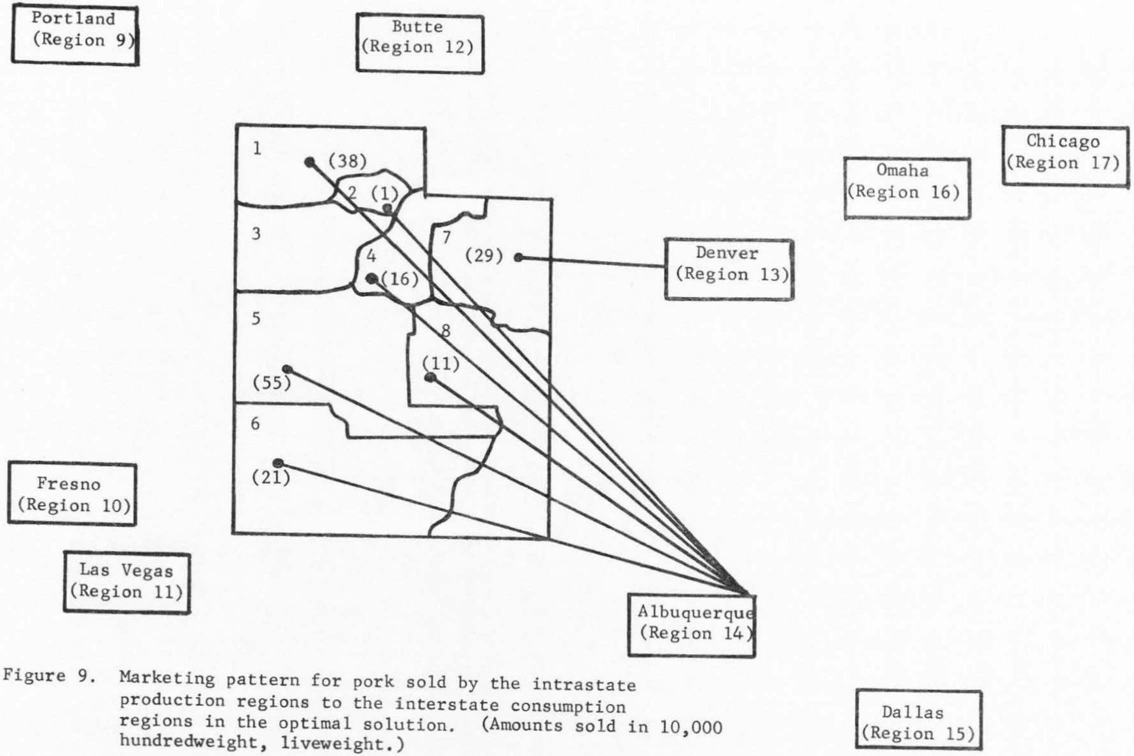

Figure 9. Marketing pattern for pork sold by the intrastate production regions to the interstate consumption regions in the optimal solution. (Amounts sold in 10,000 hundredweight, liveweight.)

Table 11. Amounts of feeds purchased by the production regions in the optimal solution

Region	Feeds purchased (cwt.)					
	Barley	Alfalfa	SOM	Feed Wheat	Oats	Corn Grain
1	4,604,019	---	387,100	806,262	700,000	---
2	1,512,249	---	254,431	840,573	---	---
3	1,382,871	---	124,538	353,165	142,901	---
4	1,631,524	---	306,719	878,292	207,099	528,686
5	1,908,244	---	551,631	1,776,218	---	---
6	1,326,907	---	114,643	751,921	---	471,314
7	516,740	---	287,879	941,304	---	1,622,699
8	614,195	---	134,618	459,366	---	377,301

alfalfa. Another acre of class 4 soil would first be used by alfalfa and then by the barley enterprise.

As shown in Table 10, turkeys are produced in region 1 in an amount equal to the input upper limit, and are fed barley and soybean oil meal (SOM). This enterprise is not very sensitive to nonfeed production cost decreases as a decrease of 42.8 percent in those costs would only increase production by less than 1 percent. However, an increase of 42.8 percent in those costs would decrease production by 54.5 percent.

Both the dairy and dairy with construction enterprises are produced at their upper allowable limits using barley, alfalfa hay, and corn silage as feeds. An 85.6 percent reduction in nonfeed production costs would only increase dairy enterprise production 1.7 percent, whereas an 85.6 percent increase in costs would decrease production 34.1 percent. The dairy construction enterprise would increase 0.8 percent with a 16.0 percent decrease in production costs and decrease 17.0 percent with a 16.0 percent increase in costs.

The cow/calf enterprise is produced at an intermediate level in region 1 using alfalfa, corn silage, pasture, and public and private range. This enterprise is quite input cost sensitive. A cost decrease of $1.72 per production unit would cause only a slight production increase. An increase of 9 cents in costs per production unit would decrease production of this enterprise 3.4 percent.

Background beef feeders are produced to their upper limit using barley, alfalfa, and corn silage. An increase in costs of only 54 cents per unit of production would decrease this enterprise's activity 9.5 percent. Fed beef are also produced at their upper limit using barley and alfalfa. An increase of 69.0 percent in fed beef production costs would decrease production 71.7 percent.

The swine enterprise is produced at its upper limit using wheat, oats, and SOM, and is very input cost stable. An increase of 59.5 percent in production costs would decrease swine enterprise production only 7.3 percent. Region 1 produced no sheep, and would produce none even if production costs decreased by 27 percent.

Given the costs and prices and other data used in the model, it is profitable for region 1 to produce all of the defined consumption products used in the region with the exception of lamb. Although selling activities were defined for the sale of alfalfa, barley, and wheat feed produced in the producing regions, in all cases it was more profitable for the regions to use those products in livestock production than to sell them.

As has been stated, it is assumed that final products produced in a region are sold first in that region until consumption constraints are met, and then any surplus products can be sold to other consumption regions. Figures 4-9 show those selling activities. It is seen that region 1 sells surplus consumer wheat to consumption region 9 (Portland). Surplus turkey produced in region 1 is sold to region 14 (Albuquerque). Given the normalized product prices and transportation costs, turkey price would have to increase by 10.8 percent in region 10 (Fresno) or by 5.1 percent in region 17 (Chicago) before surplus turkey produced in region 1 would be shipped to those regions. Surplus milk produced in region 1 is sold to region 13 (Denver). A 2 cent per cwt. increase in milk price in production/consumption region 3 would mean that surplus milk produced in region 1 would go to region 3, which is deficient in milk. A 0.6 percent increase in milk price in region 14 would make that region competitive for region 1 surplus milk. It would take a 13.9 percent increase in milk prices in region 9 or a 31.4 percent increase in region 10 before surplus milk would be sent to those regions from region 1.

Surplus fed beef produced in region 1 was sold to region 13 in the model. A price increase of 0.6 percent in region 2 or 0.8 percent in region 3 would induce surplus fed beef to those intrastate consumption regions from region 1. Fed beef prices would have to increase 5.9 percent in region 9, 4.1 percent in region 10, 0.2 percent in region 12 (Butte), or 2.8 percent in region 15 (Dallas) before surplus fed beef produced in region 1 would go to those regions.

According to the model, surplus pork produced in region 1 should be sold to consumption region 14. It would take a 1.1 percent increase in pork prices in region 3 to induce importation of region 1 surplus pork. It would take only a very slight relative change in pork price in region 13 to make region 1 pork sales to that region feasible. Surplus background beef feeders produced in region 1 are sold to region 12, while a small relative price increase in region 13 would mean region 1 would sell backgrounders there.

If one additional unit of each livestock enterprise in region 1 were allowed to enter the optimal solution, the enterprise which would contribute the greatest net revenue to the objective function is dairy. The other enterprises would follow in this order: swine, dairy with construction, finish beef feeding, beef cow/calf, turkeys, background beef feeding, and finally sheep.

Region 2

In region 2, alfalfa was produced at the lower limits on class 1, 2, and 3 soils and at an intermediate level on class 4 soil. An intermediate level of barley was produced on class 1 soil, and it was produced at the upper acreage limits on class 2, 3, and 4 soils. Again sugar beets were grown on the maximum allowable number of acres on soil classes 1, 2, and 3. Wheat was produced on all of the available dry land in the region, and irrigated pasture was grown on all of the acres of irrigated land poorer than class 4. Use was made of all the public and private range for cattle which was available, and no sheep range was used. If more land were available in the region, an extra acre of class 1 soil could most profitably be used by the sugar beet enterprise, then by barley, then corn silage, and finally alfalfa. An extra acre of class 2 or 3 soil could most profitably be used by the enterprises in this order: sugar beets, corn silage, barley, and alfalfa. An additional acre of class 4 soil would be used first by the alfalfa enterprise and then by barley.

Turkeys are produced in region 2 at the input upper limit, and are fed barley with SOM as a protein supplement. A 42.3 percent decrease in production costs would increase production by less than one percent, while a cost increase of the same proportions would decrease production 89.2 percent.

The dairy enterprises in region 2 use barley, alfalfa, and corn silage as feeds, and both of the dairy enterprises are produced at their upper limits. Although the per cow net profit would change if only 16 more dairy cows were produced in the region, net revenue per cow would decrease only slightly after that, and the original dairy enterprise would remain the most profitable livestock enterprise in the region. An increase in production costs of 19.9 percent would cause a decrease of 43.6 percent in the dairy construction enterprise.

The beef cow/calf enterprise in region 2 is produced at the upper limit using alfalfa, corn silage, pasture, and private cattle range. A decrease of 5.3 percent in costs would increase production only 0.1 percent, but a 5.3 percent cost increase would decrease production 18.1 percent. After beef cow/calf production had increased 0.1 percent, a slightly lower net profit per unit of production would result.

Background beef feeders are produced at the regional upper limit using barley, alfalfa, and corn silage. An 8.7 percent cost increase would cause production to decrease 18.8 percent. Fed beef is also produced at its upper limit using barley and alfalfa hay. But, if production costs increased 73.4 percent, there would be no fed beef produced in the region.

Swine are fed SOM and wheat in region 2 and are produced at the upper limit. An increase in production costs of 58.6 percent would decrease swine production in the region only 4.3 percent, while a similar cost decrease would increase production 14.4 percent.

Region 2 produced enough turkey, milk, and pork to meet the regional demand for those products in the optimal solution, but it only produced less than one-fourth of the wheat consumption limit and somewhat less than the fed beef consumption limit of the region. Surplus turkey produced in region 2 is sold to consumption region 14. If turkey prices in region 13 were only slightly higher, the surplus turkey would move there, but it would take a 10.4 percent price increase in region 10, a 4.8 percent increase in region 17, or a 12.9 percent rise in region 16 before surplus turkey would go to those regions.

Excess milk produced in region 2 was sold to region 13 in the model. If milk prices in intrastate region 3 were to rise only 0.5 percent, region 2 would sell its surplus milk there. A 0.7 percent price increase in region 14, a 13.7 percent increase in region 12, or a 10.1 percent increase in region 11 would make region 2 milk sales to those regions most profitable. But, milk would not be sold to regions 9 or 10 unless milk prices rose by 15.3 percent or 31.6 percent respectively in those regions.

There was only a small amount of surplus pork produced in region 2, and it was sold to interstate region 14. A very small pork price increase in region 13 would induce region 2 pork to be sent there, or it would require a 0.4 percent gain in region 9, a 1.5 percent advance in region 10, a 1.0 percent increase in region 11, or a 1.6 percent rise in region 12. There were some surplus backgrounders produced in region 2, and they were sold to interstate region 13.

One additional unit of the dairy enterprise would add the most net profit into the objective function with the swine enterprise yielding the second highest profit, followed by the dairy with construction enterprise. The beef feeding, cow/calf, backgrounding, turkey, and sheep enterprises follow in that order.

Region 3

Alfalfa was produced at the lower acreage limits on class 1, 2, and 3 soils and at an intermediate level on class 4 soil in region 3. Barley was produced at an intermediate level on the first three soil classes and at the maximum limit on soil class 4. Sugar beets were produced on the maximum allowable number of acres on soil classes 1, 2, and 3, and corn silage was produced at its upper limits on soil classes 1 and 2 and at an intermediate level on soil class 3. Both dry land wheat and irrigated pasture were produced on all the acres of land defined for their use. All of the cattle range useable on both public and private lands was utilized, and no range for sheep was used.

One extra acre of soil class 1 in region 3 would most profitably be used by the sugar beet activity, with the other enterprises following in this order: barley, corn silage, and alfalfa. An additional acre of class 2 and class 3 soil would most profitably be used by the enterprises in the same order. One more acre of class 4 soil would first be used by barley and then by the alfalfa enterprise.

In region 3, turkeys were produced at the input upper limit, using barley with SOM as a protein supplement. An increase in production costs of 39.9 percent would decrease regional turkey production 53.7 percent, and a similar production cost decrease would increase production 1.7 percent.

Both dairy enterprises are produced at the upper limits in region 3 using barley, alfalfa, and corn silage. Relatively large decreases in production costs would not elicit substantial increases in dairy enterprise production in the region, but if those costs increase 23.4 percent production of the dairy construction enterprise would decrease 78.6 percent.

The beef cow/calf enterprise uses alfalfa, pasture, corn silage, and public and private cattle range to produce at the upper limit. At this level of production, the cow/calf enterprise is very sensitive to changes in costs of production in region 3, as a 0.1 percent increase in those costs will cause a 19.7 percent decrease in the activity.

Background beef feeders were produced at the maximum limit using barley, alfalfa, and corn silage. Finish beef feeders were fed barley, alfalfa, and corn grain and were also produced at their upper bound. If the costs of producing backgrounders increased 40 cents per head, a 1.8 percent increase, this activity would decrease 30.0 percent. If the production costs of the fed beef producing activity were to increase 67.3 percent, there would be no fed beef produced in this region.

Swine are fed wheat, oats, and SOM and are produced at the upper limit in this region. A 57.5 percent decrease in costs would allow production to increase 25.8 percent, and a similar increase in production costs would stimulate a decline in this activity of 21.8 percent. No sheep were produced in region 3.

The only products which were produced in surplus amounts in region 3 were turkey and beef background feeders. All other products produced were sold for use or consumption within the region. Region 3 is not large, but since a big portion of Utah's population is concentrated there, product consumption constraints for products other than turkey were relatively much higher than the quantities of those products produced in the region.

The surplus turkey produced in the region was sent to region 14, and region 13 offered the next most competitive price for the product. The extra backgrounders produced in the region were sold to region 13.

If one additional unit of each livestock enterprise were allowed into the solution, the dairy enterprise would add the most net profit to the objective function. Dairy would be followed by swine, then the dairy with construction enterprise, then fed beef, turkeys, backgrounders, cow/calf, and lastly sheep.

Region 4

In this region, alfalfa was produced at the lower limits on classes 1, 2, and 3 soil in the model and at an intermediate level on class 4 soil. Barley was produced at an intermediate level on the first two soil classes and at the upper limits on soil classes 3 and 4. Sugar beets were produced at their upper limits on all three soil classes, and corn silage was grown at the upper limit on soil class 1 and at intermediate levels on class 2 and 3 soils. The maximum allowed amounts of dry land wheat, irrigated pasture, and cattle range were produced in the region and no range for sheep was utilized.

Most profitable use of an extra acre of soil classes 1 and 2 in this region could be made by the enterprises in this order: sugar beets, barley, corn silage, and alfalfa. An additional acre of class 3 soil would be first used by sugar beets, then corn silage, barley, and alfalfa. First alfalfa and then barley could most profitably utilize another acre of class 4 soil.

Turkeys were fed barley and SOM and were produced at the upper limit. A 39.3 percent increase in costs of production would decrease turkey production 94.3 percent, or a similar cost decrease would encourage a 291.1 percent activity increase, so this activity is extremely input cost sensitive in this region.

Barley, alfalfa, and corn silage were fed to dairy cattle in the region, and both dairy enterprises were produced at the upper limits. A cost increase of 21.3 percent would cause production of the dairy with construction enterprise to decrease 36.5 percent. A cost decrease of the same amount would see the activity increase 46.4 percent.

The cow/calf enterprise uses barley, corn silage, pasture, and public and private cattle range, and is produced at the upper limit. A 1.5 percent increase in production costs would cause this activity to decrease by 10.1 percent.

Background feeders are produced at an intermediate level using barley, alfalfa, and corn silage. A 0.5 percent increase in costs would mean a 7.8 percent decrease in backgrounding activities. Fed beef are produced at the regional maximum limit and are fed barley, alfalfa, and corn grain. A 65.6 percent increase in production costs would cause a production decline of 25.9 percent for this enterprise.

The swine enterprise uses wheat, oats, and SOM to produce at the upper limit. If production costs were to increase 56.1 percent, swine production in region 4 would drop 46.2 percent. Region 4 produced no sheep in the optimal solution.

Region 4 does not produce enough wheat to meet the regional consumption constraint, but all other consumer products except lamb are produced in amounts in excess of the consumption limits for the region. Surplus turkey produced in region 4 was sold to region 14. If turkey price increased slightly in region 13, 9.8 percent in region 11, or 3.8 percent in region 17, surplus turkey from region 4 would move to those regions.

Surplus milk produced in region 4 is also sold to region 14. It would require a price increase of 2.3 percent in region 3, 0.3 percent in region 13, or 9.0 percent in region 11 before the surplus milk would move to those regions. Excess region 4 fed beef is sold to region 13, and would not go to regions 10, 12, 14, or 15 unless prices rose by 3.3, 0.6, 0.8, or 2.0 percent, respectively, in those regions.

Region 14 buys the surplus pork produced by region 4. A small price change would cause the pork to go to region 13, or it would take a 7.7 percent change in region 10, a 0.4 percent change in region 11, or a 1.6 percent change in region 15 to make those regions competitive for the surplus pork. Some backgrounders produced in region 4 are sold to region 13.

If one additional unit of each livestock activity were allowed into the solution, the dairy enterprise would be the most profitable, followed by the swine, dairy with construction, fed beef, cow/calf, turkey, backgrounding, and sheep enterprises in that order.

Region 5

Alfalfa in region 5 was produced on soil classes 1, 2, and 3 at the lower limits and on soil class 4 at an intermediate level. On soil classes 1 and 2 barley was produced at intermediate levels, and on soil classes 3 and 4, it was produced at the maximum limits. Corn silage was grown on the maximum number of acres allowed on class 1 soil and at intermediate levels on class 2 and 3 soil. Pasture, dry land wheat, and public and private cattle range were all produced in amounts equal to the upper limits on their activities. No sheep range was used. One additional acre of soil class 1 land could most profitably be used by the barley, corn silage, and alfalfa enterprises in that order. An extra acre of soil classes 2 and 3 land would first be used by corn silage, then barley, and lastly alfalfa. One more acre of soil class 4 land would be used first by barley, then by alfalfa.

Barley and SOM were the feeds used in region 5 to produce turkeys at their upper limit. If costs were to increase 40.5 percent, turkey production would decrease 83.7 percent, while a cost decrease of the same amount would increase production 165.9 percent. Both dairy enterprises were produced at their upper limits using barley, alfalfa, and corn silage. A cost increase of 21.1 percent in the dairy construction enterprise would decrease its activity 67.5 percent.

The cow/calf enterprise used alfalfa, corn silage, pasture, and public and private cattle range and was produced at the upper limit. A cost increase of 13.1 percent would cause an activity decrease of 4.8 percent. Backgrounders were produced at an intermediate level using barley, alfalfa, and corn silage. While a 0.2 percent cost reduction would mean an increase in production of 33.0 percent, a 1.1 percent cost increase would bring a 17.3 percent activity decrease, so this enterprise is very sensitive to cost changes in this region. Fed beef are fed barley and alfalfa and are produced at the input upper bound. A 69.8 percent cost increase would decrease production of this activity 82.8 percent.

Swine were fed wheat and SOM and were produced at their upper limits. Swine production would decrease 93.1 percent if production costs rose 54.3 percent. Again no sheep were produced in this region.

Region 5 produced a surplus in all of the defined consumer products except lamb. The extra wheat produced in the region was sold to region 9. A 3.3 percent wheat price rise in region 10 would have caused wheat to move there from region 5, or it would have taken a 2.1 percent increase in region 11 or a 9.0 percent increase in region 14.

Surplus turkey produced in the region was sold to region 14, but a slight price increase in region 13, an 8.9 percent rise in region 10, or a 5.4 percent increase in region 17 would have caused turkey to move to those regions. Milk which was produced in excess of the consumption requirements in region 5 was sold to region 13. Milk would be sold to regions 10, 11, 14, or 15 if milk prices rose 27.0 percent, 6.0 percent, 0.7 percent, or 18.1 percent, respectively in those regions.

The extra fed beef which was produced in region 5 was sold to region 13. If prices were 2.9 percent higher in region 10, fed beef would be sold there. It would be sent to region 14 if prices rose 1.1 percent there, or to region 16 if prices were 4.5 percent higher there. It was most profitable for region 5 to sell its surplus pork to region 14. Small increases in price in regions 11 and 13 would induce pork to those regions, as would a 0.3 percent rise in region 10 or a 1.8 percent increase in region 9. Backgrounders produced and not used in region 5 were sold to region 13.

If the upper bounds on the livestock enterprises were changed so that one additional unit of each activity could be produced, the dairy enterprise would add the most net profit to the objective function. The other enterprises would follow in this order: swine, dairy with construction, fed beef, cow/calf, turkeys, backgrounders, and sheep.

Region 6

In region 6 alfalfa was produced at an intermediate level on soil classes 1 and 4, and at the lower bounds on soil classes 2 and 3. Barley was produced at the lower limits on soil class 1, at intermediate levels on soil classes 2 and 3, and at the upper limit on soil class 4. Corn silage was produced at an intermediate level on class 1 soil and at the upper limits on class 2 and 3 soil. Dry land wheat, pasture, and public and private cattle range were all produced at their respective upper limits. No range for sheep was used in the region. One more acre of soil class 1 land could be used most profitably by the corn silage enterprise, then by alfalfa, and then by barley. Another acre of class 2 or class 3 soil would first be used to produce corn silage, then barley, then alfalfa. Alfalfa would most profitably be grown on another acre of class 4 soil.

Turkeys were produced at the regional upper limit using barley and SOM as feeds. If production costs rose 36.4 percent, turkey production in this region would decrease 98.0 percent. Corn silage, alfalfa, and barley were fed to the dairy cows in the region, and both dairy enterprises were produced at the upper limits. If the production costs of the dairy construction enterprise increased 20.5 percent, this activity would decrease 13.1 percent.

The cow/calf enterprise used alfalfa, corn silage, pasture, and public and private range for feed and was produced at an intermediate level. A 3.3 percent cost increase would cause only a 0.8 percent production decrease. Backgrounders are also produced at an intermediate level using barley, alfalfa, and corn silage. A cost increase of 13.8 percent would mean an activity decrease of 15.0 percent for this enterprise. Using barley, alfalfa, and corn grain, fed beef are produced at the input upper limit. If production costs for this enterprise rose 55.6 percent, a 23.1 percent production decrease would result.

The production of swine in this region equaled the input upper limit. The feeds used in this production were wheat and SOM. An increment of 51.2 percent in production costs would decrease this activity 82.6 percent, and an equal price decrease would cause production to increase 158.3 percent. This region produced no range sheep.

Region 6 produced a surplus in all livestock consumer products except lamb. Surplus turkey was sold to consumption region 14, with region 13 being the next highest competitor for the turkey. A 1.9 percent price boost in region 11 or a 6.0 percent increase in region 17 would cause turkey to move to those regions. Region 6 produced a large surplus of milk which was sold to region 14. It would require price increases of 3.6 percent in region 11 or 2.8 percent in region 13 to cause milk to be sold to those regions.

Fed beef exceeding the consumption constraint in region 6 was sold to region 13, but a small price rise in region 11 would make that region equally competitive for the surplus. A 2.2 percent beef price increase in region 10 or a 0.8 percent increase in region 14 would allow beef to be more profitably sold to those regions. Region 6 surplus pork was sold to region 14 with regions 11, 10, and 13 competing closely in that order. Some backgrounders were sold from region 6 to region 13.

If one additional unit of each of the livestock enterprises were allowed or constrained into the optimal solution, the dairy enterprise would add the greatest net profit to the objective function followed by swine, dairy with construction, fed beef, cow/calf, turkeys, backgrounders, and sheep.

Region 7

On classes 2 and 3 soil in region 7 alfalfa was produced at the lower limits, and it was produced at an intermediate level on class 4 soil. Barley was grown in intermediate amounts on classes 2 and 3 soil and at the input upper limit on soil class 4. On soil class 2 and class 3, corn silage was produced at the upper limit. The maximum permitted amounts of dry land wheat, pasture, and private and public range for cattle were produced. If one additional acre of class 2 land could be made available for use in this region, it could most profitably be used to produce corn silage. The barley enterprise would add the second highest net profit, and alfalfa would be the least profitable enterprise to use that acre. The enterprises would follow the same priority list for an extra acre of class 3 soil, and an extra acre of class 4 soil would best be used by first alfalfa and then barley.

Barley and SOM were the feeds fed to turkeys, and turkeys were produced at the upper limit. A 42.3 percent rise in production costs would bring a production decrease of 43.8 percent. The dairy enterprises are produced at the upper limits using alfalfa, corn silage, and corn grain. A production cost increase of 23.5 percent would mean that the dairy construction enterprise would not be produced at all, and a similar cost decrease would see production increase 55.3 percent.

The cow/calf enterprise was produced at an intermediate level in region 7 using alfalfa, corn silage, pasture, and public and private cattle range. This activity would decrease 12.8 percent if costs increased only 0.3 percent. Backgrounders fed barley, alfalfa, corn silage, and corn grain were produced at the upper limit, but were quite sensitive to production cost increases. A 3.1 percent cost rise would mean a 20.0 percent decrease in activity. Fed beef were also produced at the maximum limit using barley, alfalfa, and corn grain.

Swine were fed wheat and SOM and were produced at the upper limit. If production costs increased 57.4 percent, swine production in the region would drop 92 percent, while a similar cost decrease would result in a 126.6 percent production increase. There were no sheep produced in this region.

Consumer wheat and lamb were the only products which were not produced in amounts sufficient to meet the consumption constraints in the region. The surplus turkey which was produced in the region was marketed in region 14, and region 13 was the second most competitive turkey-buying region. If the price of turkeys in region 17 had been 3.9 percent higher, surplus turkey would have been sold there. Milk produced in region 7 was sold interregionally to region 13. Milk price would need to increase 14.4 percent in region 11 or 1.9 percent in region 14 before the milk would be sold to those regions.

Fed beef produced in surplus amounts in region 7 was sold to region 13. A 4.7 price increase in region 10 or a 1.0 percent price rise in region 14 would induce surplus beef into those regions. The extra pork produced in the region went to region 13. Pork would go to region 14 if pork price there increased only a few cents per cwt., or it would go to region 16 if a relative price increase of 1.8 percent occurred there. The backgrounders which region 7 sold interregionally went to region 13, with region 12 being closely competitive for buying this product.

One more unit of the dairy enterprise activity would add the most to the objective function if allowed, and an additional unit of the swine enterprise would add the second most. The other livestock enterprises would follow in this order: dairy with construction, fed beef, cow/calf, turkeys, backgrounders, and sheep.

Region 8

On the first three soil classes in region 8, alfalfa hay was produced at the lower limits, and it was produced at an intermediate level on class 4 soil. Barley was produced at intermediate levels on the first three soil classes and at the upper limit on soil class 4. Corn silage was produced at the upper limits on all three classes of soil where it was defined for production. Pasture, dry land wheat, and both types of cattle range were also produced at the upper limits. If one more acre of soil class 1 were made available, it could most profitably be used by the crop enterprises in this order: barley, corn silage, alfalfa. One extra acre of classes 2 and 3 soil could best be used first by corn silage, then barley, then alfalfa. One additional acre of class 4 soil would first be used by alfalfa and then by barley.

Turkeys were produced at the upper limit in region 8 using barley and SOM. A 42.3 percent upswing in production costs would bring a turkey production decrease of 96.6 percent while a comparable cost decrease would mean production would rise 761.5 percent. The dairy cows produced in the region were fed alfalfa hay, corn silage, and corn grain and both dairy enterprises were produced at the regional upper limits. A 40.7 percent decrease in activity of the dairy construction enterprise would result from a 23.4 percent production cost increase, and a similar cost decrease would encourage production to increase 313.9 percent.

The range cow/calf enterprise used alfalfa, corn silage, pasture, public cattle range, and private cattle range and was produced at an intermediate level. A 3.5 percent cost rise would cause production to decrease only 0.1 percent. Beef backgrounders were also produced at an intermediate level in the region using barley, alfalfa, and corn silage. A 14 percent production decrease would result if costs increased only 0.2 percent, but if costs were to decrease 1.2 percent, production would increase 58.4 percent. Fed beef consuming barley, alfalfa, and corn grain were produced at the upper limit.

The upper limit number of units of swine were produced in region 8 using wheat and SOM. A 56.5 percent cost increase would mean a production decline in this enterprise of 72.6 percent, and a similar cost decrease would see production increase 253.3 percent. No sheep were produced in the region.

All of the consumer products which were produced in the region were produced in amounts which exceeded the regional demand constraints. The surplus consumer wheat which was produced in region 8 was sold to interstate region 9. A 4.9 percent wheat price increase in region 10 would cause wheat to be sold from region 8 to region 10. The surplus turkey which was produced in the region was sold to region 14, and a slight price increase in region 13 would cause surplus turkey to go to that region. It would take a 9.9 percent price increase in region 10 or a 4.0 percent increase in region 17 to draw turkey from region 8 to those regions. There was some surplus milk produced in the region, and it was sold to region 14. The net price of milk in region 13 was almost exactly the same as the net milk price for region 14, so surplus milk produced in region 8 would probably actually be sold to both of those interstate regions. Milk price in region 11 would have to increase 13.8 percent before it would compete for region 8 milk.

Fed beef was sold from region 8 to region 13. Region 14 would compete for the fed beef if price were to rise slightly there. Surplus pork produced in the region was sold to region 14, and region 13 was closely competitive price-wise for the pork. It would take increases of 1.2, 1.4, and 2.0 percent in regions 10, 11, and 16, respectively, to cause pork to go to those regions. Some background feeder calves produced in region 8 were sold to region 13.

If one additional unit of each livestock enterprise were added to the optimal solution, the dairy enterprise would add the greatest amount of net profit. The swine enterprise would contribute the second highest net revenue, followed by the dairy with construction enterprise, then fed beef, then turkeys, next backgrounders, then cow/calf, and finally sheep.

Resource shadow prices

Table 12 shows a shadow price (dual price) or reduced cost figure for each type of land resource in each region. The shadow price as output by the program for a resource can be defined as the value decrease in the objective function which would result if one less unit of that resource were available in the region. If an acre of land has a shadow price of $50.00 in this program, it means that if one less acre of land were available for agricultural use, total net revenue would decrease by $50.00.

For resources which were included in the model as bounded activities, Table 12 shows a reduced cost per unit of resource. The reduced

Table 12. Shadow prices and reduced costs of the land resources by land class and region[a]

Type of land	Unit	Region 1	2	3	4	5	6	7	8
Soil class 1	Acre	$72.69	$77.49	$77.63	$78.79	$61.03	$74.53	$ ---	$62.70
Soil class 2	Acre	56.69	56.89	60.27	62.44	46.21	51.76	41.09	44.15
Soil class 3	Acre	38.22	35.65	41.09	39.97	24.96	33.90	23.94	28.11
Soil class 4	Acre	13.87	7.46	7.43	8.67	4.32	12.58	6.28	6.94
Pasture land	Acre	30.40	24.99	28.24	27.73	23.09	26.16	25.24	27.49
Dry land	Acre	8.97	9.22	9.07	9.42	4.57	8.20	9.40	7.63
Public cattle range	AUM	1.35	1.05	1.34	1.30	0.83	1.34	1.34	1.38
Private cattle range	AUM	2.72	2.42	2.71	2.67	2.20	2.71	2.71	2.75

[a]Shadow prices and reduced costs are defined on pages 86 and 88. Shadow prices apply to soil classes 1-4. Reduced costs apply to pasture land, dry land, and range.

cost of an activity is the change in the objective function which would result from one more unit of that activity being allowed or constrained into the optimal model solution. If an activity has a reduced cost of $50.00 it means that if one more unit of that activity were allowed to occur, total net revenue would increase by $50.00

Both shadow prices and reduced costs can be used to show resource values at the production margins. They are included here to allow comparison of the relative value of the basic agricultural land and range resources both within and among regions. A general idea of the value of the land resources for agricultural purposes can be obtained by capitalizing the shadow price or reduced cost at an appropriate interest rate.

Post optimization

As stated, the main post optimal parameterizations were performed on one region only and not on the entire model. The production region used in the post optimal work was intrastate region 1. This section will present the results of the parameterizations, and the significance of those results on production in all of the intrastate regions will then be analyzed.

Tables 13, 14, and 15 show the results of parameterization A, an objective function parameterization designed to outline the results of increasing the price at which the production regions are able to purchase feeds from the interstate supply regions while all other costs and prices stay the same. Table 13 shows the normalized price and the price in the first three parameterization steps of each of the feeds available in each of the three interstate supply regions. The price increments of

Table 13. Parameterized feed prices to region 1 (Region 1 parameterization A)

Feed prices to region 1 from the main interstate supply region ($/cwt.)	Feed					
	Barley	Alfalfa	Wheat	Oats	Corn	SOM
Normalized price	$2.78	$1.99	$3.15	$2.64	$3.05	$9.00
Step 1 price	3.30	2.20	4.28	3.09	3.50	11.16
Step 2 price	3.82	2.41	5.41	3.54	3.95	13.32
Step 3 price	4.34	2.62	6.54	2.99	4.40	15.48
Feed prices to region 1 from the secondary interstate supply region ($/cwt.)						
Normalized price	$2.88	$2.21	$3.25	$2.74	$4.40	
Step 1 price	3.40	2.42	4.38	3.19	3.78	
Step 2 price	3.92	2.63	5.51	3.64	4.23	
Step 3 price	4.44	2.84	6.64	4.09	4.68	
Feed prices to region 1 from the final interstate supply region ($/cwt.)						
Normalized price	$3.17	$2.78	$3.73	$3.40	$3.63	
Step 1 price	3.69	2.99	4.86	3.85	4.08	
Step 2 price	4.21	3.20	5.99	4.30	4.53	
Step 3 price	4.73	3.41	7.12	4.75	4.98	

Table 14. Feeds purchased from interstate regions at parameterized prices (Region 1 parameterization A)

Feeds purchased from the main interstate supply region by region 1	Feed					
	Barley	Alfalfa	Wheat	Oats	Corn	SOM
Normalized price	500,000	---	500,000	50,000	200,000	432,936
Step 1 price	500,000	---	---	50,000	200,000	219,372
Step 2 price	---	---	---	50,000	---	22,599
Step 3 price	---	---	---	---	---	---
Feeds purchased from the secondary interstate supply region by region 1						
Normalized price	1,000,000	---	1,000,000	100,000	400,000	
Step 1 price	1,000,000	---	---	100,000	---	
Step 2 price	---	---	---	100,000	---	
Step 3 price	---	---	---	---	---	
Feeds purchased from the final interstate supply region by region 1						
Normalized price	1,577,715	---	---	---	---	
Step 1 price	---	---	---	---	---	
Step 2 price	---	---	---	---	---	
Step 3 price	---	---	---	---	---	

Table 15. Number of units of animal enterprises produced at parameterized feed prices (Region 1 parameterization A)

Enterprise	Number of units produced at normalized feed prices	Number of units produced at step 1 feed prices	Number of units produced at step 2 feed prices	Number of units produced at step 3 feed prices
Dairy	27,203	27,203	27,203	27,203
Dairy (with construction)	54,406	54,406	54,406	54,406
Beef cow/calf	108,885	49,825	51,280	51,128
Beef backgrounding	91,219	49,877	43,396	43,290
Fed beef	73,000	49,129	39,590	42,640
Turkeys	2,300,000	14,620	0	0
Swine	15,000	15,000	2,241	213
Sheep	0	0	0	0

each step were designed so that the step three price (not including transportation costs) for each feed is approximately equal to the average price of that feed for the year beginning in April 1973 and ending in March 1974.

Table 14 shows the amounts of feed purchased at each price level. With other costs and prices constant, it is not profitable for region 1 to buy any feeds from the interstate regions at price step 3. It is profitable to purchase oats for use in livestock production from the interstate supply regions at price step 2. Some SOM is also purchased at step 2 prices. In Table 15, the number of units of each animal enterprise produced at each price level is shown. Although the general trend of quantities produced decreases as feed prices increase, interrelationships between enterprises may cause one enterprise to increase production units from one step to another. For example, as feed prices increase from step 1 to step 2, the cow/calf and backgrounding enterprises increased production. This is explainable since in the same step production of the fed beef, turkey, and swine enterprises decreased, therefore, some of the feeds which were produced in the state and had been used by those enterprises were now available for other enterprises to use in greater amounts. The fact that the dairy enterprises do not decrease production at all as interstate feed prices rise indicates that dairy has a comparative advantage in using the feeds produced in the state. In order to produce at the optimal solution levels, all other enterprises are more or less dependent on the availability of interstate feeds at moderate prices. A one-step price increase caused turkey production to decrease 99.4 percent, and the second price increase made it unprofitable to produce turkeys in the region at all. At the second increase in feed prices, swine production decreased 85.0 percent, and the third feed price step saw production decrease to 1.4 percent of the original activity. Besides the effects on the dairy, turkey, and swine enterprises, interstate feed prices rising to approximate "current" levels would cause the cow/calf enterprise to produce 53.0 percent less, backgrounding would decrease 52.5 percent, and fed beef production would fall 41.6 percent.

Parameterizations B, C, and D were objective function changes on the price of the products produced and sold by specific livestock enterprises in the region. The enterprise activity which would result as output prices change is shown in Table 16. The fed beef enterprise proved to be very sensitive to the selling price of beef. With all other costs and prices remaining constant, a decrease of 75 cents per cwt. in beef prices caused no change in the production of the enterprise, but when prices decreased $1.50 per cwt., it became unprofitable to produce any beef in the region. This $1.50 decrease was about a 4 percent beef price drop.

The dairy with construction enterprise also became unprofitable on the second parameterization step when milk price had decreased $1.00 per cwt., a price decline of approximately 15 percent. It became unprofitable to produce turkey in the region on the third parameterization step, when turkey price had dropped $3.00 per cwt., or about 11 percent. On the fourth parameterization step when milk price had decreased $2.00 per cwt., or about 32 percent below the normalized price, production of the dairy enterprise decreased 63.4 percent. It was not until milk price had decreased $2.50 per cwt. that the region's dairy enterprise became unprofitable. This indicates that the dairy enterprise in the model is

Table 16. Number of units of the fed beef, turkey, and dairy enterprises produced at decreasing product prices (Region 1 parameterizations B, C, and D)

Price	Enterprise			
	Fed beef	Turkey	Dairy	Dairy(C)[b]
Normalized	73,000	2,300,000	27,203	54,406
Step 1[a]	73,000	2,300,000	27,203	54,406
Step 2	0	2,300,000	27,203	0
Step 3	0	0	27,203	0
Step 4	0	0	9,949	0
Step 5	[c]	0	0	0
Step 6	[c]	[c]	0	0
Step 7	[c]	[c]	0	0

[a]In each parameterization step, the product price of the enterprises changes in this manner:

-\$0.75 per hundredweight of fed beef
-\$1.00 per hundredweight of turkey
-\$0.50 per hundredweight of milk

[b]Dairy with construction enterprise.

[c]Indicates no parameterization was performed.

relatively stable to output price changes as other costs and prices remain constant.

Parameterizations E and F were run on region 1 to determine the sensitivity of the swine and sheep enterprises to changing amounts of product output per enterprise unit. Since the swine enterprise was quite profitable in the optimal solution in all regions, and since the amount of output per sow may vary substantially from the average figure used in the model, it was decided to parameterize the output per sow downward from the coefficient used originally and observe the results. Table 17 shows that with each parameterization step output decreased 110 pounds of pork or 0.50 fed hog. The swine enterprise remained in production in the amount produced in the optimal solution through parameterization step 5. On step 6, swine production became unprofitable and the enterprise was no longer produced in the region. This means that even if output (as defined in the table) decreased from 14.16 to 11.66 fed hogs per sow, it would still be profitable for the region to produce hogs in the amount indicated. Profitability of the enterprise decreased throughout the parameterization as output per sow decreased, but it remained profitable for the region to continue production until output reached a level somewhere between step 5 and 6.

Since in the original optimal solution no range sheep were produced in any of the intrastate regions, it was decided to parameterize upward the physical output per ewe to determine if, when, and to what extent it became profitable to produce the enterprise. Each parameterizing step increased the output per ewe 0.10 lamb (or 9 pounds since it was assumed that lambs were sold when they reached a weight of 90 pounds). The first parameterization step caused no changes to occur in the optimal

Table 17. Production of the swine and range sheep enterprises as amounts of product output per production unit change (Region 1 parameterizations E and F)

	Swine			Range Sheep		
	Output per Sow			Output per ewe[a]		
	Number of hogs	Pounds	Number of sows produced	Number of lambs	Pounds	Number of ewes produced
Originally	14.16	3,115	15,000	.70	63	0
Step 1	13.66	3,005	15,000	.80	72	0
Step 2	13.16	2,895	15,000	.90	81	47,896
Step 3	12.66	2,785	15,000	1.00	90	47,896
Step 4	12.16	2,675	15,000	1.10	99	79,133
Step 5	11.66	2,565	15,000	1.20	108	85,196
Step 6	11.16	2,455	0	1.30	117	174,121
Step 7				1.40	126	210,000

[a]Output as used here is the number of animals produced to market weight by the sow or ewe in a yearly production cycle, minus the number of animals per sow or ewe per year which are retained as breeding herd replacements.

solution. In the second step when output per ewe had been increased to 0.90 lamb per ewe, range sheep entered the optimal solution. They were produced at an intermediate level using all of the available private sheep range as the feed input. Production remained at the same intermediate level in step 3, but in step 4 when output per ewe had increased to 1.10 lambs, it became profitable to use the public sheep range as well as the private sheep range, so range sheep production increased somewhat. Production of the sheep enterprise continued to increase in steps 5, 6, and 7, and production reached the input maximum bound in step 7. Alfalfa hay was the additional feed used for production in steps 5, 6, and 7.

The significance of this parameterization is that it is profitable for sheep production to occur in the region if an average net output of 0.90 lamb or better per ewe is achieved. Surplus lamb produced in the region would be sold to either region 12 or 13, with region 14 being the next most competitive buying region.

Assuming that the sheep enterprise was produced in the region, a decreasing parameterization was run on the amount of feeds which were available to the production region from the interstate supply regions. Table 18 (parameterization G) shows the upper bounds on the amounts of feed available in the interstate supply regions for purchase by the intrastate region in each parameterization step. It also shows how the production of the livestock enterprises changes as less amounts of feeds are available. With this parameterization, production decreases occur in the enterprises which are least able to compete for the supplies of locally produced feeds. The backgrounding and fed beef activities decrease because of their dependency on the decreasing amounts of

Table 18. Number of units of animal enterprise produced and amounts of feed available from the interstate supply regions in each parameterization step (Region 1 parameterization G)

Enterprise	Parameterization steps			
	Original	Step 1	Step 2	Step 3
Turkeys	2,300,000	2,300,000	2,300,000	2,300,000
Dairy	27,203	27,203	27,203	27,203
Dairy (with construction)	54,406	54,406	54,406	54,406
Cow/calf	108,885	57,670	33,503	25,382
Backgrounders	91,219	55,369	38,452	25,267
Fed beef	73,000	54,539	37,875	1,285
Range sheep	210,000	210,000	210,000	210,000
Swine	15,000	15,000	15,000	15,000
Feed (thousand hundredweight)				
Barley	3,500	2,625	1,750	875
Alfalfa	1,400	1,050	700	350
Wheat	3,500	2,625	1,750	875
Corn Grain	1,400	1,050	700	350
Oats	350	262	175	87

imported feed grains. Less of the cow/calf enterprise is produced because land which was used to produce alfalfa, which was one of the basic cow/calf enterprise feeds, is switched to barley production since that enterprise has now become more profitable. With the other enterprises remaining at constant production from the original optimal solution to the third parameterizing step, the cow/calf enterprise decreases 76.7 percent, the backgrounding enterprise decreases 72.3 percent, and fed beef activity decreases 98.2 percent. It is assumed that the availability of SOM at the market price does not decrease in this parameterization even though available supplies of all other interstate feeds decrease. If SOM were less available, the production of the turkey and swine enterprises would decrease since they are so dependent on SOM as a protein supplement to the feed grains. In parameterization A when no feeds or SOM were imported from the interstate regions, turkey production ceased entirely and swine production decreased to only 1.4 percent of the original optimal level.

Analysis

Although parameterizations A through G were actually performed only on region 1, the results can be used to analyze all production regions if changes represented by the parameterizations were to occur in each region. If parameterization A were run on each region, it is expected that all regions would respond by buying less feed grains from the interstate regions in each of the first two steps, and by buying no feeds at all in the third step. The grain and SOM dependent enterprises (fed beef, swine, turkeys, and backgrounders) would decrease in activity in each region with each parameterizing step. The dairy enterprises in each region would have the greatest comparative advantage in using the feed grains produced in the region, and their activities would not decrease unless locally produced grains were not grown in quantities sufficient to maintain dairy enterprise production at the upper regional limits. Production of the cow/calf enterprise in each region would also decrease over the parameterization with the size of the step by step changes depending both on the decreasing feeds purchased, and on changes in the other enterprises, as has been explained. Livestock enterprise activities would decrease most in region 3 in this parameterization because that region is the most dependent region in the state on buying feeds from interstate regions, according to the optimal model solution. Region 5 is least dependent on interstate supplied feeds, consequently its livestock production activities would be least decreased by this parameterization.

Parametrically decreasing the selling price of fed beef would have approximately the same results in each region as those shown in parameterization B for region 1. Fed beef production would become unprofitable in the same step in each region, but an intrastep analysis would see region 6 become unprofitable in the enterprise first, and region 7 would remain profitable the longest. Decreasing turkey selling prices as in parameterization C would again have each region becoming unprofitable in turkey production in the same step as shown for region 1. If prices were to drop in smaller steps, region 1 could stand the largest price drop before turkey production would become unprofitable, but turkey production in all of the regions would become unprofitable within the range of a $0.09 cwt. price decrease.

A parameterization of milk prices on the entire model would cause the loss of profitability of the dairy construction enterprise in each region to occur on step 2. Region 1 would be the first region to become unprofitable in this enterprise, while regions 3, 7, and 8 would become unprofitable at about the same time, but not until after the other regions had lost profitability. The dairy enterprise in region 1 decreases production in parameterization step 4, but based on information in the original model output it is expected that the other regions would continue production at the optimal solution level through that step. Dairy production in all eight regions would be unprofitable in step 5.

Parametrically decreasing swine output in all regions following the pattern shown for region 1 in Table 17 would see swine production become unprofitable first in regions 5 and 6. The other regions would lose profitability next, either in the same step or perhaps one step later. Region 1 would be the last region to lose profitability in the swine enterprise.

Since no sheep were produced in the optimal solution, no meaningful data were provided in the range section of the output with which to determine the order in which the regions would begin to produce sheep as lamb output per ewe was increased parametrically. It is expected that on parameterization step 2 each region would produce enough range sheep to at least use the private sheep range which is available. All intrastate regions would probably continue to increase sheep production in a pattern similar to that followed by region 1 as output per ewe increased.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It is now possible to draw several general conclusions from the results of the linear program. It is important to note that these conclusions are reached according to the data which were prepared as described, and subject to the assumptions which were used to build the model. Several variables which need to be regarded in the individual application of the results of this study are mentioned in the policy implications section of this chapter.

It is generally profitable for each of the Utah production/consumption regions to produce the livestock products consumed in the region as long as locally produced feeds are available. It is profitable for each of the regions to purchase some feed grains from the interstate supply regions, but it is not profitable for any to buy alfalfa hay from the interstate regions. In other words, it is profitable to produce enterprises which use both concentrates and roughages as feeds only as long as locally produced roughages are available.

The sugar beet enterprise has a comparative advantage to use irrigated land in the regions and on the soil types where it is currently produced. Beyond that there is no real trend throughout the regions and soil classes as far as comparative advantage is concerned, but according to the model it would be profitable for most regions to expand production of corn silage and barley and decrease production of alfalfa. It is profitable for each region to use all of the public and private range for cattle which is available.

In order to produce the livestock enterprises at the level indicated in the optimal solution, Utah is extremely dependent upon obtaining large quantities of feed grains from out of state regions at the normalized prices. If these feeds are available, Utah could profitably increase its production of the beef backgrounding, finish beef feeding, dairy, turkey, and swine enterprises. If feed supplies from the interstate supply regions are less available or more expensive, the greatest comparative advantage for increasing production lies with the dairy and swine enterprises as they enjoy the greatest comparative advantage in using locally produced feeds.

With the major exception of region 3, most of the Utah production/consumption regions can generally produce the defined livestock products sufficient to meet regional consumption constraints for those products, and in many cases, surplus products can be produced. The main product exception to this conclusion is sheep (lamb and mutton) which is not produced in the model at all. Besides the high dependence upon interstate feed supplies to produce those quantities of products, it should be noted that no provision was made for amounts of feed wasted between production and animal use. No estimate is made of the amounts of feed wasted or lost in transfer, preparation, and actual waste by the animals. But, should the total feed loss in those areas be 10 percent, for example, at least a 10 percent decrease in the amount of livestock products produced in the solution would result. Also, quantities of locally produced feeds are exaggerated to an extent in the model since it is assumed that all of the irrigated land is used to produce feed crops (except for some land which is used for sugar beet production), and that all arable dry land is used for wheat production, a portion of which is available as a feed grain. The inclusion into the model of estimates of the amounts of feed lost or wasted and of the actual amounts of land upon which feeds can practically be produced currently would cause livestock enterprise production to decrease in the optimal problem solution. Although the size of those decreases cannot be accurately estimated, they will follow the enterprise comparative advantage pattern. That is, the livestock enterprises which have the greatest comparative advantage for the feeds which are available will suffer the smallest production cuts. The crop enterprises with a comparative advantage for using the land resources will decrease production least. Those comparative advantage relationships are a valuable result of this study.

All Utah production/consumption regions can produce turkey in amounts in excess of the regional requirements. Net income, and thus amounts of this enterprise produced are very sensitive to price changes of barley and SOM. If barley price increased $0.52 per cwt. and SOM price increased $2.16 per cwt. with other costs and prices remaining constant, turkey production in the state would be very limited. Regions 1, 2, 7, and 8 have comparative advantages for increasing turkey production. Region 14 is the most profitable market place for surplus Utah turkey.

All regions are self sufficient in milk production except region 3, and most of the regions produce sizeable surplus quantities of milk. Milk is produced using barley, alfalfa, and corn silage. Dairy can expand production in each region more profitably than any other enterprise as long as construction of completely new facilities is not necessary. Even when construction of all new facilities is necessary, the dairy enterprise is profitable, but it is then very sensitive to nonfeed cost increases. The dairy enterprise has the greatest comparative advantage for use of the available barley, corn silage, and alfalfa feeds. Consumption regions 13 and 14 offer the highest net-of-transfer price for surplus Utah milk.

Regions 2 and 3 do not produce enough fed beef to meet the regional consumption constraints, but the other six production regions do. Barley, corn grain, and alfalfa are the feeds most valuable to this enterprise, and since the fed beef ration is composed mostly of grain, the enterprise is dependent on interstate grain supplies. If those supplies are available as in the model, the enterprise has some expansion opportunities. If those supplies are not available production of this enterprise in the state cannot profitably expand. The fed beef enterprise is also sensitive to changes in the output price as a relatively small fed beef price decrease with other conditions remaining the same will cause significant production decreases.

All of the production/consumption regions except region 3 produce pork in excess of the regional demand constraints. Swine have a comparative advantage to use the feed wheat produced in or purchased by a region, and they use SOM as a protein supplement. Expansion opportunities for this enterprise depend greatly on the price and availability of grain, and especially SOM. While generally quite profitable in the model's output, this enterprise was also very sensitive to cost increases and output price decreases, and enterprise expansion decisions should be made with those facts considered. Small decreases below the average output per sow figure used in the model do not make the enterprise unprofitable. Consumption regions 13 and 14 provide the most profitable areas for surplus Utah pork.

The cow/calf enterprise has a comparative advantage in the use of the pasture and the public and private cattle range produced in the regions. It also uses alfalfa and corn silage, and the possible expansion of the enterprise in a region depends to a large extent on the amounts of those two feeds which are produced in the region and not used by other animals. The backgrounding enterprise is most profitably produced using barley, corn silage, and alfalfa hay. It does not have an advantage in the use of any of those feeds, so its production depends on the amounts of feeds available for purchase at normalized prices, amounts of those three feeds produced in the region, and the amounts of those feeds used by other enterprises. Its production in a region also depends on the production of the cow/calf enterprise in the region, since calves for backgrounding are the major output of that enterprise. Given that locally produced supplies of corn silage and alfalfa hay are available, a region could profitably expand the backgrounding enterprise, using imported feed grains if necessary, to the extent that locally-produced calves for backgrounding are available. Any surplus backgrounders produced in Utah can most profitably be sold to interstate regions 12 and 13.

It was not profitable to produce range sheep in any of the production regions in the model. As shown in parameterization F, good managers who are able to increase output per ewe over the averages used in the model may profitably produce range sheep using public and private range. Expansion of sheep enterprise production beyond the carrying capacities of presently available sheep range in each region would not be profitable. The enterprise could not compete for feeds used by other enterprises unless net output reached 1.2 lambs per ewe.

Policy implications

Completely comprehensive and unqualified policy implications and recommendations using the results and general conclusions of this study are not possible. However, adaptation of the data used in and produced by the model to individual and current situations will make the results of the study applicable to present agricultural decision making in Utah.

Some of the main points which the individual should regard in his use of the information in this study will be mentioned here. Although the normalized costs and prices used in the model are good trend indicators, those costs and prices in agriculture are subject to constant changes. At the time of this writing, most feed prices have increased substantially and some livestock prices have fluctuated markedly as compared to the normalized prices which were used. In many cases, these types of price fluctuations would be large enough to cause substantial changes in the enterprise production pattern suggested in the optimal solution to the linear programming model. Relatively normal agricultural price fluctuations may cause enterprises which were quite profitable in the model to decrease or even lose profitability. The sensitivity analysis provided in this study can be used to gain a feeling for the relative price stability of the production enterprises, and that fact should influence production decisions. Enterprise production costs and output per unit of input may differ from the averages used due to diverse qualities of management, vertical or horizontal integration of processes affecting the enterprise, or localized climatic or other physical conditions. The inertia of an enterprise in being either established or not established in a region is most definitely a factor contributing to decisions affecting the expansion or reduction of production of that enterprise. Marketing patterns may be affected by differences in transportation rates due to nonuniform rate structures, back-haul availabilities, or accessibility of a region to cheaper modes of transportation than those considered in the rate formulas used in the study. These and many other factors will influence the individual application of the study results. Still, it is possible to describe several general policy implications.

Should it be decided that an objective for which Utah ought to aim is to enhance the income of farmers in the state, then the results of this study could be used to help policy makers in the formulation of policies to obtain that goal. For livestock producers in all regions, it would be most profitable to consider expansion in the dairy and swine enterprises. (The sensitivity of the swine enterprise to changes in pork prices and production costs should be remembered in the production decision.) If good supplies of feed grains from interstate supply regions are available at moderate prices, some expansion of the fed beef industry would be profitable. Subject to the feed relationships explained in the previous section, the cow/calf and backgrounding enterprises could be increased somewhat. According to the model, crop producers could increase profits by expanding sugar beet production, although at present institutional constraints limit large production increases in that enterprise. Increased farm incomes in the state would result from emphasis on the expansion of feed grain and corn silage production for use in livestock production at the expense of decreasing alfalfa production.

Any sizeable increases in most livestock enterprises in the state are dependent not only on feed imports, but also on the availability of out-of-state markets for the livestock products. An awareness of the most profitable market areas for each product and the stability of those markets should aid the decisions of producers and policy makers.

Based on the prices which have prevailed, the regions which offer the highest prices net of transfer costs for milk produced in Utah are consumption regions 13 and 14 (Colorado, Arizona, and New Mexico). The price advantage of selling milk to those regions is quite stable in that it would take large relative population increases or other price-increasing changes in other regions to make it more profitable for Utah to sell excess milk elsewhere.

The most profitable interstate market area for Utah turkey is region 14. The second most profitable area is region 13. Moderate, but not large relative price increases in region 9 (the Pacific Northwest), 11 (Nevada), 12 (Montana, Idaho, Wyoming), and 17 (the eastern states) would enhance turkey marketing potentials in those regions. Surplus fed beef produced in Utah is most profitably sold in the interstate regions bordering Utah, especially region 13. Relative population shifts among those regions and thus temporary price changes could cause marketing pattern changes.

Hog prices net of transfer costs are generally very similar in all consumption regions. If Utah did produce a pork surplus, the most profitable market areas by a slight margin according to trend prices would be regions 13 and 14. The best out-of-state markets for Utah-produced feeder calves are regions 12 and 13. Those markets appear to be quite stable. Surplus wheat produced in Utah can most profitably be marketed in the Pacific Northwest.

If interstate feed supplies became less available either because of price increases or other reasons, or if for some reason it became desirable for Utah to be self sufficient in feed production, several production changes would have to occur. More feed grain and consequently less alfalfa should be produced. A feed grain or other feed high in protein would need to be produced. The sheep and beef cattle enterprises ought to be produced to the extent that they use the range and pasture resources. However, the comparative advantage for grain use would belong to the dairy and swine enterprises.

The complementarity among resource uses is an important factor for consideration in Utah agricultural production and policy. The availability of good range resources in each region of the state makes production of the beef cow/calf enterprise profitable. Since those range resources do exist, it is profitable to produce the enterprise using corn silage, alfalfa, and pasture as supplemental feeds. In addition, the cow/calf enterprise provides the basic input for local backgrounding and finish feeding activities, so their production level in a region is indirectly dependent on the availability of local cattle range resources. Even for sheep enterprises using good management practices, it would likely be unprofitable to produce that enterprise in the state unless range was available for sheep use. Farm income in the state of Utah would suffer substantially if the range resources were not available.

The same complementary effect is important with the swine and turkey enterprises. If supplies of a good protein supplement such as

SOM can be obtained at moderate prices, the swine enterprise can be profitably expanded in all regions of the state using wheat and SOM. Although less profitable, turkey enterprises in the state could expand using barley and SOM.

For purposes of this study, it was assumed that irrigation water sufficient to produce the crops at the specified levels was available in all regions. This water resource has a complementary effect on all crop and livestock products examined in this study except dry land wheat. Its decreased availability or increased cost would cause profitability decreases in all of those dependent enterprises. Producers and policy makers should note these and other complementary effects among resources in making their decisions.

Recommendations

The conclusions of this study indicate that some adjustments in the agricultural production patterns in the state would enhance net profit to the state's agricultural producers. Such adjustments would probably affect, and in some cases may be dependent on factors which were not considered in the model. Further research on those factors would prove to be a valuable and desirable extension of this work. A study of that nature could include evaluation of the regional and local impacts of state-wide adjustments to the more profitable production patterns suggested by this study. Consideration ought to be given not only to impacts on the farmers themselves, but also to the ways in which the entire rural community would be affected.

This study did not give much attention to the location of livestock slaughter facilities, but research on that subject would be an important addition to the Utah agricultural picture. The availability of local slaughtering and processing facilities would encourage local production and help extend the output markets. A study on this subject should include an assessment of present facilities in the state, and an estimation of the profitability of facility expansion. Some helpful work has been done in this area. (See Taylor et al., 1970.)

The transportation rate formulas used to determine transport costs in this thesis provided good general indications of product transportation fees between regions. However, the dependence of rates between regions or between areas within regions on local physical conditions, availability of alternative transportation sources, and institutional considerations makes the transportation rate problem an extremely involved one. Since the comparative advantage position of regions and enterprises in production and marketing may change with relative transportation rate changes, research providing more sophisticated rate information specific to the Utah agricultural sector would improve the analysis of future studies of this nature. Major emphasis in this area recently has resulted in an important study by Taylor and Baker (1974).

In the model, expansion of the swine and turkey enterprises in all intrastate regions was profitable providing adequate supplies of SOM were available at the normalized price. It would be useful to study the possibility of producing locally a high protein feed supplement, or of securing a steady supply of a supplement at moderate prices in some other way.

Further elaboration of the basic model developed in this study is possible in many areas. Each of the production/consumption regions in the state could be considered individually, and an optimal production solution found for each. Additional crop and livestock enterprises could be included in such regional models to provide a more detailed analysis of regional production possibilities. It would be interesting and useful to update the input and production costs and output prices which were used in the model to a more current situation. Some modifications on the bounds used in the model could be useful. One such change would be to delete the upper and lower bounds on barley and alfalfa acreages and observe the resultant cropping pattern. Should irrigated pasture production be allowed in the model on soil types other than those poorer than class 4, the comparative advantage of pasture as a major crop on those soil classes could be determined. The costs in net income to farmers of a reduction in the available amounts of public range for beef cattle could be determined by decreasing the bounds on the amounts of range available. Additional research in these areas would require some data accumulation and refinement, but a good analysis of these other facets of the Utah agricultural sector could be made by manipulating the basic model developed in this thesis.

LITERATURE CITED

Anderson, Mark H., Jay C. Andersen, John E. Keith, and Calvin G. Clyde. 1973. The Demand for Agricultural Water in Utah. Utah Water Research Laboratory/College of Engineering. Utah State University, Logan, Utah.

Beneke, Raymond R., and Ronald Winterboer. 1973. Linear Programming Applications to Agriculture. Iowa State University Press, Ames, Iowa.

Blackham, Chesley T. 1973. Spatial Impact of Factor Payments: A Case Study of Turkey Production and Processing in Utah. M.S. thesis. Utah State University, Logan, Utah.

Brokken, Ray F., and Earl O. Heady. 1968. Interregional Adjustments in Crop and Livestock Production a Linear Programming Analysis. Economics Research Service Technical Bulletin No. 1396, U.S. Department of Agriculture.

Brown, Larry A., William D. Gorman, and George R. Dawson. 1973. Feasibility of Hog Production in the Four Corners Economic Development Region. New Mexico State University Agricultural Experiment Station Research Report 259.

Burroughs Tempo B 6700 Mathematical Programming System Users Manual. 1973. Burroughs Corporation, Detroit, Michigan.

Capener, William N., William D. Gorman, and Charles H. Greene. 1973. Feasibility of Background Feeder Calves in the Four Corners Economic Development Region. New Mexico State University Agricultural Experiment Station Research Report 249.

Christensen, Rondo A., Lynn H. Davis, and Stuart H. Richards. 1973. Enterprise Budgets for Farm and Ranch Planning in Utah. Utah State University Agricultural Experiment Station Research Report 5.

Cliff, Oliver. 1973. Assistant Regional Forester, Division of Range Management, U.S. Department of Agriculture, Forest Service. Personal letter. December 13.

Dietrich, Raymond A. 1970. Assistant Professor, Department of Agricultural Economics and Sociology, Texas A & M University, College Station, Texas. Letter to James G. Youder, Associate Professor, Department of Agricultural Economics, Oregon State University, Corvallis, Oregon. June 3.

Dorfman, Robert, Paul A. Sammuelson, and Robert M. Solow. 1958. Linear Programming and Economic Analysis. McGraw-Hill Book Company, Inc. New York.

Fox, Karl A. 1953. A Spatial Equilibrium Model of the Livestock-Feed Economy in the United States. Econometrica 21:547-566.

Gray, Kenneth H. 1972. An Evaluation of the Competitive Position of Utah Livestock Production to Other Livestock Producing Areas. M.S. thesis. Utah State University, Logan, Utah.

Grimshaw, Paul Randolph. 1972. Economic Considerations for Expanded Feeding of Livestock in the Pacific Northwest. Ph.D. dissertation. Oregon State University, Corvallis, Oregon.

Heady, Earl O. 1952. Economics of Agricultural Production and Resource Use. Prentice-Hall, Inc., New York.

Heady, Earl O. 1954. Simplified Presentation and Logical Aspects of Linear Programming Technique. Journal of Farm Economics 36(5): 1035-1050.

Heady, Earl O., and Wilfred Candler. 1973. Linear Programming Methods. The Iowa State University Press, Ames, Iowa.

Keith, John E., Jay C. Andersen, Calvin G. Clyde. 1973. The Economic Efficiency of Inter-Basin Agricultural Water Transfers in Utah: A Mathematical Programming Approach. Utah Water Research Laboratory/College of Engineering. Utah State University, Logan, Utah.

McArthur, J'Wayne, Darwin B. Nielsen, and Jay C. Andersen. 1973. Feasibility of Range Improvement on the Rangelands of the Four Corners Economic Development Region. New Mexico State University Agricultural Experiment Station Special Report No. 23.

Minshall, Charles W., Dorothy Douglass, Fred Goodman, and Janet Baker. 1971. An Analysis of the Economic Structure and Industrial Potential of the Four Corners Region. Battelle Memorial Institute, Columbus, Ohio.

National Academy of Sciences. 1966. Nutrient Requirements of Poultry. Fifth Revised Edition. Publication 1345. Washington, D.C.

National Academy of Sciences. 1968. Nutrient Requirements of Sheep. Fourth Revised Edition. Publication 1693. Washington, D.C.

National Academy of Sciences. 1968. Nutrient Requirements of Swine. Sixth Revised Edition. Publication 1599. Washington, D.C.

National Academy of Sciences. 1969. United States-Canadian Tables of Feed Composition. Second Revision. Publication 1684. Washington, D.C.

National Academy of Sciences. 1970. Nutrient Requirements of Beef Cattle. Fourth Revised Edition. Washington, D.C.

National Academy of Sciences. 1971. Nutrient Requirements of Dairy Cattle. Fourth Revised Edition. Washington, D.C.

National Academy of Sciences. 1971. Nutrient Requirements of Poultry. Sixth Revised Edition. Washington, D.C.

Nielsen, Max. 1973. U.S. Department of the Interior, Bureau of Land Management, Utah State Office. Personal letter including unpublished range data. December.

Ohlin, Bertil G. 1935. Interregional and International Trade. Harvard University Press, Cambridge, Massachusetts.

Rand McNally and Company. 1973a. Commercial Atlas and Marketing Guide. Rand McNally and Company, Chicago, Illinois.

Rand McNally and Company. 1973b. Road Atlas. Rand McNally and Company, Chicago, Illinois.

Savelli C., Roberto. 1972. Present Livestock Feed Balance, Projected Feed Requirement and Potential for the State of Utah. M.S. thesis. Utah State University, Logan, Utah.

State Road Commission of Utah. 1973. Utah Highway Map.

Successful Farming. 1974. What a New Milking System Will Cost You. Planting Issue 72(4):D8.

Taylor, Morris H., and Forrest Baker, Jr. 1974. Transportation: Implementing Change in Freight Rate Structure with Emphasis on Utah's Agribusiness. Utah State University Extension Services, Utah State University, Logan, Utah.

Taylor, Morris H., Lynn H. Davis, Darwin B. Nielsen, Thomas L. Williams, Stephen L. Olsen, and Ronald J. Woolf. 1970. Feasibility of Expanding the Livestock Feeding and Meat Packing Industry in Utah. Utah Extension Service, Economics Report No. 9.

Thurgood, Vern. 1974. Western General Dairies, Ogden Office. Personal telephone conversation. January 31.

U.S. Department of Agriculture, Economic Research Service. 1973. National Food Situation. Washington, D.C. November.

U.S. Department of Agriculture, Soil Conservation Service. 1972. Land Uses by Land Capability Classes. Form S-2B. Source: N-2B.

U.S. Department of Agriculture, Statistical Reporting Service, Crop Reporting Board. 1960-1972. Agricultural Prices. Annual Summaries. Washington, D.C.

U.S. Department of Agriculture, Statistical Reporting Service, Crop Reporting Board. 1973-1974. Agricultural Prices. Monthly issues. Washington, D.C. January 15, 1973 through March 15, 1974.

U.S. Department of the Interior, Bureau of Land Management. 1969. BLM Facts and Figures for Utah.

U.S. Department of the Interior, Bureau of Land Management. 1973. BLM Facts and Figures for Utah.

Utah Agricultural Statistics. 1972. A report prepared by the U.S. Department of Agriculture-Statistical Reporting Service, Utah Crop and Livestock Reporting Service, and the Utah State Department of Agriculture.

Utah Agricultural Statistics. 1973. A report prepared by the U.S. Department of Agriculture-Statistical Reporting Service, Utah Crop and Livestock Reporting Service, and the Utah State Department of Agriculture.

APPENDIX

Table 19. Mileages used in calculating transportation costs

Production Region	Consumption Regions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	--	46	80	122	235	341	260	260	753	907	500	399	592	691	1,321	1,035	1,511
2	--	--	35	81	191	293	165	218	753	862	466	394	547	646	1,276	990	1,466
3	--	--	--	46	159	262	180	185	788	827	420	429	512	611	1,241	955	1,431
4	--	--	--	--	111	213	152	138	834	762	378	475	508	565	1,195	1,001	1,477
5	--	--	--	--	--	130	234	168	947	695	309	588	526	625	1,264	1,066	1,542
6	--	--	--	--	--	--	352	239	1,014	565	179	691	597	558	1,197	1,137	1,613
7	--	--	--	--	--	--	--	175	968	1,007	530	609	332	603	1,242	872	1,348
8	--	--	--	--	--	--	--	--	973	804	507	614	358	428	1,067	898	1,374

Sources: Utah State Road Map (1973) and Rand McNally Road Atlas (1973b).

Table 20. Product consumption constraints in intrastate regions

Region	Product (1,000 pounds. Meat products converted to liveweight.)					
	Beef	Lamb	Pork	Turkey	Milk[a]	Wheat[b]
1	15,569	481	8,260	874	59,235	8,598
2	50,549	1,496	26,817	2,837	192,318	27,915
3	108,466	3,211	57,543	6,088	412,666	59,899
4	34,750	1,028	18,435	1,950	132,208	19,190
5	7,680	227	4,074	431	29,220	4,241
6	8,181	242	4,335	459	31,126	4,518
7	4,695	139	2,491	263	17,866	2,593
8	8,035	237	4,262	451	30,570	4,437

[a]Includes fluid milk and milk used in milk products.

[b]Includes wheat and wheat cereals.

Source: Calculated using current population estimates (Rand McNally, 1973a) and per capita consumption figures (National Food Situation, November 1973).

Table 21. Exogeneous feed requirements

	Requirements (hundredweight)	
Region	Grain	Roughage
1	609,400	996,600
2	464,200	711,000
3	500,000	412,000
4	847,400	933,600
5	608,000	1,013,200
6	394,400	631,200
7	506,400	820,600
8	290,200	461,800

Source: Calculated from information in Savelli C. (1972).

Table 22. Updated prices of agricultural products in Utah[a]

Product	Price[b]
Fed beef	$44.40
Calves	55.40
Lambs	34.50
Turkeys	39.20
Hogs	38.20
Milk	7.60
Alfalfa	2.05
Wheat	6.13
Barley	4.46
Oats[c]	3.78
Corn[c]	3.84
SOM	15.50
Sugar Beets	1.09

[a]An average of mid-month prices for the months April, 1973 through March, 1974.

[b]Price per hundredweight. Price for live animals.

[c]Prices in the interstate supply regions for those products.