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The Market for Ethanol Feed Joint Products

Donald Hertzmark
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Solar Energy Research Institute
A Division of Midwest Research Institute

1536 Cole Boulevard
Golden, Colorado 80401

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DONALD HERTZMARK
BRIAN GOULD

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PREPARED UNDER TASK NO. 3346.6

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FOREWORD

This report was prepared as a part of SERI Task No. 3346.60, Gasohol Policy Analysis. This work is supported by the Biomass Energy Systems Branch of the Office of Energy Technology, U.S. Department of Energy.

The report describes the findings of econometric estimation and simulation of the feed joint-product markets for ethanol produced from grain. This report is a companion to the forthcoming report on the agricultural sector impacts of grain-to-ethanol conversion. Policy issues related to this work concern domestic and export feed market policies and support of large-scale grain to alcohol facilities.

The leader for this subtask is Silvio Flaim of the Economic Analysis Branch. The authors acknowledge the helpful comments of Bert Mason, James Doane, and Silvio Flaim.

Approved for:
SOLAR ENERGY RESEARCH INSTITUTE

James W. Doane

James W. Doane, Chief
Policy Analysis Branch

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SECTION 1.0

INTRODUCTION

A proper economic analysis of the production of ethanol from grain has three major components. The first issue concerns the effects of ethanol production on feedstock markets. The second concerns the impacts of large-scale production of food and feed joint products, distillers' grains, corn gluten meal and feed, and corn oil. From these two analyses, we can derive estimates of the overall agricultural-sector impacts of ethanol production. The present report constitutes the second step in this analytical process. A final report, detailing agricultural-sector price, quantity, and trade impacts, will be released later in the year.

The approach used in this paper differs analytically from the one commonly used for determining the impacts of obtaining ethanol from grain. An assumption maintained throughout this analysis is that ethanol is produced in a biomass refinery that yields ethanol, feed products, cooking oil, and sugars. Such a production set up will produce a number of joint products from a given stock of capital equipment and raw materials. The problem for the refinery, and for society, is to produce the products at minimum cost. (The analytical representation of this process is given in Appendix A.) This approach also presumes flexibility in production.

An alternative approach is to assume that ethanol is produced in fixed proportions with distillers' dried grains (DDG). In this latter mode of analysis, the joint-product credit becomes a prime determinant of the viability of ethanol production. If excessive output of DDG were to cause its price to decrease, then ethanol production itself could become economically marginal or even impractical. Allowing a greater degree of flexibility in the output mix is more realistic in terms of the processing potential of corn and other grains. In addition, the joint-product approach allows a more accurate determination of the real resource costs of ethanol than will the fixed-proportions approach.

Two different analytical techniques have been used in this paper. Current price relationships among high-protein feeds and corn were estimated using single-equation econometric techniques on time-series data. Simulations of the least-cost rations for a number of animals were obtained using linear programming techniques in a variant of the "feedmix" problem common to livestock operators.

The following sections of this paper contain a summary, econometric results, and linear programming simulations. The summary presents the results of the analysis in a nontechnical form. An informal discussion of techniques that were used to arrive at the results also follows.

SECTION 2.0

SUMMARY

This section presents a nontechnical discussion of the analysis and results of the econometric and simulation work that the subtask comprises. The goal of this subtask was to determine the impacts of feeding increased proportions of ethanol feed joint products to a variety of livestock.

Two types of impacts are of concern. The first is the effect of large increases in the supply of DDG and gluten meal feed on existing high-protein feed markets. The second is the impact on supplies of carbohydrate energy for livestock, given the diversion of some of the starch to ethanol. The current analysis allows us to draw some inferences on the question of land availability for growing crops to use, at least in part, for energy and for chemicals.

The role of DDG and gluten meal in current high-protein feed markets is shown in Table 2-1. The dominant feed in these markets is soybean meal, which accounts for more than 50% of the total tonnage. To keep the high-protein situation in perspective, Table 2-2 shows the quantities of feed in the concentrates market. High-protein feeds are limited compared to corn and milo, on a gross tonnage basis. The protein contribution to livestock is approximately equivalent from both protein and feed-concentrate markets. The value of grains as feed consists of their protein content and the digestible energy and bulk they provide. A basis for a discussion of results, a brief overview of output coefficients, and the relative importance of ethanol to grain production is presented. For example, about 200 million bushels of corn would be required for the production of 500 million gallons of ethanol annually. This is equivalent to 5.6 million tons of corn or 4.7% of the total 1977 use of domestic feedgrain. This quantity is approximately equal to the mean annual fluctuations in domestic grain consumption for feed.

An ethanol plant or biomass refinery produces 17-18 lb of DDG for every bushel of corn that is sent through the conversion process. Alternatively, the plant can preprocess the corn to get 3 lb of corn oil and 11-12 lb of gluten meal for each bushel of corn. A refinery designed to get either of the joint-product packages will then have at least four potential end products, a cushion against wide variations in the prices for these products.

If we assume that 50% of ethanol production yields DDG and 50% goes to gluten meal-plus-oil, then the increment to the high-protein feed markets would be 900 thousand tons of DDG and 600 thousand tons of gluten meal. This represents a tripling of DDG output and a 60% increase in gluten meal output. In the high-protein feed market, it represents an increase of 3.4% over the 1976 domestic use on a protein-equivalent basis.

Table 2-1. HIGH-PROTEIN FEEDS: 1963-1977[a]

Year Beginning October	Quantity for Feeding[b] (1,000 tons)						High Protein Feed Prices (Index Numbers 1967 = 100)
	Oilseed Meal						
	Soybean Meal	Other Oilseed Meals[c]	Total	Animal Protein	Grain Protein[d]	Total	
1963	9,138	2,518	11,656	3,753	1,136	16,545	91
1964	9,236	2,568	11,804	3,557	1,181	16,542	92
1965	10,274[e]	2,415[e]	12,689	3,577	1,238	17,504	105
1966	10,820	1,741	12,561	3,950	1,074	17,585	103
1967	10,753	1,487	12,240	4,290	1,006	17,536	99
1968	11,525	1,995	13,520	3,868	946	18,334	95
1969	13,582	1,729	15,311	3,444	976	19,731	105
1970	13,467	1,760	15,227	3,539	1,095	19,861	105
1971	13,173	1,920	15,093	3,616	1,008	19,717	117
1972	11,972	2,159	14,131	3,059	1,134	18,324	272
1973	13,854	1,945	15,799	3,012	1,202	20,013	197
1974	12,552	1,698	14,250	3,058	1,129	18,437	171
1975	15,613	1,391	17,004	3,185	1,238	21,427	193
1976[f]	14,056	1,545	15,601	3,252	943	19,796	252
1977[f]	15,900	1,835	17,735	3,239	935	21,909	--

[a] Agricultural Statistics - 1978, p. 56. Economics Statistics, and Cooperative Service--Economics, Data for 1952-62 in Agricultural Statistics, 1974, Table 519.

[b] In terms of 44% protein soybean meal equivalent.

[c] Includes cottonseed, linseed, and peanut meal.

[d] Beginning 1966, adjusted for exports of corn gluten feed and meal.

[e] Beginning 1965, includes 30,000 tons previously excluded for industrial uses and for fertilizer.

[f] Preliminary.

Table 2-2. FEED CONCENTRATES FOR LIVESTOCK AND POULTRY, 1963-77[a]

Year Beginning October	Feed Grains (million tons)				Wheat (million tons)	Rye (million tons)	By-product Feeds[b] (million tons)	Total Concentrates (million tons)	Grain-Consumming Animal Units (millions)	Concentrates Fed per Grain-Consuming Animal Unit (tons)
	Corn	Sorghum	Oats and Barley	Total						
1963	84.3	13.2	18.9	116.4	1.4	0.3	30.2	148.3	76.0	1.95
1964	82.8	11.5	17.3	111.6	3.2	0.3	30.2	145.3	74.3	1.96
1965	94.1	15.9	16.8	126.8	3.3	0.3	31.1	161.5	74.4	2.17
1966	93.2	16.8	17.0	127.0	3.6	0.3	31.2	162.1	77.2	2.10
1967	98.2	14.9	15.8	128.9	4.3	0.3	31.1	164.6	77.1	2.13
1968	100.2	17.2	18.1	135.5	5.2	0.3	32.9	173.9	78.4	2.22
1969	106.3	17.9	18.2	142.4	6.7	0.3	34.7	184.1	78.5	2.35
1970	100.3	19.1	18.9	138.3	7.2	0.4	34.5	180.1	80.0	2.25
1971	111.4	19.4	18.3	149.1	8.5	0.5	34.0	192.1	80.2	2.40
1972	120.7	18.5	16.1	155.3	5.0	0.5	33.3	194.1	79.4	2.44
1973	117.7	19.4	15.1	152.2	1.7	0.3	34.4	188.6	78.5	2.40
1974	90.3	12.1	13.6	116.0	1.9	0.2	32.5	150.6	69.8	2.16
1975	100.6	14.1	12.8	127.5	1.6	0.2	36.7	166.0	75.0	2.21
1976[c]	100.4	12.0	11.5	123.9	7.5	0.1	34.3	165.8	76.2	2.17
1977[c]	107.1	12.6	11.6	131.3	5.1	0.3	36.2	172.9	78.3	2.22

[a] Agricultural Statistics — 1978, p. 56. Economics, Statistics, and Cooperative Service -- Economics.

[b] Oilseed meals, animal protein feeds, and mill joint products.

[c] Preliminary.

In the econometric estimations, the price of DDG was largely explained by movements in the prices of soybean meal, corn, and wheat bran (or some other roughage source). The dominance of soybean meal in the high-protein market means that some other protein source, such as cottonseed meal, is not an explanation of the movements of the DDG price. Though the DDG price is related strongly to soybean meal prices, it is not related to the export of that crop. A probable explanation is the geographic dispersion of the current distilling industry throughout the country. To test the estimation of DDG price movements, we looked at the price behavior of brewers' dried grains, a similar product. The price of the brewers' grains is determined almost entirely by gluten meal and bran or by soybean meal and bran. Since the price of the brewers' grain is set in Milwaukee, it is much more sensitive to the exports of soybeans than DDG prices. This confirms the importance of geographic factors in determining the value of these products.

The movements of the gluten meal feed are similar to those of DDG. However, since the product has a low fiber content, roughage is not an adequate explanatory variable for the price. Soybeans, cottonseed meal, corn, and DDG are all necessary to explain the price of gluten. The tie between the DDG and gluten prices is important since it indicates that a firm would need to consider the interrelationships among the joint product feed prices in order to determine the optimum balance among available products.

From the econometric analysis we may conclude that the joint products DDG and gluten meal are related to both high-protein feed prices and costs for digestible energy. Under the current market structure it would appear that the protein component dominates. However, large increases in the availability of the two joint products would effect some structural changes in the high-protein markets, at least in regions near large ethanol production facilities. If the types of changes that the markets will undergo cannot be estimated by marginal analysis, then the alternative is to simulate the relevant markets and constrain them to reflect the structural changes that are forced by the additional concentrated feedstuffs from ethanol manufacture. We have done this by estimating the least-cost rations for beef cattle, dairy cattle, swine, and poultry under different usage levels for DDG and gluten meal.

The results of the feeding simulations indicate that DDG is of primary use as a protein source in cattle rations while gluten meal is relatively more useful as a feed in the dairy and poultry rations. DDG and gluten meal appear less suitable for the swine ration. In a normal (i.e., unconstrained) beef ration and dairy ration, brewers' grains will enter the solution but DDG will not. Some relative price decline appears to be necessary in order to induce the least-cost ration to use DDG. We should note at this point that neither soybean meal nor cottonseed meal entered the least-cost cattle rations as they were formulated in our model. This is probably due to three factors. First, handling costs at the feedlot are not included in this model. Second, many extant rations are not least-cost rations. And finally, this model was unable to specify precisely the varied locational factors that lead to using different rations for the same animal growth or output rates. Primarily, our models use specific locational prices and transportation costs.

The relative price decline that appeared to be necessary to bring DDG and gluten meal into the rations was about 25% for 10-20% diet penetration. This is a larger amount than would be used nationally with a 500-million-gallon annual program. As we expected, corn and milo are the dominant feed types. Surprisingly, DDG and gluten meal substituted more than proportionately for energy sources as well as protein sources. Thus, the use of the joint products in the animal ration will at least partially offset the diversion of corn from being an energy source for the animal. Loss of energy can be made up easily by using forages. Results indicate that adverse effects on grain prices resulting from diversion to energy production are at least partially mitigated. Much of the demand for additional land resulting from diversion of grains to energy production will then be taken up by increased production of forages, which are easier to grow on marginal lands than are row crops. In short, these results indicate that the impacts of the joint products on grain and feed markets will be minimal even for substantial alcohol programs (up to at least 1 billion gallons of ethanol/yr). Larger programs would require some export promotion efforts.

SECTION 3.0

THE MARKET FOR ETHANOL FEED JOINT PRODUCTS

Producing ethanol from grain is a process that, as is typical in the food processing industry, yields a multitude of products. Some of them must be produced in fixed proportions, while others are produced in substitution for one another. Ethanol, dextrose, fructose, and corn starch, all available in varying proportions, come from the starch portion of corn grain. From the rest of the kernel come distillers' dried grains (DDG), corn gluten meal, and oil. The latter three products are the focus of this analysis. Both DDG and gluten meal are used as protein supplements for animal feeds. Other major sources of protein supplements are soybean meal (about half the total market), various meat and fish products, cottonseed meal, wheat mill products, dried and molasses beet pulp, alfalfa meal, and other minor feeds such as brewers' dried grains (BDG) and oilseed meals (see Table 3-1). Of primary interest are the price relationships between gluten meal, DDG, and other feeds, especially soybean meal.

One of the concerns voiced in the evaluation of the desirability of converting grains to alcohol is that joint products will have a deleterious effect on the value of soybeans and other commercial feeds. This issue is explored more fully in the workings of the POLYSIM model, to be detailed in a subsequent paper. However, though the relations of the commercial feed market are complex, the general nature of the market interactions can be described easily. Corn and soybeans may be grown on the same land throughout much of the Midwest. Which crop a farmer plants in a given year depends primarily on two factors: the rotation being followed by the farmer and the corn-soybean price ratio (P_c/P_s)*. Diversion of corn to alcohol will, other things being equal, raise P_c/P_s. This will induce farmers to plant more corn to satisfy the increased demand, thus restoring the equilibrium value of the ratio. At the other end of the market, DDG and gluten meal will have a depressing effect on soybean prices if the quantities of those feeds reaching the market increase substantially.** Once again, the decline in the relative value of soybeans would be offset by decreased plantings. Thus the overall effect of grain to alcohol programs would be a decrease in plantings of soybeans relative to corn and other crops.

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*Assuming that the costs of growing both corn and soybeans are known, the ratio P_c/P_s will determine the relative profitability of choosing the one crop over the other.

**The increase in DDG and gluten meal necessary to depress soybean prices is one of the major outputs of POLYSIM.

Table 3-1. COMMERCIAL FEEDS: DISAPPEARANCE FOR FEED, UNITED STATES, 1963-76[a]

Year Beginning October	Oilseed cake and meal (1,000 tons) Soybean	Cottonseed	Linseed	Peanut	Copra	Total	Animal proteins (1,000 tons) Tankage and Meat Meal	Fish Meal	Dried Milk[b]	Total
1963	9,138	2,696	327	79	93	12,333	1,940	737	214	2,891
1964	9,236	2,680	306	99	101	12,422	1,932	625	236	2,793
1965	10,274	2,563	284	108	109	13,338	1,960	627	275	2,862
1966	10,820	1,755	248	115	90	13,028	2,068	827	255	3,150
1967	10,753	1,462	183	133	119	12,650	2,059	1,083	250	3,392
1968	11,525	2,086	197	135	111	14,054	2,021	835	235	3,091
1969	13,582	1,794	182	122	83	15,763	2,014	567	230	2,811
1970	13,467	1,693	258	173	99	15,690	2,039	609	260	2,908
1971	13,173	1,885	246	174	100	15,596	1,889	752	330	2,971
1972	11,972	2,225	212	180	100	14,689	1,739	462	330	2,531
1973	13,854	2,096	184	130	--	16,264	1,854	350	315	2,519
1974	12,552	1,846	95	151	--	14,644	1,981	444	150	2,575
1975	15,613	1,266	87	313	--	17,279	2,001	508	162	2,671
1976[c]	14,056	1,556	129	203	--	15,944	2,200	405	160	2,765

Table 3-1. COMMERCIAL FEEDS: DISAPPEARANCE FOR FEED, UNITED STATES, 1963-76 (concluded)

Year Beginning October	Mill Products[d]								Total Commercial Feeds
	Wheat Mill-Feeds	Gluten Feed and meal[e]	Rice Mill-Feeds	Brewer's Dried Grains	Distiller's Dried Grains	Dried and Molasses Beet Pulp[f]	Alfalfa Meal	Total	
1963	5,051	1,240	373	276	382	1,203	1,322	9,847	25,071
1964	4,716	1,165	395	295	409	1,289	1,586	9,885	25,070
1965	4,612	1,135	395	304	426	1,153	1,652	9,677	25,877
1966	4,499	1,193	451	324	425	1,129	1,599	9,620	25,798
1967	4,490	1,053	476	336	447	1,130	1,550	9,482	25,524
1968	4,469	963	494	333	437	1,523	1,662	9,881	27,026
1969	4,633	1,000	490	361	428	1,675	1,545	10,132	28,706
1970	4,499	1,236	436	361	382	1,509	1,584	10,007	28,605
1971	4,364	1,067	479	369	404	1,570	1,568	9,821	28,388
1972	4,327	1,262	442	361	428	1,566	1,799	10,185	27,405
1973	4,332	1,361	467	348	458	1,375	1,550	9,891	28,674
1974	4,482	1,340	576	346	339	1,325	1,572	9,980	27,199
1975	4,667	1,490	547	321	400	1,860	1,552	10,837	30,787
1976[b]	4,516	1,038	602	296	374	1,800	1,203	9,829	28,538

[a] Agricultural Statistics -- 1978, p. 55. Economics, Statistics, and Cooperatives Service -- Economics. Data for 1942-62 in Agricultural Statistics, 1972, Table 80.

[b] Includes dried skim milk, buttermilk, and whey for feed, but does not include any milk products fed on farms. Beginning 1974, not comparable with earlier years.

[c] Preliminary.

[d] Other mill products that are not listed include screening, hominy, and oats feeds, etc., for which no statistics are available.

[e] Adjusted for export data.

[f] Does not include wet sugarbeet pulp.

Econometric estimates of the price forecasting coefficients follow. These coefficients give the relative contribution of corn, soybeans, and other factors to prices for DDG, gluten meal, and two other feeds. From the results of the estimating equations, we can determine whether two feeds are substitutes or complements, and thus the effect on the price of the dependent variable of a change in one of the explanatory variables.

SECTION 4.0

ECONOMETRIC ESTIMATION

The joint products of grain to ethanol conversion processes can be divided into high-protein feedstuffs, soluble by-products, chemical feedstocks, and human food products. Determination of the optimal mix of these products is crucial to the economic desirability of ethanol production from the standpoints of agricultural and energy markets. First, consider the behavior of prices in the high-protein feed market, comprising distillers' dried grains (DDG), brewers' dried grains (BDG), soybean meal, cottonseed meal, and corn gluten meal. Corn and soybean exports are also noted, since corn is a major feedstock for the feed and ethanol markets while soybean exports clearly would be expected to influence the prices of other feedgrains. Fish meal, tankage, and other feedstuffs were not part of this study since it is assumed that a futures market in soybean meal will account for these factors appropriately in soybean-meal prices.

Normally, the demand for a product is measured by the demand function

$$Q = d(P),$$

where Q is quantity demanded and P is price. In the present case, however, DDG, BDG, and gluten meal are produced in approximately fixed proportions from the alcoholic beverage and food-processing industries. Thus, the measurement of price elasticities of demand would be meaningless, since

$$\frac{\Delta Q}{\Delta P} = 0$$

from the technical relations of production [1].* An alternative is to estimate the elasticity of price, i.e.,

$$\frac{\partial \ln P_i}{\partial \ln P_j} \text{ for } i \neq j,$$

with respect to movements of other, related prices. Clearly, if some systematic relations among these prices can be found, then we have the ability to forecast the value of these protein joint products for relatively small

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*Because the notes to this part are extensive, they are listed together on the last page of the section.

changes in the quantities of DDG, BDG, and corn gluten meal that come on the market.

That is, given the current structure of the high protein feed market, the models described below show the reaction of the price of a particular feedstuff given changes in substitutes, or, in the case of wheat bran, of complements.

One model that was estimated is one that is linear in logs, the familiar Cobb-Douglas form:

$$P_i = A \prod_{j=1}^{n} P_j^{\beta_j} . \tag{1}$$

This is estimated as $\ln P_i = \ln A + \sum_{j=1}^{n} \beta_j \ln P_j + \varepsilon,$ (2)

and has the useful property that

$$\frac{\partial \ln P_i}{\partial \ln P_j} = \beta_j ,$$

so that the estimated coefficients give the desired elasticities directly. That is, if $\beta_j = 0.5$, then an increase in P_j of 1% implies an increase in P_i of 0.5%. Since this is a logarithmic equation, we can infer that the range over which these elasticities remain constant is fairly broad. In this case, it is clearly desirable for the coefficients to sum to 1 since this implies that the model has explained all of the variation in the price of the dependent variable. On the other hand, direct estimation of the linear function

$$P_i = A + \sum_{j=1}^{n} \beta_j P_j + \varepsilon ,$$

gives β_j that are the actual changes in P_i in dollars for a given change in P_j, all else constant. The two models have different explanatory purposes, and, while the signs and the relative magnitudes of the coefficients should be the same in both models, the actual coefficients will differ from the linear model to the logarithmic one.

The maintained hypothesis in the regressions is that movements in the prices of distillers' grains, brewers' grains, and gluten meal (Tables 4-1 to 4-3) could be explained by the movements of two high-protein feedstuffs, soybean meal and cottonseed meal. A dilution with wheat bran will make these feeds

Table 4-1. DISTILLERS' DRIED GRAINS REGRESSIONS[a]

	Coefficients[c]				
Variable[b] Model	Full	A	B	C	D
Brewers' dried grains	0.524 (0.784)				0.624 (0.079)
Cottonseed meal	-0.616 (0.209)	-0.412 (0.370)	0.304 (0.143)		
Soybean meal	0.430 (0.167)	0.494 (0.256)		0.232 (0.103)	
Corn	0.155 (0.096)		0.224 (0.101)		0.243 (0.062)
Corn gluten meal	0.643 (0.543)				
Wheat bran	-0.118 (0.325)	0.725 (0.187)	0.312 (0.216)	0.613 (0.159)	
Soybean exports	-0.306 (0.193)	-0.199 (0.214)	0.044 (0.219)	-0.184 (0.216)	
Constant	1.247 (0.662)	1.684 (0.613)	0.619 (0.622)	1.439 (0.579)	0.743 (0.309)
R^2, R^{-2}	0.979,0.955	0.817,0.814	0.882,0.830	0.853,0.809	0.917,0.902
Hypothesis tests on restricted[d] regressions v. full.		reject H_0	reject H_0	reject H_0	accept H_0

---

[a] *Agricultural Statistics - 1978.*

[b] All variables are in ln $/ton (1967 = 100) except soybean exports, which are expressed as ln% of total crop.

[c] Standard errors are in parentheses.

[d] The restricted hypothesis is H_0: $_i = 0$ for some i.

Table 4-2. BREWER'S DRIED GRAINS REGRESSIONS[a]

	Coefficients				
Variable Model	Full	A	B	C	D
Distillers' dried grains	0.132				
	(0.198)				
Cottonseed meal	0.065	0.281		0.337	0.326
	(0.162)	(0.188)		(0.072)	(0.075)
Soybean meal	0.666	0.492	0.222		
	(0.118)	(0.131)	(0.055)		
Corn	-0.112				-0.037
	(0.033)				(0.053)
Corn gluten meal	0.499				
	(0.224)				
Wheat bran	0.359	0.549	0.623	0.538	0.587
	(0.076)	(0.095)	(0.084)	(0.086)	(0.113)
Soybean exports	0.219	0.341	0.331	0.347	0.317
	(0.073)	(0.109)	(0.115)	(0.103)	(0.115)
Constant	-0.831	-0.741	0.580	-0.783	-0.675
	(0.246)	(0.313)	(0.307)	(0.280)	(0.326)
R^2, R^{-2}	0.996,0.992	0.976,0.966	0.971,0.962	0.976,0.969	0.977,0.967
Hypothesis tests on restricted regressions v. full.		reject H_0	reject H_0	reject H_0	reject H_0

[a] See notes to Table 4-1.

Table 4-3. COTTONSEED MEAL REGRESSIONS[a]

Variable Model	Full	A	B	C	D	E
	Coefficients					
Distillers' dried grains	-0.959 (0.326)	-0.832 (0.262)	-0.294 (0.264)	-0.954 (0.297)	-0.756 (0.232)	
Brewers' dried grains	0.402 (1.001)	-0.016 (0.590)		0.329 (0.414)	0.153 (0.383)	
Soybean meal	0.652 (0.142)	0.696 (0.123)	0.704 (0.105)	0.661 (0.089)	0.637 (0.087)	0.636 (0.087)
Corn	0.098 (0.138)			0.089 (0.084)		
Corn gluten meal	0.876 (0.662)	1.159 (0.509)		0.911 (0.469)	1.027 (0.459)	
Wheat bran	-0.033 (0.410)	0.185 (0.260)	0.453 (0.209)			0.273 (0.134)
Soybean exports	-0.340 (0.252)	-0.238 (0.199)	0.09 (0.187)	-0.327 (0.171)	-0.303 (0.171)	-0.036 (0.182)
Constant	1.349 (0.884)	0.924 (0.624)	1.0185 (0.614)	1.30 (0.588)	1.093 (0.559)	0.596 (0.489)
R^2, R^{-2}	0.981,0.960	0.980,0.963	0.947,0.923	0.981,0.965	0.978,0.965	0.94,0.922
Hypothesis tests on restricted regressions v. full, A, and C.		accept H_0	accept H_0 reject H_0	accept H_0	accept H_0 accept H_0 accept H_0	accept H_0

[a] See notes to Table 4-1.

equivalent to either pure DDG, BDG, or gluten meal. If soybean meal (49% protein) and wheat bran (15% protein) are mixed to obtain the DDG equivalent (28% protein) the resulting mixture will be 38% soybean meal and 62% bran. If soybean meal is \$218/ton and wheat bran \$80/ton, then the resulting mix will cost about \$133/ton at 28% protein equivalent. Similarly, a mixture of cottonseed meal (41% protein) diluted with bran to 28% protein would cost \$128/ton with cottonseed meal at \$175/ton (51% cottonseed meal, 49% bran). The equilibrium price of DDG at this location would thus be about \$130/ton. In 1976 these prices obtained for the above feedstuffs; the actual price of DDG was \$132/ton (<u>Agricultural Statistics 1978</u>).

For the regressions of Tables 4-4 to 4-9, we seek the regression equations that can explain the variance of the dependent feedstuff with the minimum number of regressors. Given the variety of processes and joint products that are relevant in ethanol production, it is legitimate to look at the prices of one potential joint product, DDG, to explain the variance of another one, gluten meal. Eventually, of course, the movements must be explained outside the joint product market, though the nature of the data makes this difficult [2]. Only a few of the regressions contained other potential joint products as explanatory variables. The full model could be represented as (in matrix notation):

$$\underset{n\times 1}{y} = \underset{n\times k}{x}\ \underset{k\times 1}{B} + \underset{n\times 1}{u}.$$

The restricted model would appear as

$$\underset{n\times 1}{y} = \underset{n\times L}{\tilde{x}}\ \underset{1\times L}{\tilde{B}} + \underset{n\times 1}{v}$$

where $1 < k$ and $k-L = h$. This forms the basis of the standard Chow-Fisher test in which the F statistic is

$$F = \frac{(v'v - u'u)/h}{u'u/n-k} \sim F_{h,n-k,\alpha}$$

where $v'v$ is the sum of squared residuals from the restricted regressions, $u'u$ is the sum of squared residuals from the unrestricted regression, h is the number of linear restrictions, and α is the level of significance of the test. Multicolinearity was a problem. F tests were valuable to select among alternative functional forms [3]. Restricted regressions have the same functional form as the unrestricted regressions for both the log and linear cases. The difference is simply that one or more variables has been deleted from the restricted equations. Since additional variables always decrease the

Table 4-4. CORN GLUTEN MEAL REGRESSIONS[a]

Variable Model	Full	A	B
	Coefficients		
Distillers' dried grains	−0.085 (0.158)		
Cottonseed meal	0.655 (0.160)	0.853 (0.317)	
Soybean meal	−0.446 (0.128)	−0.242 (0.248)	0.395 (0.096)
Corn	−0.095 (0.064)	0.182 (0.084)	0.216 (0.104)
Constant	−0.297 (0.284)	0.559 (0.487)	1.295 (0.504)
R^2, R^{-2}	0.996,0.992	0.976,0.966	0.971,0.962
Hypothesis tests on restricted regressions v. full.		reject H_0	reject H_0

[a] See notes to Table 4-1.

Table 4-5. DISTILLERS' DRIED GRAINS REGRESSIONS[a]

	Coefficients				
Variable[a] Model	Full	A	B	C	D
Brewers' dried grains	0.178 (0.778)			0.818 (.087)	
Cottonseed meal	-0.525 (0.172)	-0.215 (0.319)		0.236	
Soybean meal	0.313 (0.098)	0.229 (0.169)	0.120 (0.051)		0.134 (0.045)
Corn	0.110 (0.080)			0.230 (0.067)	0.217 (0.100)
Corn gluten meal	1.236 (0.600)				
Wheat bran	0.004 (0.344)	0.944 (0.242)	0.850 (0.192)		0.578 (0.216)
Soybean exports	-0.451 (0.314)	-0.181 (0.417)	-0.192 (0.405)		0.077 (0.379)
Constant	15.457 (10.389)	24.069 (11.702)	21.538 (10.776)	9.811	8.829
R^2, R^{-2}	0.984,0.964	0.879,0.825	0.873,0.834	0.929,0.917	0.912,0.873
Hypothesis tests on restricted regression v. full.		reject H_0	reject H_0	accept H_0	reject H_0

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[a]Variables are expressed in constant $/ton; exports are a percentage of total. See also the notes to Table 4-1.

Table 4-6. BREWERS' DRIED GRAINS REGRESSIONS[a]

Variable Model	Coefficients Full	 A	 B	 C	 D
Distillers' dried grains	0.049 (0.212)				
Cottonseed meal	0.016 (0.143)	-0.009 (0.083)		0.124 (0.030)	0.114 (0.039)
Soybean meal	-0.053 (0.082)	0.068 (0.042)	0.064 (0.012)		
Corn	-0.075 (0.037)	-0.071 (0.028)	-0.070 (0.025)	-0.058 (0.030)	-0.092 (0.037)
Corn gluten meal	0.625 (0.321)	0.691 (0.130)	0.683 (0.105)	0.614 (0.136)	0.757 (0.167)
Wheat bran	0.375 (0.096)	0.378 (0.087)	0.377 (0.081)	0.361 (0.096)	0.375 (0.127)
Soybean exports	0.307 (0.143)	0.287 (0.108)	0.291 (0.097)	0.328 (0.117)	
Constant	-11.617 (4.228)	-10.959 (2.888)	-11.069 (2.563)	-12.773 (2.983)	-6.978 (2.874)
R^2, R^{-2}	0.995,0.990	0.995,0.992	0.995,0.991	0.993,0.989	0.987,0.981
Hypothesis tests on restricted regressions v. full, A, and C.		accept H_0	accept H_0 accept H_0	accept H_0 accept H_0	reject H_0 reject H_0 reject H_0

[a]See notes to Table 4-1.

Table 4-7. COTTONSEED MEAL REGRESSIONS[a]

Variable Model	Full	A	B	C	D
Distillers' dried grains	-1.160 (0.379)	-0.970 (0.272)		-1.156 (0.350)	-0.977 (0.370)
Brewers' dried grains	0.128 (1.159)	0.124 (0.528)			
Soybean meal	0.547 (0.087)	0.524 (0.053)	0.505 (0.052)	0.555 (0.047)	0.541 (0.051)
Corn	0.074 (0.133)			0.065 (0.094)	0.096 (0.100)
Corn gluten meal	1.795 (0.906)	1.768 (0.679)		1.878 (0.459)	1.595 (0.368)
Wheat bran	0.070 (0.510)		0.437 (0.195)	0.118 (0.245)	
Soybean exports	-0.626 (0.477)	-0.655 (0.350)	0.050 (0.412)	-0.588 (0.306)	
Constant	21.375 (15.813)	20.707 (11.122)	11.761 (10.975)	19.932 (8.204)	7.942 (5.906)
R^2, R^{-2}	0.989,0.975	0.987,0.979	0.959,0.946	0.989,0.979	0.982,0.975
Hypothesis tests on restricted regressions v. full and C		accept H_0	reject H_0	accept H_0	accept H_0 accept H_0

[a]See notes to Table 4-1.

Table 4-8. CORN GLUTEN MEAL REGRESSIONS[a]

	Coefficients				
Variable Model	Full	A	B	C	D
Distillers' dried grains	0.612 (0.139)	0.699 (0.101)			
Cottonseed meal	0.366 (0.117)	0.424 (0.098)	0.703 (0.212)		0.786 (0.236)
Soybean meal	-0.207 (0.066)	-0.241 (0.054)	-0.243 (0.128)	0.165 (0.047)	-0.287 (0.143)
Corn	-0.077 (0.048)	-0.078 (0.048)	0.159 (0.078)	0.209 (0.106)	
Wheat bran	0.124 (0.133)				
Constant	-1.052 (3.614)	-2.500 (3.231)	8.418 (6.709)	24.394 (6.435)	13.400 (7.078)
R^2, R^{-2}	0.976,0.961	0.973,0.961	0.831,0.780	0.646,0.581	0.761,0.718
Hypothesis tests on restricted regressions v. full		accept H_0	reject H_0	reject H_0	reject H_0

[a] See notes to Table 4-1.

Table 4-9. CORRELATION MATRIX OF THE VARIABLES

	Distillers' Grains	Brewers' Grains	Cotton-seed meal	Soybean meal	Corn	Corn gluten meal	Wheat bran
Brewers' dried grains	0.925422						
Cottonseed meal	0.81146	0.87979					
Soybean meal	0.76813	0.79914	0.96536				
Corn	0.60721	0.38296	0.24144	0.19911			
Corn gluten meal	0.94834	0.97577	0.82460	0.72164	0.49023		
Wheat bran	0.89503	0.93321	0.73597	0.63131	0.54692	0.93022	
Soybean exports	0.54995	0.73927	0.56437	0.51610	0.08019	0.67529	0.61164

sum of squared residuals (SSR), the F test determines whether the increased SSR in the restricted models is less than what would be expected simply by adding unnecessary regressors to the full model.

For the DDG regressions (Table 4-4) we can see the multicolinearity problem manifest itself in the high variability of the β coefficients for soybean meal and cottonseed meal in the various regressions. On the basis of the F tests, only regression D can be accepted in lieu of the full regression. Unfortunately, this regression uses BDG as a regressor so that its explanatory power does not lie outside the joint-product arena. Surprisingly, soybean exports did not carry explanatory weight in this model, though they figure prominently in the price of soybeans and cottonseed meal themselves [4]. As was expected, wheat bran has significant power at the .05 level in these regressions, thus underlying the validity of the pricing formula given above. For example, if the price of bran rises 1% to $80.80/ton, then the price of the soybean-bran mixture will rise to $132.50/ton, a 0.4% increase. Alternatively, in a year of relatively expensive bran ($88.80/ton) and relatively inexpensive soybean meal ($150.70/ton), such as 1975, a ton of 28% protein soybean-meal bran would cost $114.80/ton and a 1% increase in bran prices would increase the mixture price to $115.40/ton, a 0.5% increase (the 1975 price of DDG was $112.40/ton) [5]. The elasticity measure given by the β coefficient is the mean of all of these years and thus reflects the average elasticity of DDG prices with respect to changes in wheat bran prices. The inability of the models to explain adequately the price movements of DDG independently of the joint products, brewers' grains, and gluten meal indicates the need for full simultaneity. Unfortunately, this is beyond the capability of the data in the current formulation. The simultaneous equation framework of POLYSIM should help to overcome this problem.

The BDG regressions are better behaved than the DDG regressions; the elasticity figures are relatively more accurate in this model than in the DDG model due to our apparently smaller degree of multicolinearity. It is interesting to note that cottonseed meal has a negative, significant coefficient in the DDG regressions but is positive and significant in the BDG regressions. One possible explanation for the different signs of these coefficients is that DDG and cottonseed meal are strong complements in the southern United States, a center of both whiskey and cotton production, while the brewing industry is more concentrated in the North. We find that soybean exports are more important for BDG than for DDG; almost 1/3 of the variance is explained by exports alone. The importance of soybean exports in the BDG model is easily explained by the proximity of Milwaukee, where BDG prices are set, to major soybean areas in Illinois and Iowa. None of the restricted regressions can be accepted as valid in place of the full regression, though the coefficients may be more accurate if one of the multicolinear variables in the restricted equations B, C, and D is eliminated. Comparison of the restricted models A, B, and C indicates that soybean meal and cottonseed meal are not needed as explanatory variables in the BDG regressions.

One possible behavior pattern for high-protein joint products of ethanol production (once higher production levels are reached) is that of cottonseed meal (CM). Current use of CM in the United States is equal to that of DDG, BDG, and corn gluten meal combined; a doubling of this total would make these joint products at least as important as CM in the protein market. The elasticity of CM prices with respect to soybean meal (SM) prices is about 0.6 to 0.7 and the simple correlation coefficient for the two is 0.965. Virtually no other information beyond SM prices is required to explain the movements in CM prices. Currently, DDG and BDG prices are driven strongly by bran and corn prices which are not strongly related to either SM or CM prices (r = 0.631 and 0.736, respectively). The emergence of DDG and gluten meal as major protein sources would probably lead to their being more strongly tied to SM prices than they are currently. At some point, however, the expansion of these joint-product quantities would affect the overall price level of the feed market. Such an eventuality is beyond the scope of linear regression models although it is possible to provide some approximate answers using the mathematical programming procedures outlined below.

The full corn gluten meal regression (Table 4-8) seems to explain price movements adequately only with the inclusion of DDG. As with DDG and CM, the sign on the SM coefficients is negative, indicating that SM and corn gluten meal are strong substitutes in feeding rations. As in the DDG case, we need to know more about specific rations in particular markets before we can generalize. Since gluten meal and DDG are both potential joint products from the ethanol manufacturing process and may be produced in variable proportions within the same plant, we should expect a strong degree of dependence of one price upon the other. A properly designed grain ethanol plant would have the capacity to produce DDG, gluten meal, corn oil, dextrose, ethanol, and, possibly, other products. Given that DDG and gluten meal are in the same market, the decision on how much of each to produce would be done in the context of their relative price ratios and relative production costs. This is given in detail in Appendix A as a model of the multiproduct firm with fixed capital resources. The conclusions from the analysis in the appendix indicate that the firm will shift its production of alternative products until the cost/price ratios are equivalent for each product. Thus, a deterioration of the DDG price due to oversupply would lead to an increase in gluten meal production and a fall in DDG production.

The linear, untransformed regressions tell a similar story to the logarithmic regressions. The coefficients generally have the same signs and significances and thus support the elasticity figures. It may be, though, that the untransformed regressions are of more use quantitatively for analyzing current price movements than are the log regressions. In the linear regressions, the multicolinearity of CM and SM is obviated when one or the other is dropped. Unfortunately, this multicolinearity causes the sign on CM to change to positive. In the CM regressions, the sign on the DDG coefficient is uniformly significant with a mean value of -1.066, indicating that multicolinearity caused the sign change in the DDG regressions. Corn gluten meal is strongly explanatory in the BDG and CM regressions, so that interaction among the potential joint products is clearly important.

In conclusion, at production levels that are within the quantity range of some of the other high protein feeds, such as CM, we can expect that current price behavior will continue. A large increase in the DDG-BDG-gluten meal market would have a clearly adverse effect on bran prices. In fact, we may generalize and say that an order-of-magnitude increase in the above three joint products would reverse the order of causality, at least with respect to bran and CM. The current models show that the overall high-protein feed market is driven mostly by SM and somewhat by corn. For the high-fiber feedstuffs, DDG and BDG, the price of bran is crucial; the farm prices are set by a formula rather than by supply and demand. All of this statistical evidence provides support for information provided by feed marketers in the West and Midwest concerning pricing strategies. Feed marketers reported that they used the pricing formula for brewers' grains. Thus, the present effort was directed primarily at determining whether that pricing formula was used for DDG as well.

NOTES

1. This also provides the justification for using single-equation estimation techniques. For example, if quantity supplied of the joint products was a function of its own price and the prices of substitutes and complements, then estimating the demand for the joint products would require (at least) the system

$$q_i = D(P_{ij}P_j)$$

$$q_i = S(P_{ij}P_{ji}q_j)$$

where q_j is the commodity coproduced with q_i approximately fixed, the producer is concerned with a price that will clear all of the firm's output since disposal costs are nonzero. For further discussion of the choice between single-equation estimation and simultaneous equation models, see Wallis (1973, p. 99). Cramer (1971, p. 209) considers the problem of demand estimation when q_i is predetermined. That is, there is no supply equation for commodity i. Thus q_i cannot be treated as a dependent variable and should not be on the LHS of the equation. Rather, P_i is the only dependent variable, so that the proper reduced form is $P_i = P(P_j,q_i,q_j) + E$. Where q_i is too small to influence P_i, we cannot move back to the structural form and get price elasticities so that the reduced form and the structural form are identical. In the current joint-product market, the price elasticity of demand has no meaning due to the method by which prices are set.

2. A complete model of the sort that would be required to explain joint-product price movements, once there is a substantial expansion of ethanol production, would still be subject to such simple data problems as multicolinearity. In addition, we would expect that the structure of the model would shift. First, the model would require full simultaneity, since there would be some discretion (albeit with a lag) as to which joint products to produce and in what proportions (see Appendix A). Second, crop acreages could shift in response to changes in use patterns. Third, the order of causality between the joint products and cottonseed meal or bran would likely be reversed. In any event, the model would then bne fully simultaneous with some sort of lag structure. Of course, we would need to wait 15 years or so to have sufficient degrees of freedom to make much sense of the data.

NOTES (concluded)

3. In many cases, the full regression was found to have superior explanatory power despite the problem of low t values that are a consequence of multiconinearity. (This shows strongly in Tables 4-1, 4-2, 4-3, 4-7, and 4-8.)

4. In a true Walrasian market a factor such as proportion of the crop exported would not enter the pricing scheme directly. Rather, it would enter through its effect on the price of soybeans and in the demand for cottonseed meal.

5. The lack of a perfect fit here between the elasticity measure and the actual point elasticity could reflect the removal of one of the multiconinear variables and the shifting of some explanatory weight to bran.

SERI

SECTION 5.0

THE VALUE OF FEED JOINT PRODUCTS IN LIVESTOCK RATIONS

Earlier sections of this report contained discussions of the effects of various prices of DDG and corn gluten meal on the prices of corn, soybeans, and other feedgrains.* This section will investigate relationships between DDG and corn gluten meal in the actual feed rations of selected livestock. Corn is a major input in the ethanol production process. As such, there should be a positive relationship between the price of corn, corn gluten meal, and DDG.** In contrast to the complementary relationship that exists in the production process, these three feed grains may be substitutable in the ration formulations of commerical livestock operations. If such a substitute relationship does exist, then, with increased usage of DDG or corn gluten meal, it would slow the upward pressure on corn prices resulting from diversion of corn to alcohol. As such, the positive relationship between joint-product prices and corn prices may be mitigated or turned into a negative relationship depending upon the relative strengths of the appropriate output and price elasticities. This section of the report investigates the movements of corn, DDG, and gluten meal in some least-cost ration formulations for several types of livestock.

The feed nutritive analysis of corn (grain), DDG, and corn gluten meal is given in Table 5-1. Note that DDG is relatively high in fiber, compared with the other two feedstuffs. This has the implication that DDG may be more readily introduced into the diets of ruminants vis-à-vis poultry and swine. We hypothesize that DDG will most easily be adopted by the beef and dairy industries. All three feedstuffs are relatively high in energy content. Protein requirements can most easily be met by corn gluten meal, followed by DDG and corn grain. This suggests that the inclusion of gluten meal or DDG in a ration may not be solely for providing protein.

5.1 FORMULATION OF RATIONS

To facilitate the investigation of the change in feed ingredients in livestock rations, a linear programming model was developed in which the objective function was to minimize of the cost of the daily feed required by a particular livestock. In matrix notation, the linear programming problem appeared as:

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*See Wisner and Gidel (1977) for a discussion of the effects of these joint products on other high-protein feed supplements.

**See elsewhere in this report for the material on feedgrain prices.

Table 5-1. NUTRITIVE CHARACTERISTICS OF CORN (GRAIN), DISTILLERS' DRIED GRAINS (WITH SOLUBLES) AND CORN GLUTEN MEAL[a]

Characteristic	Unit	Feedstuffs		
		Corn	DDGS	Gluten Meal[b]
Dry matter	%	89	93	90
Protein (crude)	%	8.8	27.2	62
Ether extract (fat)	%	3.8	9.0	2.5
Crude fiber	%	2.0	9.1	1.3
Calcium	%	0.02	0.17	0.164
Phosphorus	%	0.28	0.72	0.5
Iron	%	0.007	0.028	0.04
Niacin	mg/kg	34	71	55
Riboflavin	mg/kg	0.9	8.6	2.2
Thiamin	mg/kg	3.5	2.9	0.3
B_{12}	mg/kg	0	0	0
Vitamin A	Iu/kg	2703	1869	6364
Vitamin E	mg/kg	22	40	24
Digestible energy (swine)	kcal/kg	3525	3568	3230[c]
Metabolizable energy (swine)	kcal/kg	3325	3390	3069
Digestible protein (ruminants)	%	7.5	23.4	47.4
Digestible energy (ruminants)	kcal/kg	3495	3626	3364
Metabolizable energy (ruminants)	kcal/kg	3126	3243	2991
Metablizable energy (poultry)	kcal/kg	2770	2480	3720
Productive energy (poultry)	kcal/kg	1980	1960	2820
TDN (ruminants)	%	80	87	86

[a] On an as-fed basis.

[b] 60% protein minimum.

[c] 41% protein corn gluten meal.

$$\begin{array}{rl} \text{Min} & c'\chi \\ \text{subject to} & A\chi \geq b \\ & \chi \geq 0 \end{array}$$

where c = 1 x n vector of cost coefficients. For this study these costs were the prices-per-ton for wholesale bulk buying of the feedgrains at a major market point plus a transportation charge.* χ = an n x 1 vector of activities which represent the use of an ingredient in the ration. The units were either pounds or grams. A = an m x n matrix of technical coefficients where m = the number of constraints and n = the number of activities. The technical coefficients are primarily the nutritional characteristics of the particular feedstuffs involved in the program; b = m x 1 vector of nutritional requirements (minimum or maximum) as well as technical relationships (e.g. calcium-phosphorus ratio = 7:1).

Note that the driving mechanism for this or any other program is the objective function. As such, the solutions received depended upon the particular vector of prices used. However, the particular ingredients selected as the optimum solution may not be optimal for all sections of the United States. In addition, the costs of handling various feeds were not included. The solutions received will reflect local price conditions. For this analysis, all prices were set at an average monthly level for May 1979.**

5.2 DAIRY CATTLE RESULTS

The dairy model used for this section was formulated according to the nutritional requirements set forth in a series of National Academy of Sciences publications on dairy, beef cattle, swine, and poultry. In the model, we assumed a typical Wisconsin dairy operation in which the objective was to minimize the cost of feeding a lactating cow weighing 1300-1400 lb. In addition to the constraints that were necessary to maintain good animal health, the ration was formulated so that a cow would be capable of sustained commercial levels of milk production (46-64 lb/day) at a consumption rate of at least 40 lb of dry matter each day. This insured that the optimal solution was economically feasible for quantities of milk production demanded in modern dairy operations. Table 5-2 shows potential ingredients and delivered

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*Excluding such items as trace mineral salt, vitamin premixes, and home produced crops. The latter group were priced at farm-level costs; the first two items were priced at local bulk prices. The transportation charge was computed on the basis of mileage from a central market such as Kansas City or Minneapolis. Forage crops were assumed to be available locally while the other feeds would come from the central market.

**For ration program formulations, see Appendix B.

TABLE 5-2. FEED INGREDIENTS USED IN THE DAIRY CATTLE RATION AND DELIVERED PRICES

Ingredients	Delivered Price (¢/lb)
Alfalfa (dehydrated)	6.719
Alfalfa hay (early)	2.0
Barley	4.419
Bone meal (steamed)	14.5
Brewers' dried grains	5.773
Distillers' dried grains	9.128
Hominy feed	5.412
Corn (#2 ground)	3.75
Cottonseed meal	12.48
Dicalcium phosphate	12.20
Fish Meal (menhaden)	24.92
Linseed meal	8.803
Meat meal	15.38
Meat and bone meal	14.50
Milk (whole, dehydrated)	85.45
Oats	5.237
Soybean meal (solvent)	12.69
Timothy hay	2.00
Wheat bran	9.061
Corn gluten meal (60% protein)	8.268
Wheat (hard)	18.60
Wheat middlings	9.327
Bermuda grass hay	not used
Rock phosphate	12.00
Salt	4.950
Urea	11.20
Corn stover silage	1.00
Limestone	3.20

prices. The prices used in this program were bulk prices f.o.b. Minneapolis (or f.o.b. Milwaukee, in the case of brewers' grains) and in the original optimal solution (Table 5-3) the daily cost of the ration was $1.81 per head.

The roughage in the optimal solution was provided by corn silage, timothy hay, and alfalfa hay. The digestible energy sources in this least-cost ration were corn grain, hays, and brewers' grains. Brewers' grains and DDG provided the necessary protein. Table 5-4 shows that DDG provided a disproportionate amount of protein and at least a proportionate amount of digestible energy. This suggests that in a relatively low-protein diet, for animals that are capable of obtaining large proportions of their dietary needs from roughages, high-protein supplements play a limited role. That is, we cannot reasonably expect DDG to make major inroads into dairy rations without a price decrease that could seriously devalue the protein content of the DDG. Alternatively, feeding wet spent grains, as is done presently with brewers' grains, may be suitable for some regions to reduce the cost of DDG.

The main purpose of this exercise is to determine the effects on the cost of the ration of using larger quantities of DDG or gluten meal in solution. We are interested in the effects on the total cost of the ration of forcing DDG into the ration at high levels. Clearly, this changes the mix of other feeds in the modified rations. There must be relative price changes for DDG to enter the rations in larger quantities than are optimal initially.

The subsequent tables (5-5 and 5-6) give the results of modifications of price and quantity parameters. As would be expected from the econometric results, increasing the quantity of DDG in the ration exerted its major impact on utilization of brewers' grains. Obviously, forcing larger proportions of a nutritionally similar feed into the ration will, other things being equal, lower the use of brewers' grains. The brewers' grain feed was completely eliminated once DDG assumed a 20-30% role in the ration. Corn use also decreased dramatically. In a pattern repeated in subsequent cases, DDG and gluten meal are not only protein sources but also strong substitutes for corn as an energy source. In any event, they make the protein content of the corn largely redundant and, therefore, valueless.

One of the strong conclusions emerging from this simulation is that basing ethanol facilities locally would permit more complete utilization of DDG and gluten meal joint products. In the current model, the price of DDG at the farm (including transport costs) is equivalent to about $180.00/ton, and over 25% of that is for transport. Given the relative unimportance of the protein constraint in a dairy ration, the existence of centralized ethanol facilities with their attendant transport costs make high levels of DDG utilization unlikely in dairy regions.

When the initial delivered price of 9.128¢/lb was lowered by 50%, DDG entered the ration at 33% of the total. This gives evidence of the discounting of

TABLE 5-3. OPTIMAL SOLUTION FOR THE DAIRY RATION

Ingredient	lb	% of Total Ration
Alfalfa hay	8.468	18.03
Brewers' dried grains	7.216	15.37
Distillers' dried grains	2.303	4.90
Corn (grain)	14.03	29.88
Timothy hay	8.387	17.86
Wheat middlings	2.353	5.01
Rock phosphate	0.4801	1.03
Trace mineral salt	0.1917	0.41
Corn silage	3.533	7.52
Total ration (lb)	46.96	

TABLE 5-4. CONTRIBUTION OF FEED INGREDIENTS TOWARD FULFILLMENT OF PROTEIN AND DIGESTIBLE ENERGY REQUIREMENTS

Ingredients	Crude Protein (lb)	% of Total	Digestible Energy (mcal)	% of Total
Alfalfa hay	1.321	21.50	8.89	15.65
Brewers' dried grains	1.739	28.31	8.80	15.49
Distillers' dried grains	0.636	10.35	3.75	6.61
Corn (grain)	1.263	20.56	22.25	39.18
Timothy hay	0.713	11.61	8.68	15.28
Wheat middlings	0.400	6.51	3.42	6.03
Corn silage	0.071	1.15	0.99	1.74
Total supplied	6.1424		56.8	

TABLE 5-5. PARAMATERIZATION OF DISTILLERS' DRIED GRAINS IN THE OPTIMAL DAIRY RATION

Price Level	Activity Levels		% of Total Ration
8.378¢/lb	Alfalfa hay	9.462	20.12
	BDG	6.901	14.68
	Corn (grain)	14.04	29.86
	DDG	2.378	5.06
	Timothy hay	7.498	15.95
	Wheat mids	2.425	5.21
	Rock phospate	0.4939	1.05
	Salt	0.1917	0.41
	Corn silage	3.631	7.72
	Total Ration	47.021 (lb)	
8.378	Alfalfa hay	17.84	37.64
	BDG	4.246	8.95
	DDG	3.009	6.35
	Corn (grain)	14.008	29.55
	Wheat mids	3.027	6.39
	Rock phospate	0.6101	1.29
	Salt	0.1917	0.40
	Corn silage	4.465	9.42
	Total ration	47.3973 (lb)	
6.878	Alfalfa hay	18.03	39.27
	BDG	4.801	10.46
	DDG	4.665	10.16
	Corn (grain)	13.41	29.20
	Wheat mids	1.696	3.69
	Rock phospate	0.7623	1.66
	Salt	0.1917	0.43
	Corn silage	2.361	1.76
	Total ration	45.917 (lb)	
6.128	Alfalfa hay	19.71	44.62
	BDG	2.983	6.75
	DDG	9.016	20.61
	Corn (grain)	10.42	23.59
	Limestone	0.0595	0.13
	Wheat mids	0.6073	1.37
	Rock phospate	0.8604	1.95
	Salt	0.1917	0.43
	Corn silage	0.7761	1.76
	Total ration	44.174 (lb)	

TABLE 5-5. PARAMATERIZATION OF DISTILLERS' DRIED GRAINS IN THE OPTIMAL DAIRY RATION (concluded)

Price Level	Activity Levels		% of Total Ration
6.128	Alfalfa hay	21.86	49.08
	DDG	13.54	30.40
	Corn	6.950	15.60
	Limestone	0.1007	0.23
	Wheat mids	0.3996	0.89
	Rock phospate	0.8619	1.94
	Salt	0.1917	0.43
	Corn silage	0.6389	1.44
	Total ration	44.5308 (lb)	
5.378	Alfalfa hay	28.53	48.93
	DDG	14.33	32.04
	Corn (grain)	6.66	14.89
	Limestone	0.1536	0.34
	Rock phosphate	0.9039	2.02
	Salt	0.1917	0.36
	Corn silage	0.9599	2.15
	Total ration	44.7291 (lb)	
4.628	Alfalfa hay	18.27	40.62
	DDG	15.13	33.63
	Corn	5.968	13.27
	Limestone	0.3631	0.81
	Timothy hay	3.026	6.73
	Rock phosphate	0.7614	1.69
	Salt	0.1917	0.43
	Corn silage	1.270	2.82
	Total ration	44.9802 (lb)	

TABLE 5-6. PARAMATERIZATION OF GLUTEN MEAL IN THE OPTIMAL DAIRY RATION

Price Level	Activity Levels		% of Total Ration
5.586¢/lb	Alfalfa hay	9.485	19.08
	BDG	5.221	10.50
	Corn	12.82	25.79
	Timothy hay	7.228	14.54
	Gluten meal	2.349	4.73
	Wheat mids	4.793	9.64
	Rock phosphate	0.2402	0.48
	Salt	0.1917	0.39
	Corn silage	7.374	14.84
	Total ration	14.84 (lb)	
5.086	Alfalfa hay	11.84	23.67
	BDG	4.350	8.70
	Corn	12.74	25.47
	Timothy hay	5.10	10.19
	Gluten meal	2.524	5.05
	Wheat mids	5.139	10.27
	Rock phosphate	0.2540	10.27
	Salt	0.1917	0.38
	Corn silage	7.887	15.76
	Total ration	50.0257 (lb)	
5.086	Alfalfa hay	17.49	34.42
	BDG	2.261	4.45
	Corn (grain)	12.55	24.70
	Gluten meal	2.944	5.79
	Wheat mids	5.960	11.75
	Rock phosphate	0.2869	0.56
	Salt	0.1917	0.38
	Corn silage	9.117	17.94
	Total ration	50.8086 (lb)	
3.586	Alfalfa hay	17.49	34.15
	BDG	1.520	2.97
	Corn (grain)	10.48	20.46
	Gluten meal	5.173	10.10
	Wheat mids	6.363	12.42
	Rock phosphate	0.2515	0.49
	Salt	0.1917	0.37
	Corn silage	9.748	19.03
	Total ration	51.2172 (lb)	

TABLE 5-6. PARAMATERIZATION OF GLUTEN MEAL IN THE OPTIMAL DAIRY RATION (concluded)

Price Level	Activity Levels		% of Total Ration
3.586	Alfalfa hay	17.51	33.63
	Corn (grain)	6.227	11.96
	Gluten meal	9.746	18.72
	Wheat mids	7.175	13.78
	Wheat (hard)	0.1787	0.34
	Salt	0.1917	0.37
	Corn silage	11.04	21.20
	Total ration	52.07 (lb)	
3.086	Alfalfa hay	16.77	32.18
	Corn (grain)	5.481	10.52
	Timothy hay	0.6726	1.29
	Gluten meal	10.52	20.18
	Wheat mids	7.212	13.84
	Rock phosphate	0.1612	0.30
	Salt	0.1917	0.37
	Corn silage	11.11	21.32
	Total ration	52.1185 (lb)	

excess protein that is necessary to achieve utilization levels of DDG beyond its role as a protein source. It is entirely conceivable that localized DDG production would allow replacement of the brewer's grains in the ration as an energy source as well as a protein source. This is primarily due to two factors. The first is that localized production will permit lower transport costs. The second is that utilization of wet DDG would be possible. Saving the drying step would permit a steep price reduction for DDG (possibly $50/ton).

The parameterization of gluten meal prices and quantities (Table 5-6) indicates once again that the dairy industry in an agriculturally diversified region has no need to pay the transport costs that are associated with the purchase of feed concentrates from centralized markets. The price of gluten meal had to decrease by 2.375¢/lb before this feed ingredient would enter the solution, a decline of 28.6%. As the proportion of gluten meal in the ration increased, there appeared to be a positive relationship between the quantity of gluten meal fed and the amounts of silage, hay, and wheat middlings. This complementarity can be explained by the low fiber content of the gluten meal as well as the apparent surfeit of protein as gluten meal achieves high levels of use in the ration. As Table 5-7 indicates, gluten meal is a relatively expensive way to provide both digestible and metabolizable energy. Obviously, the relationship of gluten meal to DDG will be one of substitutibility unless the distillers' grains were to be fed wet from small-scale production units; then, DDG would decline in price relative to gluten meal because of increased costs to the farmer of handling the wet slops as well as lower processing costs at the distillery. Note that when there is a large amount of gluten meal in the ration, there must be a corresponding maximization of fiber content from the remainder of the feed.* The complementarity of gluten meal and high-fiber feeds thus holds for both economic and dietary reasons.

We may note that the substitutibility of gluten meal for DDG is so great that DDG disappears from the ration altogether when gluten meal achieves just 4.7% of the ration. As was to be expected, gluten meal also substituted for brewers' grains. The high protein content of gluten meal allowed it to be the only protein supplement in the diet when the percentage of the feed was at 10% of the total ration.

5.3 BEEF FEEDLOT SIMULATIONS

The program used to simulate the feeding of beef cattle was based on mineral and vitamin requirements of a 772-lb yearling steer. These requirements allow for a daily gain of 2.4 lb. This daily gain was to be achieved through the

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*The minimum constraint on crude fiber intake was 6.8 lb/day.

TABLE 5-7. MCAL/$ OF DIGESTIBLE AND METABOLIZABLE ENERGY AND THE AMOUNT OF CRUDE FIBER/$

Ingredient	Metobolizable Energy (Mcal/$)	Digestable Energy (Mcal/$)	Crude Fiber (lb/$)
Alfalfa hay	43.95	52.5	14.1
Corn silage	55.9	67.0	8.7
Wheat middlings	8.22	15.6	0.77
Gluten meal	11.32	18.59	0.33

TABLE 5-8. INGREDIENT LIST FOR BEEF RATION AND DELIVERED PRICES

Ingredient	Delivered Price/lb
Brewers' dried grains	6.721
Corn gluten meal (60% protein)	15.75
Hominy feed	6.814
Calcium carbonate	3.20
Rock phosphate	12.00
Dicalium phosphate	12.20
Urea	11.20
Bone meal	26.81
DDGS	9.572
Cottonseed meal	12.00
Soybean meal	12.86
Wheat middlings	8.254
Wheat bran	8.247
Meat meal	16.27
Oats	7.188
Milo sorghum	5.982
Wheat mill run	10.41
Wheat (hard)	16.33
Alfalfa hay (early)	4.726
Alfalfa - dehydrated (17% protein)	7.773
Corn stover silage	0.8380
Linseed meal	10.16
Bermuda grass hay	2.993
Trace mineral salt	4.950
Corn (#2 ground)	7.274

consumption of a minimum of 17.8 lb of dry matter per day. The cost coefficients for the program were set so as to replicate the cost structure of a farm beef feedlot located in the Midwest region. The costs of the feed ingredients were set at bulk price levels at the nearest central market with the transportation charge added. Table 5-8 gives a listing of the potential ingredients that were used in the ration along with their delivered prices. Using the specifications of the program shown in Table B-2, Table 5-9 shows the optimal solution at current delivered price levels. According to this program, daily nutritive and mineral requirements for the animal would require an outlay of approximately $1.065.

In this optimal solution, milo sorghum and Bermuda grass hay were the main energy sources, supplying 83% of the metabolizable energy. Alfalfa hay and Bermuda grass hay supplied the roughage. Protein supplies exceeded minimum requirements.* Milo sorghum provided a majority of the crude protein, indicating its importance not only as an energy source but also as a protein source. The amount of total digestible nutrients (TDNs) were at the minimum allowable level. Milo again supplied a major percentage (75.2%) of TDNs; 82% of its matter is digestible. Milo was exceeded only by gluten meal, hominy feed, and soybean meal. These results show that milo was used as a substitute for corn as an energy source and such protein supplements as soybean meal, cottonseed meal, etc.

TABLE 5-9. OPTIMAL SOLUTION IN A MIDWEST BEEF RATION AT THE CURRENT PRICE STRUCTURE

Ingredient	Pounds of Feed	% of Feed
Brewer's dried grains	0.6958	3.55
Calcium carbonate	0.6074	3.10
Milo sorhum	12.57	64.2
Alfalfa hay	2.513	12.84
Bermuda grass hay	2.381	12.16
Trace mineral salt	0.1019	0.52
Corn (grain)	0.7101	3.63
Total	19.579	

Distillers' dried grains did not enter into the optimal solution. The delivered price of DDG would have had to decrease approximately 3¢/lb before the program would recommend its use in the ration formulation. With a current delivered price of 9.572¢/lb, this constitutes a relative price decline of

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*The minimum amount of crude protein was set at 1.828 lb. The minimum amount of digestible protein was 1.145 lb.

31.6%. As in the dairy model, the necessity for such a large relative price decline justifies the establishment of small, localized ethanol producers. If the trend toward higher transportation charges continues, larger percentages of the delivered price potentially could be composed of these charges. With local production of ethanol, such charges could be avoided, resulting in a relative price decline of these feed joint products. This conclusion can also be applied to gluten meal, which must experience a relative price decline of 59% before its usage in the ration becomes economical.

It should be noted that there were no high-protein feeds in solution. Since the above program considers only the cost of the feed ingredients and not the cost of handling the feed, the fact that high-protein feeds are compact and easier to handle was not taken into consideration. Local supply availability is another environmental factor that should be considered. The solution algorithm assumes that the feedlot operator has the ability to obtain as much of the feed as desired. Often, however, supplies of all the potential feed ingredients may not be available. Other factors affecting feedgrain usage are local price conditions at the time of the ration formulation. Again, this is interrelated with the supply issue. Local custom, another consideration that determines the type of ration developed, will vary across regions.*

Tables 5-10 and 5-11 give the results of parameterizing prices and maximum allowable quantitities of DDG and corn gluten meal in the beef ration. As these joint products become relatively inexpensive, and as more of these feeds are allowed to be used, they supply major portions of energy and protein. This is similar to the pattern exhibited in the dairy ration. Tables 5-12 and 5-13 give protein and metabolizable energy composition as the parameterization process continued. An important factor to note is that the forages remained at a relatively constant level. Although ethanol joint products supply energy and protein in this situation, they cannot assume the role of the forages essential to the digestion process of ruminants such as dairy and beef cattle. As with dairy cattle, the greater the percentage of energy and protein requirements of beef cattle that can be met out of forage crops, the more difficult it will be for joint products to significantly affect the feedgrain market. In the beef ration, forages supply approximately 25% of metabolizable energy and 15-20% of digestible protein. The joint-product feeds replace the remaining energy supplied by milo sorghum and brewer's dried grains. Again, this implies that the extent to which these joint products can enter into the feedgrain market is dependent on the amount of protein and energy supplied by roughages.

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*See E. L. Bramhall et al., and the Protein Supplementation for Feedlot Cattle, November 1978.

Table 5-10. PARAMATERIZATION OF DISTILLERS' DRIED GRAINS IN THE OPTIMAL BEEF RATION

Price Level	Feed Composition Values (lb)		% of Ration
6.072¢/lb	Calcium carbonate	0.7345	3.77
	BDG	0.3785	1.94
	Distiller's grains	1.951	10.00
	Milo sorghum	11.00	56.39
	Alfalfa hay	2.609	13.38
	Bermuda grass hay	2.268	11.63
	Trace mineral salt	0.1016	0.52
	Corn (grain)	0.4633	2.38
	Total ration	19.5056	
6.072	Calcium carbonate	0.8607	4.424
	BDG	0.0628	0.3230
	DDG	3.888	20.00
	Milo sorghum	9.449	48.61
	Alfalfa hay	2.703	13.91
	Bermuda grass hay	2.156	11.09
	Trace mineral salt	0.1012	0.5206
	Corn (grain)	0.2183	1.123
	Total ration	19.439	
6.072	Calcium carbonate	0.9349	4.827
	DDG	5.811	30.00
	Milo sorghum	7.680	39.65
	Alfalfa hay	2.793	14.42
	Bermuda grass hay	2.049	10.57
	Trace mineral salt	0.1009	0.5209
	Total ration	19.3688	
6.072	Calcium carbonate	0.9885	5.123
	DDG	7.720	40.00
	Milo sorghum	5.666	29.36
	Alfalfa hay	2.786	14.44
	Bermuda grass hay	2.039	10.57
	Trace mineral salt	0.1005	0.5208
	Total ration	19.297	

Table 5-11. PARAMATERIZATION OF GLUTEN MEAL IN THE OPTIMAL BEEF RATION

Price Level	Feed Composition Values		% of Total Ration
6.25¢/1b	BDG	0.1293	0.6612
	Gluten meal	1.955	9.997
	Calcium carbonate	0.8048	4.115
	Milo sorghum	11.42	58.40
	Alfalfa hay	2.694	13.78
	Bermuda grass hay	2.194	11.22
	Trace mineral salt	0.1018	0.5206
	Corn (grain)	0.2570	1.314
	Total ration	19.5559	
6.25	Gluten meal	3.023	15.47
	Calcium carbonate	0.8769	4.489
	Milo sorghum	10.65	54.52
	Alfalfa hay	2.802	14.34
	Bermuda grass hay	2.082	10.66
	Trace mineral salt	0.107	0.5206
	Total ration	19.5356	
5.75	Gluten meal	3.905	20.00
	Calcium carbonate	0.9075	4.648
	Milo sorghum	9.729	49.83
	Alfalfa hay	2.797	14.33
	Bermuda grass hay	2.084	10.67
	Trace mineral salt	0.1017	0.5209
	Total ration	19.5242	

Table 5-11. PARAMATERIZATION OF GLUTEN MEAL IN THE OPTIMAL BEEF RATION (concluded)

Price Level	Feed Composition	Values	% of Total Ration
5.75	Corn gluten meal	5.848	30.00
	Calcium carbonate	0.9751	5.002
	Milo sorghum	7.696	39.48
	Alfalfa hay	2.788	14.30
	Bermuda grass hay	2.086	10.70
	Trace mineral salt	0.1015	0.5207
	Total ration	19.4946	
5.75	Gluten meal	7.785	40.00
	Calcium carbonate	1.042	5.354
	Milo sorghum	5.669	29.13
	Alfalfa hay	2.778	14.27
	Bermuda grass hay	2.088	10.73
	Trace mineral salt	0.1014	0.5210
	Total ration	19.4634	

TABLE 5-12. COMPOSITION OF METABOLIZABLE ENERGY AND DIGESTIBLE PROTEIN AT THE CURRENT PRICE STRUCTURE FOR DISTILLERS' DRIED GRAINS AT 6.072¢/LB

Ingredients	% Met Energy Original	% Met. Energy 10% of Ration	% Met. Energy 20% of Ration	% Met. Energy 30% of Ration	% Met. Energy 40% of Ration	% Dig Protein Original	% Dig. Protein 10% of Ration	% Dig. Protein 20% of Ration	% Dig. Protein 30% of Ration	% Dig. Portein 40% of Ration
Brewers' dried grains	3.12	1.70	0.28	0	0	5.39	4.54	0.65	0	0
DDG	0	11.58	23.09	34.47	45.84	0	26.37	45.5	58.89	69.04
Alfalfa hay	9.52	9.89	10.25	10.58	10.56	21.37	18.70	16.78	15.01	13.21
Bermuda grass hay	16.9	16.1	15.30	14.52	14.47	8.095	4.85	3.99	3.28	2.88
Corn	4.26	2.78	1.31	0	0	3.58	2.18	0.89	0	0
Milo	66.2	57.9	49.78	40.42	29.847	59.09	43.56	32.42	22.81	14.85
Total supplied	22.4 (mcal)	22.4	22.4	22.4	22.4	1.3401 (lb)	1.5907	1.8364	2.1213	2.404

TABLE 5-13. COMPOSITION OF METABOLIZABLE ENERGY AND DIGESTABLE PROTEIN AT THE CURRENT PRICE STRUCTURE FOR GLUTEN MEAL AT 5.75¢/LB

Ingredients	% Met. Energy Original Solution	% Met. Energy 10% of Ration	% Met. Energy 20% of Ration	% Met. Energy 30% of Ration	% Met. Energy 40% of Ration	% Dig. Protein Original Solution	% Dig. Protein 10% of Ration	% Dig. Protein 20% of Ration	% Dig. Protein 30% of Ration	% Dig. Portein 40% of Ration
BDG	3.12	0.58	0	0	0	5.39	1.19	0	0	0
Gluten meal	0	11.96	23.76	35.17	46.31	0	44.77	64.8	76.02	83.20
Milo sorghum	66.2	60.16	50.98	39.37	29.05	43.56	34.77	21.48	13.30	8.05
Alfalfa hay	9.52	10.21	10.54	10.39	10.24	21.37	14.84	11.21	8.72	7.14
Bermuda grass hay	16.9	15.57	14.71	14.56	14.42	8.095	3.61	2.48	1.95	1.60
Corn	4.26	1.52	0	0	0	3.58	0.82	0	0	0
Amount supplied	22.4 (mcal)	22.4	22.52	22.78	23.03	1.3401 (lb)	2.069	2.854	3.646	4.435

Table 5-14. INGREDIENTS USED FOR THE POULTRY PROGRAM AND DELIVERED PRICES

Ingredient	Delivered Price (¢/lb)
Corn (ground #2)	8.540
Alfalfa meal (dehydrated-17% protein)	10.93
Soybean meal	14.39
Dicalcium phosphate	30.90
Ground limestone	3.196
Trace mineral salt	54.00
Meat and bone meal	14.85
Meat meal	16.67
Distiller's dried grains (with solubles)	9.3751
Corn gluten meal (60% protein)	15.04
Cottonseed meal	11.36
Deflourinated rock phosphate	12.00
Milo sorghum	7.568
Hominy feed	9.734
Brewer's dried grains	5.916
Fish meal (menhaden)	26.71
Oats	9.915
Wheat bran	8.199
Wheat middlings	8.526
Wheat (hard)	16.25
Brewers' yeast	6.183

Table 5-15. OPTIMAL POULTRY SOLUTION

Ingredient	Value (grams)	% of Total
Corn	0.6118	0.56
Ground limestone	8.638	7.85
Trace mineral salt	0.4010	0.36
Vitamin premix	0.04735	0.04
DDGS	0.06196	0.06
Gluten meal	10.02	9.11
Defluorinated rock phosphate	0.1226	0.11
Milo sorghum	55.00	50.00
Brewer's dried grains	18.17	16.52
Fish meal	3.781	3.44
Wheat middlings	13.14	11.95
Total ration	110.0	

5.4 POULTRY SIMULATIONS

The program developed for the poultry phase of the analysis was based on nutritional and mineral requirements established for Single-Comb White Leghorns and similar laying breeds weighing approximately 1.8 kilograms (3.96 lb). The tableau used for the analysis is shown in Table B-3. Table 5-14 lists the feed ingredients included in the program formulation and their delivered prices. The price data was based upon the price structure facing the California poultry industry. Table 5-15 gives the solution to the optimization process. With this vector of activities, the daily cost per laying hen was approximately 2.040¢. The amount of feed intake per day was set at 110 grams. This allowed for an egg production level of 90% of the maximum at a temperature of 70°C.*

Since poultry are not ruminants, the amount of fiber in their diet was a major concern. Surprisingly, supplying 40% of the ration with DDG did not increase the amount of fiber in the diet (4.7%). The reason for this is that the higher fiber ingredient BDG was completely replaced by DDG, which has 41% less fiber. The implication is that, unlike the application of these joint products to swine, the fiber content of DDG was not a problem. With the optimal solution there was an excess amount of protein supplied. With a minimum requirement of 16.5 grams per day, the program exceeded that by 22%. The high protein concentration of gluten meal caused an increase in the excess protein supplied. Metabolizable energy was at the minimum level of 297 kcal. Table 5-16 shows contributions to protein and energy requirements in the optimal solution.

TABLE 5-16. CONTRIBUTION OF FEED INGREDIENTS IN THE POULTRY RATION TOWARD PROTEIN AND METABOLIZABLE ENERGY REQUIREMENTS

Ingredients	Protein Supplied	% of Total	M. E. Supplied	% of Total
Corn (grain)	0.054	0.27	2.1	0.71
DDGS	0.017	0.08	0.042	0.014
Gluten meal	6.21	30.8	37.27	12.55
Milo sorghum	4.895	24.27	185.35	62.41
BDG	4.597	22.79	37.79	12.72
Fish meal	2.288	11.34	10.66	3.59
Wheat middlings	2.102	10.42	23.65	7.96

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*To get an idea of the magnitude of these feed costs, an operation with 50,000 birds using the results of this program would have a daily feed bill of $1,020.00.

Milo sorghum was the key energy-supplying feed ingredient. Because of corn gluten meal's relatively high metabolizable energy coefficient (and the fact that the energy constraint was at its minimum allowable level) gluten meal replaced the energy source more quickly than did DDG. As seen in Tables 5-17 and 5-18, when the upper bounds of DDG were relaxed to a level of 40%, milo decreased by 29% from the original solution level (along with decreasing the level of wheat middlings by 10 grams). Alternatively, allowing the ration to be composed of 40% gluten meal caused a decrease of 70.9% in milo, as a result of the 32% increase in gluten meal usage. Not only did gluten meal replace milo as an energy source, but it also supplied sufficient energy to enable fish meal, DDG, corn, and wheat middlings to be left out of the solution.

The results of the optimization process imply that the most important property of these joint product feeds for poultry production is their composition. The impacts of extending usage of these feeds in the poultry industry will be felt not only in protein markets but also in energy feed markets. This concurs with results obtained from the dairy and beef cattle analyses.

5.5 SWINE RESULTS

The least-cost ration for swine was formulated in order to simulate the price structure and physical operations of a commercial hog operation located in Iowa. Nutritional and mineral requirements were established to meet the needs for an animal weighing between 135-200 lb and with an expected daily gain of 2 lb. These requirements were met through consumption of at least 7.75 lb of feed. Bulk prices used for the program were taken from the nearest central market with a transportation charge added. Table 5-19 shows the potential feed ingredients used in the program and their delivered prices. The original tableau is shown in Table B-4.

The least-cost solution shown in Table 5-20 shows a daily outlay per animal of 50.556¢. As shown in Table 5-21, ground corn was the major supplier of energy and protein, comprising 62% of the ration. The feed supplements had a combined contribution of 49% of the crude protein supplied. Because swine are nonruminants, fiber concentration was an important attribute in the ration formulation.

In the original formulation of the ration, the fiber concentration was below the maximum allowable level. The addition of DDG, relatively high in fiber, will cause the fiber level to increase. Parameterizing the allowable levels of DDG in the solution, the maximum amount of fiber was reached when DDG

Table 5-17. METABOLIZABLE ENERGY AND PROTEIN COMPOSITION AT SELECTED PRICES AND CONSTRAINT SITUATIONS FOR DDG

	10% at 7.468¢/lb		20% at 6.6511¢/lb		30% at 6.6511¢/lb		40% at 5.743¢/lb	
Ingredient	% M. E.	% Protein	% M. E. at 0%	% Protein	% M. E.	% Protein	% M. E.	% Protein
Corn	0	0	0	0	0	0	0	0
DDGS	9.15	15.14	18.37	29.87	27.56	41.35	36.7	48.47
Gluten meal	9.42	23.69	8.07	19.94	10.13	23.09	13.65	27.37
Milo sorghum	62.14	24.77	59.87	23.44	53.61	19.37	44.48	14.13
BDG	7.48	13.73	2.95	5.33	0	0	0	0
Wheat mids	7.51	10.07	6.83	9.00	5.44	6.62	2.12	2.27
Fish meal	4.21	12.60	3.91	12.43	3.25	2.076	3.01	7.77
Amount supplied	298.29	19.759	297.0	20.034	297.0	21.707	297.0	24.692

Table 5-18. METABOLIZABLE ENERGY AND PROTEIN COMPOSITION, SELECTED PRICES AND CONSTRAINT SITUATIONS FOR GLUTEN MEAL

	10% at 14.1194¢/lb		20% at 14.1194¢/lb		30% at 8.222¢/lb		40% at 8.222¢/lb	
Ingredient	% M. E.	% Protein	% M. E.	% Protein	% M. E.	% Protein	% M. E.	% Protein
Corn	0	0	0	0	0	0	0	0
DDGS	0.05	0.082	0.05	0.064	0	0	0	0
Gluten meal	13.73	33.02	27.55	52.23	41.33	61.7	55.11	72.04
Milo sorghum	68.63	23.48	47.40	14.24	30.26	7.16	18.13	3.76
Fish meal	3.46	10.41	0.009	2.22	0	0	0	0
Wheat mids	7.81	9.91	5.52	5.58	0	0	0	0
Brewer's yeast	0	0	0	0	0.20	0.43	0	0
Amount supplied	298.109	20.654	297.0	26.116	297.0	33.16	297.0	37.87

Table 5-19. FEED INGREDIENTS USED IN THE SWINE RATION AND DELIVERED PRICES

Feed Ingredient	Delivered price/lb
Alfalfa (dehydrated)	6.478
Alfalfa (suncured)	5.410
Barley	6.492
Corn (#2 ground)	4.500
Cottonseed meal	12.48
Distillers' dried grains	9.377
Fish meal (anchovy)	
Fish meal (menhaden)	15.43
Corn gluten meal	5.540
Hominy feed	19.46
Meat and bone meal	5.768
Milo sorghum	6.145
Oats	6.145
Cane molasses	6.903
Skim milk (dehydrated)	
Soybean meal	11.00
Tankage	17.26
Wheat (hard)	17.73
Wheat middlings	8.954
Brewers' yeast	6.183
Linseed meal	11.89
Trace mineral salt	4.950
Vitamin premix	54.00

Table 5-20. OPTIMAL SOLUTION FOR THE SWINE RATION

Ingredient	Value (lb)	% of Total Ration
Corn (#2 ground)	4.834	62.37
Alfalfa (dehydrated)	0.3875	5.0
Alfalfa (suncured)	0.3875	5.0
DDG	0.3875	5.0
Meat and Bone Meal	0.3875	5.0
Soybean Meal	0.5879	7.59
Wheat Middlings	0.5701	7.36
Brewer's Yeast	0.1425	1.84
Trace Mineral Salt	0.06055	0.78
Vitamin Premix	0.005	0.06
Total Ration	7.75	

Table 5-21. CONTRIBUTION OF FEED INGREDIENTS TOWARD SUPPLYING ENERGY AND PROTEIN

Ingredient	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Corn (#2 ground)	33.62	66.35	67.39
Alfalfa (dehydrated)	5.36	3.89	3.68
Alfalfa (suncured)	4.59	3.89	3.18
Distiller's dried grains	8.33	5.38	5.50
Meat and bone meal	15.44	4.32	3.95
Soybean meal	20.45	7.69	7.61
Wheat middlings	7.21	6.77	7.02
Brewers' yeast	5.00	1.74	1.70
Total supplied	1.2652 (lb)	11660 (kcal)	10838 (kcal)

constituted slightly less than 20% of the ration.* This implies that even with localized production of this feedstuff, the use of DDG as a feed supplement may be limited. (See also Tables 5-22 and 5-23.)

As expected, increased use of these joint-product feed ingredients in the ration affected the levels of the other protein supplements most. The substitutions that occurred in the ration were such that DDG and gluten meal did not displace the energy source (corn grain) at as high a rate as in the previous ration formulations. DDG and gluten meal consistently supplied more than proportionate amounts of crude protein, but just proportionate amounts of energy. As shown in previous ration formulations, there must be substantial price reductions before these joint products will be used to any great degree. Again, this supports the concept of localized production facilities. What is unique to the swine operation is that there is no substitution of joint products for the energy component in the ration. For example, there would be competition (in this case, for corn) if an ethanol plant were located in an area that specialized in hog production. Such a situation could cause dramatic increases in local production costs and could change the structure of local or regional economies.

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*This level of DDC usage was reached after a 40% decrease in its relative cost had occured.

Table 5-22. CONTRIBUTION OF FEED INGREDIENTS TOWARD MEETING ENERGY AND PROTEIN REQUIREMENTS AS THE AMOUNT OF DISTILLERS' DRIED GRAINS IS INCREASED IN THE SWINE RATION

Distillers' Dried Grains at a Maximum of 10% of the Ration (Current Price Situation)

Optimal Solution		% of Total	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3875	5.0	6.39	3.85	3.63
Alfalfa (suncured)	0.3875	5.0	5.48	3.85	3.14
Corn	5.274	60.05	43.76	71.66	72.45
DDG	0.7750	10.00	19.87	10.66	10.85
Meat and bone meal	0.2443	3.15	11.61	2.70	2.46
Soybean meal	0.01321	0.17	0.55	0.17	0.17
Wheat mids	0.4820	6.22	7.27	5.67	5.85
Brewer's yeast	0.1205	1.55	5.05	1.46	1.41
Trace mineral salt	0.06055	0.78	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Total supplied	7.75 (lb)		1.0604 (lb)	1.1779 (kcal)	1.0989 (kcal)

Distillers' Dried Grains at a Maximum of 20% of the Ration (Current Price Situation)

Optimal Solution		% of Total	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3828	4.94	6.28	3.76	3.54
Alfalfa (suncured)	0.3875	5.0	5.45	3.81	3.10
Corn	5.376	69.37	44.36	72.19	72.96
DDG	1.246	16.07	31.78	16.94	17.24
Meat and bone meal	0.1632	2.11	7.71	1.78	1.62
Soybean meal	0.01313	0.17	0.54	0.17	0.17
Brewer's yeast	0.1154	1.49	4.8	1.34	1.34
Trace mineral salt	0.06055	0.78	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Total supplied	7.75 (lb)		1.0665	1.1919 (kcal)	1.1123 (kcal)

Distillers' Dried Grains at a Maximum of 20% of the Ration (Current Price Situation)

Optimal Solution		% of Total	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3875	5.0	6.21	3.83	3.61
Alfalfa (suncured)	0.3875	5.0	5.32	3.83	3.12
Corn	5.279	68.12	42.51	71.31	72.00
DDG	1.398	18.04	34.80	18.16	19.44
Meat and bone meal	0.09051	1.17	4.17	0.99	0.95
Oats	0.01332	0.17	0.14	0.15	0.13
Soybean meal	0.01321	0.17	0.53	0.17	0.17
Trace mineral salt	0.06055	0.78	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Linseed meal	0.1150	1.48	6.31	0.61	0.60
Total supplied	7.75 (lb)		1.0927 (lb)	1.1847 (kcal)	1.1069 (kcal)

Table 5-23. CONTRIBUTION OF FEED INGREDIENTS TOWARD MEETING ENERGY AND PROTEIN REQUIREMENTS AS THE AMOUNT OF GLUTEN MEAL IS INCREASED IN THE SWINE RATION DUE TO A RELATIVE PRICE DECLINE

Gluten Meal at a Maximum of 5% of the Ration (10.83¢/lb)

Optimal Solution		% Of Total Ration	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3875	5.0	5.13	3.89	3.68
Alfalfa (suncured)	0.3875	5.0	32.79	3.89	3.18
Corn	4.925	63.55	32.79	67.59	68.50
DDG	0.3875	5.0	7.97	5.38	5.50
Gluten meal	0.3875	5.0	17.59	4.87	4.97
Meat and bone meal	0.3875	5.0	14.77	4.32	3.95
Soybean meal	0.2292	2.96	7.63	2.99	2.96
Wheat mids	0.4744	6.12	5.74	5.63	5.83
Brewer's yeast	0.1186	1.53	3.98	1.45	1.41
Trace mineral salt	0.06055	0.78	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Total supplied	7.75		1.3219	1.1662 (kcal)	1.0853 (kcal)

Gluten Meal at a Maximim of 10% of the Ration (10.83¢/lb)

Optimal Solution		% of Total Ration	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3875	5.0	5.0	3.89	3.68
Alfalfa (suncured)	0.3875	4.29	4.29	3.89	3.18
Corn	4.979	64.25	32.31	68.33	69.20
DDG	0.3875	5.0	7.77	5.38	5.49
Gluten meal	0.6208	8.01	27.46	7.81	7.96
Meat and bone meal	0.3875	5.0	14.40	4.32	3.94
Soybean meal	0.01321	0.17	0.43	0.17	0.17
Wheat mids	0.4169	5.38	4.92	4.95	5.12
Brewer's yeast	0.1042	1.34	3.41	1.27	1.24
Trace mineral salt	0.06055	0.78	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Total supplied	7.75		1.3561 (lb)	1.1662 (kcal)	1.0862 (kcal)

Gluten Meal at a Maximum 10% of the Ration (8.83¢/lb)

Optimal Solution		% of Total Ration	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3875	5.0	4.80	3.89	3.68
Alfalfa (suncured)	0.3875	5.0	4.11	3.89	3.17
Corn	4.889	63.08	30.45	67.11	67.72
DDG	0.3875	5.0	7.46	5.38	5.49
Gluten meal	0.7750	10.00	32.91	9.75	9.94
Meat and bone meal	0.3394	4.38	12.11	3.79	4.17
Soybean meal	0.01321	0.17	0.41	0.17	0.17
Wheat middlings	0.4040	5.21	4.57	4.80	4.96
Brewer's yeast	0.1010	1.30	3.17	1.23	1.20
Trace mineral salt	0.06055	0.7	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Total supplied	7.75		1.413	1.1659 (kcal)	1.0866 (kcal)

TABLE 5-23. CONTRIBUTION OF FEED INGREDIENTS TOWARDS MEETING ENERGY AND PROTEIN REQUIREMENTS AS THE AMOUNT OF GLUTEN MEAL IS INCREASED IN THE SWINE RATION DUE TO A RELATIVE PRICE DECLINE (concluded)

Gluten Meal at a Maximum of 20% of the Ration (8.83¢/lb)

Optimal Solution		% Total Ration	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3875	5.0	4.56	3.09	3.67
Alfalfa (suncured)	0.3875	5.0	3.91	3.89	3.17
Corn	4.773	61.59	28.26	65.54	66.27
DDG	0.3875	5.0	10.54	5.38	5.45
Gluten meal	0.9738	12.57	39.31	13.25	12.40
Meat and bone meal	0.2774	3.58	9.41	3.72	2.82
Soybean meal	0.01321	0.17	0.39	0.17	0.17
Wheat mids	0.3875	5.0	4.17	4.60	4.76
Brewer's yeast	0.09688	1.25	2.89	1.18	1.15
Trace mineral salt	0.06055	0.78	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Total supplied	7.75 (lb)		1.4863 (lb)	1.1655 (kcal)	1.0872 (kcal)

Gluten Meal at a Maximum of 20% of the Ration (6.833¢/lb)

Optimal Solution		% Total Ration	% Crude Protein	% Digestible Energy	% Metabolizable Energy
Alfalfa (dehydrated)	0.3325	4.29	3.42	3.35	3.15
Alfalfa (suncured)	0.3325	4.29	2.93	3.35	2.72
Corn	4.472	57.7	23.10	61.52	62.00
DDG	0.3325	4.29	5.31	4.63	4.70
Gluten meal	1.550	20.00	54.60	19.53	19.83
Meat and bone meal	0.1669	2.15	4.94	1.87	1.69
Molasses	0.0711	0.92	0.1200	0.6800	0.6900
Soybean meal	0.01133	0.15	0.29	0.15	0.15
Wheat Mids	0.3325	4.29	3.12	3.96	4.08
Brewer's yeast	0.08312	1.07	2.17	1.02	0.98
Trace mineral salt	0.06055	0.78	0	0	0
Vitamin premix	0.005	0.06	0	0	0
Total supplied	7.75		1.7033	1.1638	1.0889

SECTION 6.0

CONCLUSION

The linear programming simulations of least-cost ration formulations for beef and dairy cattle, poultry, and swine indicate that transport costs are an important component of the overall cost of a ration. An alcohol production program maximizing local production will be accepted with the fewest upsets to feed prices. In hog-producing areas, the potential for local consumption of joint products appears limited due to the low productivity of DDG or gluten meal in the hog's diet. Overall, using DDG/gluten meal for 10% of animal protein requirements appears feasible, with local production of ethanol.*

Beyond these protein-market effects, increased use of DDG and gluten meal will mitigate upward pressures on corn and milo prices to the extent that these two crops are feedstocks for ethanol production. Given the ability of DDG/gluten meal to substitute for energy and protein, the demand for additional digestible energy as a replacement for that lost to the ethanol can come from forages rather than from significant additions to grain acreage -- at least in the initial stages (up to at least 1 billion gal./yr) of a program. This appears beneficial both ecologically (in terms of minimizing stress on marginal croplands) and economially (in terms of preventing a cost-price squeeze on farmers that vastly increased cultivation of marginal lands would imply).

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*This would imply production of at least 3 billion gal./yr of ethanol from grain.

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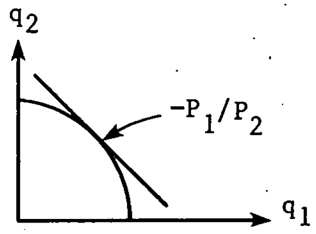
APPENDIX A

OUTPUT AND PRICE DECISIONS OF A MULTIPRODUCT FIRM AND VALUATION OF ETHANOL JOINT PRODUCTS

In this paper, we have assumed a fixed-proportions joint-production function for ethanol of the form

$$X_1 = \alpha q_1 + (1-\alpha)q_2$$

where X is the grain input, q_1 is ethanol output, q_2 is DDG and α is the fixed proportions production coefficient. Since $\frac{dq_1}{dq_2} = \frac{dx_1}{\alpha}$, this relation does not define a product transformation curve that permits equilibrium pricing as in the standard diagram below.



At b $\frac{P_1}{P_2} = \frac{\partial q_2}{\partial q_1}$,

in our example of fixed proportions, the equilibrium condition is $\frac{P_1}{P_2} = \frac{\alpha}{(1-\alpha)}$. There is no reason to believe that this condition will be met when the outputs q_1, q_2 are produced from a relatively small number of plants. We may argue, then, that we need to consider the additional joint products corn oil (q_3), gluten meal (q_4), and other joint products (q_5) that can be wrought from the ethanol process. Clearly the ability to produce a wide variety of outputs should allow adjustment according to marginal allocation rules. This requires admission of such additional inputs as fixed capital (x_2), working capital (x_3), other feedstocks (x_4), and the cost of switching from one process to another. If we denote the fixed capital inputs F, and aggregate x_1, x_3, and x_4 into variable costs V, then we get the multiproduct firm model of Ferguson (1969, pp. 201-11). The producer's objective is to minimize the cost of producing given levels of output of the various products. Defining the additional variables:

S_{ij} = cost of switching fixed input i to use j
j = Total amount of input i where

$$\sum_{j=1}^{n} y_{ij} - y_i \leqslant 0 \quad (i = 1,2,\ldots,n)$$

$$S = S(y_{ij}), \quad (i = 1,2,\ldots,n), \quad (j = 1,2,\ldots,m)$$

w_k = cost of input $x_{kj} (k = 1,2,\ldots,r)$.

The cost function is

$$V + S + F = \sum_{k=1}^{r} \sum_{j=1}^{n} w_k x_{kj} + S(y_{ij}) + F ,$$

subject to the output constraint

$$\underline{q} = \underline{f} \; (x,y) \text{ (in matrix notation) or}$$
$$q_j = f_j \; (x_{kj}, y_{ij}) \quad ,$$

and the fixed capital constraint

$$\sum_{j=1}^{m} y_{ij} \leqslant y \quad .$$

This gives the nonlinear programming problem

$$L(x,y,\lambda_1,\lambda_2) = \sum_{k=1}^{r} \sum_{j=1}^{m} W_j \, x_{kj} + S(y_{ij}) + F + \sum_{j=1}^{m} \lambda_{ij} \left[q_j - f_j(x_{kj}, y_{ij}) \right]$$

$$+ \sum_{j=1}^{m} \lambda_{2j} \left[\sum_{i=1}^{n} y_{ij} - y_i \right] \quad . \tag{1}$$

The Kuhn-Tucker conditions are

$$\frac{\partial L}{\partial x_{kj}} = W_j - \lambda_{ij} \frac{\partial f_j}{\partial x_{kj}} \leqslant 0 \tag{2}$$

$$x_{kj} \frac{\partial L}{\partial x_{kj}} = 0$$

$$\frac{\partial L}{\partial y_{ij}} = \frac{\partial S}{\partial y_{ij}} - \lambda_{ij} \frac{\partial f_j}{\partial y_{ij}} + \lambda_{2j} \leqslant 0 \tag{3}$$

$$y_{ij} \frac{\partial L}{\partial y_{ij}} = 0$$

$$\frac{\partial L}{\partial \lambda_{ij}} = q_j - f_j(x_{kj}, y_{ij}) \geqslant 0 \tag{4}$$

$$\lambda_{ij} \frac{\partial L}{\partial \lambda_{ij}} = 0 \ .$$

$$\frac{\partial L}{\partial \lambda_{2j}} = \sum_{i=1}^{n} y_{ij} - y_i \geqslant 0 \tag{4}$$

$$\lambda_{2j} \frac{\partial L}{\partial \lambda_{2j}} = 0 \ . \tag{5}$$

INTERPRETATION

The equilibrium conditions given by (2) through (5) show the production equilibrium and also show why a good may not be produced. For example, we have assumed continuous production functions. In reality, this is not likely to occur. Rather, there will be a series of fixed-proportions relations similar to activity analysis problems. The first equilibrium condition is

$$\frac{w_a}{w_b} = \frac{\partial f_j / \partial x_{aj}}{\partial f_j / \partial x_{bj}} \ , \tag{6}$$

the familiar equality of input prices, ratios, and rates of technical substitution. Secondly,

$$\frac{\lambda_{ic}(\partial f_c / \partial x_{kc})}{\lambda_{1d}(\partial f_d / \partial x_{kd})} = 1 \ , \tag{7}$$

i.e., the imputed marginal revenue product must be the same for all outputs.

For the fixed capital inputs we have the equilibrium conditions

$$\frac{\partial S}{\partial y_{ij}} = \lambda_{ij} \frac{\partial f_j}{\partial y_{ij}} - \lambda_{2j} \quad , \tag{8}$$

$$\text{i.e.,} \quad \frac{\partial S}{\partial y_{ij}} + \lambda_{2j} = \lambda_{ij} \frac{\partial f_i}{\partial y_{ij}} \quad . \tag{9}$$

which means that the switching cost plus the imputed value of a particular fixed capital good must equal the marginal revenue product of additional production. As with the variable inputs, this condition generalizes to a ratio equilibrium condition that

$$\frac{(\partial S/\partial y_{ia}) + \lambda_{2a}}{(\partial S/\partial y_{ib}) + \lambda_{2b}} = \frac{\lambda_{1a}(\partial f_a/\partial y_{ka})}{\lambda_{1b}(\partial f_b/\partial y_{kb})} \quad ,$$

which means that the ratio of switching costs must be equivalent to the ratio of marginal revenue products for all outputs.

How is such an abstract model to be used? First, we consider the estimation of the production functions and simplify them through activity analysis to manageable form. Second, we consider the range of variations of input prices and switching costs that obtain. Finally, solving the problem will, for a range of input prices and fixed capital constraints and/or output constraints, give a series of imputed values or shadow prices of output that will serve as a surrogate supply curve. To this supply model we add a cattle feeding model that gives imputed values for the feed joint products in terms of incremental productivity in livestock and dairy production. Short of waiting, the requisite amount of time to get enough observations for statistical validity, the best alternative seems to be construction of supply-and-demand simulation models of the form given in (1).

APPENDIX B

RATION FORMULATIONS FOR DAIRY AND BEEF CATTLE, POULTRY, AND SWINE

Table B-1. Dairy Cattle Ration Formulation

Activities Constraints	Alfalfa, Dehydrated	Alfalfa Hay (early)	Barley Grain	Bone Meal (steamed)	Brewer's Dried Grains	Distiller's Dried Grains	Hominy Feed	Corn (02 Ground)	Cottonseed Meal	Dicalcium Phosphate	Fish Meal Menhaden	Linseed Meal	Limestone	Meat Meal	Meat and Bone Meal	Milk (Whole Dehydrated)	Oats, Grain	Soybean Meal	Timothy Hay	Wheat Bran	Corn Gluten Meal	Wheat (Hard)	Wheat Middlings	Bermuda Grass Hay	Rock Phosphate	Salt	Calcium Use	Phosphorous Use	Urea	Corn Stover Silage		RHS	
Crude Protein	.1840	.1560	.1250	.1104	.2410	.2760	.1083	.090	.4190	0	.6170	.3541	0	.5336	.5080	.2538	.1225	.4470	.085	1622	.6050	.1297	.1700	.055	0	0	0	0	2.810	.02	≥	6.0	(lb)
Net Energy (Lac)	.5940	.5360	.7810	.1069	.6310	.8540	.8870	.8310	.7299	0	.7100	.7648	0	.7883	.7030	0	.7117	.7600	.5270	6505	.8080	.8306	.7590	.4376	0	0	0	0	0	.3410	≥	29.2	(mcal)
Metabolizable Energy	.9790	.8790	1.320	.1026	1.050	1.440	1.523	1.414	1.224	0	1.194	1.220	0	1.243	1.179	2.217	1.198	1.288	.8630	1.090	1.367	1.420	.7670	.7000	0	0	0	0	0	.5596	≥	49.2	(mcal)
Digestable Energy	1.159	1.050	1.500	.2765	1.220	1.630	1.688	1.586	1.404	0	1.370	1.395	0	1.420	1.358	2.450	1.370	1.459	1.035	1.261	1.540	1.587	1.455	.8771	0	0	0	0	0	.6700	≥	56.8	(mcal)
TDN	.5790	.5270	.7480	.1391	.6100	.8150	.8440	.7930	.7009	0	.6850	.6972	0	.7100	.6790	1.226	.6850	.7297	.5180	.6310	.7710	.7930	.7270	.8991	0	0	0	0	0	.1400	≥	28.4	(lb)
Crude Fiber	.2520	.2820	.0540	.0173	.1480	.0530	.0550	.0180	.1215	0	.0093	.0917	0	.0187	.0189	0	.1081	.0631	.2860	.0591	.0275	.0270	.0727	.3119	0	0	0	0	0	.0870	≥	6.8	(lb)
Acid Det. Fiber	.3270	.3640	.0630	0	.2130	0	.1100	.0270	0	0	0	0	0	0	0	0	.1530	.0900	.3570	.1081	0	0	0	.3211	0	0	0	0	0	.4000	≥	8.4	(lb)
Calcium	.0134	.0114	.00045	.2653	.0027	.00148	.00055	.00027	.0016	.2279	.0519	.0039	.3607	.0791	.0971	.0101	.00063	.0032	.0037	.0011	.00165	.00045	.0011	.0042	.165	0	0	0	0	.001	≥	.216	(lb)
Phosphorous	.0024	.0021	.0033	.1244	.0050	.0073	.0053	.0023	.0122	.1811	.0282	.0033	.0002	.0401	.0508	.0069	.0035	.0068	.0017	.01189	.0047	.0041	.0092	.0017	.1370	.0012	0	0	0	.0005	≥	.152	(lb)
Magnesium	.0036	.0027	.0014	.0058	.0014	.00065	.0024	.0015	.0057	0	.0016	.0051	.0205	.0027	.0113	.00093	.0017	.0027	.0014	.00522	.00046	.0011	.0037	.0016	.0027	0	0	0	0	.0331	≥	.084	(lb)
Potassium	.0234	.0189	.0041	.0017	.0008	.00046	.0054	.0031	.0143	.00038	.0069	.0119	.0012	.0055	.0130	.0127	.0038	.01991	.0142	.01252	.00028	.0043	.0098	.0144	.0016	0	0	0	0	.0165	≥	.32	(lb)
Sodium	.0007	.0014	.00027	.0042	.0026	.0090	.00083	.00049	.00047	.0250	.0037	.0014	.0005	.0133	.0074	.0098	.0016	.0028	.0016	.0006	.0092	.00018	.0017	.0040	.0019	0	0	0	0	.0003	≥	.072	(lb)
Sodium Chloride (lower bound)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	≥	.184	(lb)
Sulfur (lower bound)	0	.0027	.0016	.0011	.0031	.0030	.00027	.00126	.0022	0	.0045	.0040	.0004	.0050	.0026	.00085	.0034	.0044	.0012	.00252	.0040	.0015	.0016	0	.0013	0	0	0	0	0	≥	.084	(lb)
Iron (lower bound)	207.9	82.55	36.81	347.4	113.5	840.7	291.6	122.7	101.8	576.2	214.4	149.9	1589	199.4	227.0	4.283	32.72	53.17	56.75	77.71	616.4	163.6	412.7	0	3219	0	0	0	0	0	≥	56.75	(mg)
Cobalt (L.B.)	.1655	.03715	.04499	.03948	.04204	.1387	.02749	.01636	.06959	0	.07146	.05831	0	.05831	.08352	0	.02853	.0409	0	.004499	.02083	.06544	.04127	0	0	0	0	0	0	0	≥	.01816	(mg)
Manganese (U.B.)	13.15	13.21	7.771	12.63	17.24	8.407	6.664	2.454	10.18	66.79	15.13	17.08	127.1	4.243	5.996	0	17.59	12.68	18.65	53.17	3.332	18.00	54.48	0	316.0	0	0	0	0	0	≥	726.4	(mg)
Zinc (L.B.)	7.213	7.016	6.953	157.9	44.54	36.15	0	8.589	38.51	12.22	68.10	0	0	47.52	43.69	18.85	13.50	19.63	0	50.72	12.08	17.59	60.26	83.30	0	0	0	0	0	0	≥	726.4	(mg)
Vitamin A (1,000 I.U.)	20.37	14.03	0	0	0	.8407	1.250	.4090	0	0	0	0	0	0	0	.3570	0	0	8.510	.4090	2.916	0	0	10.41	0	0	0	0	0	8.80	≥	58.0	(1,000 I.U
NACL (Upper Bound)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	≤	.20	(lb)
Copper (L.B.)	4.498	8.956	3.721	6.790	9.332	20.43	6.706	1.472	9.038	2.70[illegible]	4.952	11.75	0	.143	.6853	.4711	2.700	16.69	0	5.644	12.91	2.209	8.089	0	30.05	0	0	0	0	0	≥	181.6	(mg)
Sulfur (U.B.)	0	.0027	.0016	.0011	.0031	.0030	.00027	.00125	.0022	0	.0045	.0040	.0004	.0050	.0026	.00085	.0034	.0044	.0012	.00252	.0040	.0015	.0016	0	.0013	0	0	0	0	0	≤	.6356	(lb)
Iron (U.B.)	207.9	82.55	36.81	347.4	113.5	840.7	291.6	122.7	101.8	576.2	214.4	149.9	.1589	199.4	227.0	4.283	32.72	53.17	56.75	77.71	616.4	163.6	412.7	0	3219	0	0	0	0	0	≤	18160	(lb)
Cobalt (U.B.)	.1655	.03715	.04499	.03948	.04204	.1387	.02749	.01635	.06959	0	.07146	.05831	0	.05831	.08352	0	.02863	.0409	0	.004499	.02083	.06544	.04127	0	0	0	0	0	0	0	≤	181.6	(mg)
Copper (U.B.)	4.498	8.956	3.721	6.790	9.332	20.43	6.706	1.472	9.038	2.70[illegible]	4.952	11.75	0	.143	.6853	.4711	2.700	16.69	0	5.644	12.91	2.209	8.089	0	30.05	0	0	0	0	0	≤	1453	(mg)
Manganese (U.B.)	13.15	13.21	7.771	12.63	17.24	8.407	6.664	2.454	10.18	66.79	15.13	17.08	127.1	4.243	5.996	0	17.59	12.68	18.65	53.17	3.332	18.00	54.48	0	316.0	0	0	0	0	0	≤	18160	(mg)
Zinc (U.B.)	7.213	7.016	6.953	157.9	44.54	36.15	0	8.589	38.61	12.22	68.10	0	0	47.52	43.69	18.85	13.50	19.63	0	50.72	12.08	17.59	60.26	83.30	0	0	0	0	0	0	≤	9080	(mg)
Calcium Inventory	.0134	.0114	.00045	.2653	.0027	.00148	.00055	.00027	.0016	.2279	.0519	.0039	.3607	.0793	.09710	.1010	.00063	.0032	.0037	.0011	.00165	.00045	.0011	.0042	.3565	0	-1.0	0	0	.001	=	0	
Phos. Inventory	.0024	.0021	.0033	.1244	.0050	.0073	.0053	.0028	.0122	.1811	.0282	.0083	.0002	.0403	.0508	.0069	.0035	.0068	.0017	.01189	.0047	.0041	.0092	.0017	.1370	0	0	-1.0	0	.0005	=	0	
Cal-Phos ratio (L.B.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0	-1.0	0	0	≥	0	
Cal-Phos ratio (U.B.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0	-7.0	0	0	≤	0	
Ration Size	.93	.90	.89	.95	.92	.92	.91	.89	.93	.96	.92	.91	1.0	.93	.94	.94	.89	.89	.88	.89	.91	.89	.90	.91	1.0	1.0	0	0	1.0	.2720	=	40	(lb)

Table B-2. Beef Ration Formulation

Activities Constraints	Brewer's Dried Grain	Corn Gluten Meal	Hominey Feed	Calcium Carbonate	Rock Phosphate	Dicalcium Phosphate	Urea	Bone Meal	Distiller's Dried Grain	Cottonseed Meal	Soybean Meal	Wheat Middlings	Wheat Bran	Meat Meal	Oats	Milo Sorghum	Wheat Mill Run	Wheat (Hard)	Alfalfa Hay (early)	Alfalfa Dehydrated	Corn Stover Silage	Linseed Meal	Soybeans	Bermuda Grass Hay	Corn (ground #2)	Trace Mineral Salt		RHS
Objective Func.	.06721	.1575	.06814	.0320	.1200	.1220	1.20	.2681	.09572	.1200	.1286	.08254	.08247	.1627	.07183	.05982	.1041	.1633	.04726	.07773	.00838	.1016	.1208	.02993	.07274	.0495		
Dry Matter	.92	.90	.906	1.0	1.0	.96	1.0	.95	.92	.915	.89	.89	.89	.935	.89	.89	.90	.89	.9	.927	.272	.91	.9	.912	.89	1.0	≥	17.6 (lb)
Roughage (Lower bound)	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.20	-.8	-.8	-.8	-.20	-.20	.8	-.20	-.20	≥	0
Roughage (Upper bound)	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.25	-.75	-.75	-.75	-.25	-.25	.75	-.25	-.25	≤	0
Total Digestable Protein	.191	.474	.072	0	0	0	1.97	.082	.215	.348	.390	.130	.125	.486	.088	.063	.104	.102	.114	.140	.008	.309	.341	.034	.0676	0	≥	1.145 (lb)
Total Crude Protein	.260	.60	.105	0	0	0	2.81	.120	.270	.410	.440	.180	.160	.550	.120	.110	.150	.130	.156	.170	.020	.350	.380	.072	.090	0	≥	1.828 (lb)
TDN	-.66	.86	.84	0	0	0	0	0	.87	.66	.72	.80	.60	.68	.68	.82	.72	.80	-.51	.50	.14	.7	.82	.45	.820	0	≥	13.7 (lb)
Calcium	1.14	.091	.228	172.9	109.2	122.9	0	127.4	4.095	.683	1.136	.454	.454	36.4	.454	.273	.454	.227	5.096	5.92	.454	1.83	1.138	1.68	8.18	0	≥	23.0 (g)
Phosphorous	2.273	3.185	2.275	0	52.73	86.91	0	61.43	1.68	5.01	2.95	2.27	.454	18.2	1.59	1.32	4.54	1.82	.956	1.05	.227	3.79	2.73	.864	1.432	0	≥	20 (g)
Crude Fiber	.10	-.035	-.01	-.06	-.06	-.06	-.06	-.04	-.03	.06	0	-.04	.04	-.035	.05	-.04	.02	-.03	.208	.19	.027	.03	-.01	.208	-.0408	-.06	≥	0
Vitamin A (1,000 I.U.)	-	2.889	1.245	0	0	0	0	0	2.943	0	0	0	.4090	0	0	0	0	0	14.03	20.36	.5255	0	0	10.43	0	0	≥	18 (1,000 I.U.)
Metabolizable Energy	1.005	1.370	1.430	0	0	0	0	0	1.330	1.135	1.200	1.240	1.040	1.249	1.130	1.180	1.210	2.860	.8490	.9490	.5517	2.31	1.400	1.59	1.340	0	≥	22.4 (mcal)
Wheat Ratio	-.4	-.4	-.4	-.4	-.4	-.4	-.4	-.4	-.4	-.4	-.4	.60	.60	-.4	-.4	-.4	.60	.60	-.4	-.4	-.4	-.4	-.4	-.4	-.4	-.4	≤	0
Net Energy (Maintenance)	.5950	.8289	1.02	0	0	0	0	0	.9080	.7080	.790	.8080	.6270	.7375	.708	.758	.781	1.95	.5040	.5630	.3260	1.460	.994	.9470	.9325	0	≥	6.24 (mcal)
Net Energy (Growth)	.3500	.5540	.6550	0	0	0	0	0	.5950	.4630	.5270	.5400	.3900	.4860	.4630	.5040	.5220	1.280	.2270	.3090	.1550	.9630	.6310	.1750	.6053	0	≥	5.36 (mcal)
Salt	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	-.9552	=	0
Urea	.006	.006	.006	.006	.006	.006	-.994	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	≥	0
Magnesium	.0631	.0015	.0024	.0205	.0027	0	0	.0064	.0420	.0056	.0027	.0037	.0056	.0027	.0017	.0020	.0052	.00099	.00273	.002989	.001794	.006055	0	.001563	.001171	.300	≥	.0056 (lb)
Potassium	.00083	.0041	.0068	.0012	.0016	.0003846	0	0	.00093	.0141	.0199	.0098	.0126	.0055	.00378	.00351	.01291	0	.01891	.02498	.008276	.0139	0	.01351	.003153	0	≥	.0560 (lb)
Vitamin D_3	0	0	0	0	0	0	0	0	231666	0	0	0	0	0	0	0	0	0	821740	200132	0	0	0	0	0	0	≥	2200 (I.U.)
Sulfur	0	0	.00027	.0004	.0013	0	0	0	0	0	0	0	0	0	0	0	0	0	.00273	0	0	0	0	0	.001261	0	≥	.008 (lb)
Iron	.00025	8.255	.000064	1589	3219	576.2	0	.0838	.00019	.0003	.000053	.000091	.01712	199.8	.00072	0	.00009	0	.00018	.0004567	0	.000330	0	.000267	12.27	597.8	≥	80 (mg)
Copper	9.333	10.98	6.682	0	30.05	2.707	0	7.44	20.43	8.913	16.69	10.14	5.644	4.40	2.699	6.462	8.585	2.086	5.531	3.897	0	11.74	0	0	1.472	90.72	≥	32 (mg)
Cobalt	.0420	.0413	.0274	0	0	0	0	.0432	.0420	.0686	.0409	.0413	.0180	0	.0286	.0409	.0825	.0409	.0371	.1651	0	.08330	0	0	.01636	0	≥	.60 (mg)
Manganese	17.19	1.816	6.682	127.1	3160	66.79	0	.0031	8.618	9.833	12.64	54.27	53.17	4.313	17.55	5.931	47.09	18.00	13.00	13.20	0	17.20	0	0	2.454	1089	≥	40 (mg)
Zinc	44.56	16.92	0	0	0	12.22	0	193.3	12.16	29.36	19.63	60.26	50.72	47.52	13.50	6.544	0	17.59	7.016	7.218	0	0	7.429	8.346	0	90.72	≥	160 (mg)

Table B-3. Poultry Ration Formulation

Constraints / Activities	Alfalfa Meal (D)	Soybean Meal	Dicalcium Phosphate	Ground Limestone	Trace Mineral	Vitamin Premix	Meat + Bone Meal	Meat Meal	DDGS	Corn Gluten Meal	Cottonseed Meal	Deflourine + Rock Phos.	Milo Sorghum	Hominy Feed	BDG	Fish Meal (Menhaden)	Corn (#2 ground)	Oats	Wheat Bran	Wheat Mids	Wheat (Hard)	Brewer's Yeast		R H S
Total feed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	=	110 (g)
Protein	.175	.440	0	0	0	0	.504	.544	.2720	.6200	.4140	0	.089	.100	.253	.6050	.088	.1140	.1570	.1600	.1410	.4440	≥	16.5 (g)
Methionine	.0023	.0065	0	0	0	0	.0065	.0075	.0060	.0191	.0052	0	.0012	.0013	.0057	.0178	.002	.0018	.0017	.0021	.0019	.0070	≥	.3 (g)
Methionine + Cystine	.0043	.0134	0	0	0	0	.0090	.0141	.0100	.0302	.0104	0	.0027	.0026	.0096	.0234	.0035	.0040	.0042	.0053	.0045	.0120	≥	.53 (g)
Lysine	.0073	.0243	0	0	0	0	.0260	.0300	.0075	.0100	.0171	0	.0022	.0040	.0090	.0483	.0024	.0050	.0059	.0069	.0040	.0320	≥	.66 (g)
Calcium	.0144	.0029	.2100	.3800	0	0	.1010	.0827	.0015	0	.0015	.3200	.0003	.0004	.0029	.05110	.0002	.0006	.0014	.0012	.0005	.0012	≥	3.6 (g)
Phosphorous	.0022	.0065	.1850	0	0	0	.04960	.0410	.0072	.0050	.0097	.1800	.0028	.0050	.0052	.0288	.0028	0027	.0115	.0090	.0037	.0140	≥	.55 (g)
Sodium	.0012	.0026	.0060	.0005	0	0	.0072	.0115	.0048	.0002	.0004	.0570	.0040	.0010	.0015	.0041	.0002	0008	.0005	.0012	.0004	.0007	≥	.16 (g)
Potassium	.0217	.0200	0	0	0	0	.0102	.0060	.0065	.0035	.01220	0	.0032	.0046	.0009	.0077	.003	0045	.0119	.0099	.0045	.0017	≥	.11 (g)
Magnesium	.0036	.0027	0	0	.2988	0	.0112	.0058	.0019	.0015	.0040	0	.0013	.0016	.0016	.0016	.0012	.0016	.0052	.0016	.0017	.0023	≥	.055 (g)
Vitamin A	61.5	0	0	0	0	2203	0	0	3.100	30.00	0	0	0	7.650	0	0	1.1	0	0	2.600	0	3.100	≥	440 (I.U.)
Vitamin D	288.8	0	0	0	0	440.5	0	0	551.1	0	0	0	0	0	0	0	0	0	0	0	0	0	≥	55 (I.C.U.)
Thiamin	.0034	.0045	0	0	0	0	.0003	.0002	.0029	.0003	.0033	0	.0040	.0079	.0005	.0005	.0035	.0060	0	.0165	.0045	.0918	≥	.0088 (mg)
Riboflavin	.0138	.0029	0	0	0	1.762	.0044	.0055	.0086	.0022	.0040	0	.0011	.0022	.0014	.0049	.001	.0011	.0046	.0022	.0014	.0370	≥	.24 (mg)
Pantothenic Acid	.0250	.0160	0	0	0	6.608	.0041	.0050	.0110	.0030	.0070	0	.0120	.0080	.0080	.0090	.004	.01024	.0310	.0130	.0099	.1090	≥	.24 (mg)
Niacin	.0380	.0290	0	0	0	13.22	.0460	.0570	.0710	.0550	.0400	0	.0410	.0460	.0290	.0550	024	.0120	.1860	.0980	.0480	.4480	≥	1.1 (mg)
Pyridoxine	.0065	0	0	0	0	0	.0128	.0030	.0022	.0062	.0030	0	.0032	.0110	.00065	.0040	007	.0010	.0070	.0090	.0034	.0428	≥	.33 (mg)
Biotin	.0003	.00032	0	0	0	0	.00064	.00017	.00078	.00015	.00055	0	.00018	.00013	.00096	.0002	00006	.00011	.00048	.00037	.00011	.00105	≥	.011 (mg)
Cholin	1.401	2.794	0	0	0	88.11	1.996	1.077	2.637	.3300	2.933	0	.4500	.9710	1.723	3.056	.620	.3460	1.880	1.439	1.090	3.984	≥	55 (mg)
Folacin	.0042	.0013	0	0	0	0	.00032	0003	.0009	.0002	.0027	0	.0002	.0003	.0071	.0006	.0004	.0003	.0012	.0008	.00035	.0099	≥	.03 (mg)
Vitamin B_{12}	.000004	0	0	0	0	.008811	.0007	000068	0	0	0	0	0	0	0	.000104	0	0	0	0	0	0	≥	.00033 (mg)
Metabolizable Energy	1.370	2.230	0	0	0	0	1.360	2.000	2.480	3.720	2.400	0	3.370	2.970	2.080	2.820	3.43	2.550	1.300	1.800	2.800	1.990	≥	297 (kcal)
Arginine	.008	.0328	0	0	0	0	.03620	.03730	.0098	.01930	.0454	0	.0038	.0047	.01280	.0379	.005	.0079	.0098	.0115	.0058	.0219	≥	.88 (mg)
Glycine + Serine	.0167	.0474	0	0	0	0	.0364	.0790	.0218	.0471	.0170	0	.0084	.0040	.0189	.0644	.0077	.009	.0180	.0138	.0135	.0209	≥	.55 (mg)
Histidine	.0032	.0115	0	0	0	0	.069	.0130	.0066	.0122	.0110	0	.0027	.0020	.0057	.0146	.002	.0024	.0034	.0037	.0022	.0107	≥	.24 (mg)
Isoleucine	.0084	.0239	0	0	0	0	.0140	.0160	.0100	.0229	.0133	0	.0053	.0040	.01440	.0285	.0037	.0052	.0059	.0058	.0058	.0214	≥	.55 (mg)
Leucine	.0126	.0352	0	0	0	0	.0380	.03220	.0220	.1011	.0241	0	.0142	.0084	.0248	.0450	.011	.0089	.0091	.0107	.0094	.0319	≥	1.32 (mg)
Phenylalinine - Tyrosine	.0135	.0355	0	0	0	0	.0126	.0254	.0194	.0671	.0324	0	.0079	.0084	.0264	.0446	.0092	.0112	.0089	.0109	.0114	.0330	≥	.88 (mg)
Threonine	.0070	.0181	0	0	0	0	.0150	.0174	.0092	.0197	.0132	0	.0027	.0040	.0098	.0250	.0039	.0043	.0042	.0049	.0037	.0206	≥	.44 (mg)
Tryptophan	.0028	.0062	0	0	0	0	.0028	.0036	.0019	.0025	.0047	0	.0010	.0010	.0034	.0068	.0039	.0016	.0030	.0020	.0018	.0049	≥	.12 (mg)
Valine	.0084	.0234	0	0	0	0	.0200	.0230	.0130	.0274	.0189	0	.0053	.0049	.0166	.0323	.0052	.0068	.0073	.0071	.0063	.0232	≥	.55 (mg)
Iron	.00048	.00012	0	0	00.317	0	.00049	.00043	.00028	.0004	.00011	0	.00004	.00007	.00025	.00044	.00035	.00007	.00017	.00004	.00005	.00012	≥	.055 (g)
Copper	.0102	.0215	0	0	19.8	0	.0015	.0098	.0566	.0264	.0178	0	.0190	.0133	.0211	.0108	.0032	.0083	.0141	.0181	.0058	.0328	≥	.33 (mg)
Zinc	.0240	.0270	0	0	19.8	0	.0530	.1030	.0800	.0330	.0820	0	.0140	.0030	.0980	.1470	.01	.0170	.1330	.1500	.0310	.0390	≥	5.5 (g)
Selinium	.00033	.0001	.0002	.0002	0	0	.00025	.00042	.00039	.0010	0	.0014	0	.0001	.0007	.002103	.0003	.0003	.00085	.0008	.0002	.0010	≥	.011 (mg)
Vitamin E	.1250	.0210	0	0	0	4.405	.0010	.0010	.0400	.0024	0	0	.0120	0	.0250	.007	.022	.0100	.0135	.0405	.0126	0	≥	.55 (g)
Salt	0	0	0	0	.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	.385 (g)
Milo Restriction	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	≤	55 (g)
Wheat Restriction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	≤	22 (g)
Alfalfa Restriction	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	8.25 (g)
DDGS Restriction	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	5.5 (g)
Meat + Bone Restriction	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	5.5 (g)
Meat Meal Restriction	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	5.5 (g)
Fish Meal Restriction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	≤	11.0 (g)
CS4 Restriction	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	≤	11.0 (g)
Corngluten Restriction	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	≤	22 (g)
Phenylalanine	.0079	.0227	0	0	0	0	.0152	.0170	.0120	.0377	.0222	0	.0044	.0035	.0145	.0248	.0047	.0059	.0049	.0064	.0071	.0181	≥	.44 (mg)
Manganese	.0300	0293	0	0	2.398	0	.0145	.0097	.0239	.0044	.0200	0	.01360	.0145	.0378	.0330	.005	.0432	.1132	.1180	.0318	.0052	≥	2.75 (mg)

Table B-4. Swine Ration Formulation

Appendix E

	Alfalfa Dehydrated	Alfalfa Meal Suncured	Barley	Corn (#2 ground)	Cottonseed Meal	Distiller's Dried Grains	Fish Meal (Anchovy)	Fish Meal (Menhaden)	Corn Gluten Meal	Hominy Meal	Meat and Bone Meal	Milo Sorghum	Oats	Cane Molasses	Skim Milk (Dehydrated)	Soybean Meal	Tankage	Wheat (Hard)	Wheat (Middlings)	Brewer's Yeast	Linseed Meal	Trace Mineral Salt	Vitamin Premix		RHS
Iron (mg)	140.7	104.4	22.7	[illegible]5.89	49.94	127.1	99.90	199.8	9.080	31.78	222.5	18.16	31.78	90.80	22.70	54.50	404.1	22.70	18.20	54.48	136.2	597.8	0	≥	120
Copper (mg)	3.700	4.440	3.410	[illegible].540	8.080	20.30	4.220	4.900	12.08	6.040	.6810	6.400	2.680	27.[illegible]0	5.200	16.50	17.57	4.800	2.000	14.89	11.70	90.72	0	≥	9.0
Manganese (mg)	12.70	12.26	3.630	[illegible].270	9.170	13.60	4.300	14.98	1.998	6.580	6.450	5.860	19.61	19.20	.9080	13.30	8.670	28.20	19.50	2.360	17.10	1089	0	≥	6.0
Zinc (mg)	7.700	7.260	7.700	[illegible].540	0	36.30	46.76	66.70	18.60	1.360	42.20	6.360	.4540	0	18.16	12.30	0	6.400	29.10	17.71	0	90.72	0	≥	90
Calcium (lb)	.0144	.0140	.0005	0002	.0015	.0035	.0373	.0511	.0023	.0004	.1010	.0003	.0006	.0032	.0128	.0029	.0600	.0005	.0012	.0012	.0600	0	0	≥	.03304
Phosphorous (lb)	.0022	.0020	.0036	0028	.0097	.0095	.0243	.0288	.0070	.0050	.0496	.0028	.0027	.0008	.0102	.0065	.0300	.0037	.0090	.01460	.0025	0	0	≥	.02634
Potassium (lb)	.0240	.0210	.0048	003	.0122	.0100	.0090	.0077	.0045	.0067	.0140	.0032	.0037	.0238	.0159	.0200	.0056	.0045	.0060	.0170	.0075	0	0	≥	.01123
Magnesium (lb)	.0026	.0022	.0014	0012	.0040	.0035	.0024	.0016	.0015	.0024	.0112	.0020	.0016	.0035	.0011	.0027	.0016	.0017	.0029	.0023	.0060	.2998	0	≥	.002643
Selinium (mg)	.2720	.2270	.0454	.01815	0	.0039	.6170	.9530	.4540	0	.0225	0	.1362	0	.0540	.0454	0	.0006	.0080	.0100	.0075	0	0	≥	.30
Vitamin A (I.U.)	9980	817.2	0	[illegible]99.6	0	844.4	0	0	8173	2.085	0	0	0	0	0	0	0	0	708.2	0	0	0	1,000,000	≥	3900
Vitamin D (I.U.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200,000	≥	375.0
Vitamin E (I.U.)	56.75	18.16	16.34	9.990	6.810	18.16	2.720	3.200	11.58	0	.3630	5.450	9.080	2.000	4.130	.9530	0	5.720	0	0	2.630	0	2000	≥	33
Riboflavin (mg)	7.130	3.980	.5450	.4540	1.820	3.900	3.200	2.200	.9990	.9990	2.000	.5000	.4890	1.040	9.990	1.320	1.090	.6400	.9990	16.80	1.960	0	800.0	≥	7.0
Niacin (mg)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6000	≥	30
Pantothenic Acid (mg)	12.89	6.990	4.180	3.405	4.490	4.990	9.080	4.090	1.320	3.630	1.860	5.860	13.26	17.70	14.98	6.040	1.090	6.130	5.900	49.50	7.490	0	3000	≥	33
Vitamin B_{12} (mg)	1.820	0	0	0	0	0	.1600	.0680	0	0	.0320	0	0	0	.0045	0	.0600	0	0	0	0	0	4.000	≥	.033
Choline (mg)	498.0	685.5	449.5	240.6	1332	1554	2315	1387	204.3	681.0	506.2	307.8	499.4	299.6	567.5	1269	984.7	494.9	499.4	1809	799.0	0	40000	≥	1200
Thiamin (mg)	1.540	1.270	1.820	1.590	3.500	1.590	.0454	.0910	.1270	3.590	.0910	1.820	2.720	.4090	1.590	.7720	.0999	2.040	8.580	41.70	3.000	0	0	≥	3.3
Histidine (lb)	.0035	.0022	.0030	.0020	.0110	.0070	.0150	.0150	.0120	.0020	.0120	.0030	.0020	0	.0080	.0120	.0190	.0020	.0040	.0110	.0070	0	0	≥	.009912
Isoleucine (lb)	.0080	.0060	.0050	.0040	.0130	.0100	.0300	.0290	.0230	.0040	.0140	.0050	.0050	0	.0220	.0240	.0190	.0060	.0060	.0210	.0180	0	0	≥	.02709
Leucine (lb)	1.300	1.100	.0080	.0110	.0240	.0260	.0500	.0500	.0940	.0080	.0032	.0140	.0090	0	.0320	.0350	.0510	.0090	.0110	.0320	.0200	0	0	≥	.0317
Methionine + Cystine (lb)	.0040	.0037	.0050	.0040	.0110	.0090	.0250	.0240	.0300	.0020	.0100	.0030	.0040	0	.0110	.0090	.0250	.0240	.0300	.0020	.0106	.0040	0	≥	.01928
Phenylalanine + Tyrosine (lb)	.0140	.0180	.0090	.010[illegible]	.0320	.0190	.0490	.0450	.0480	.0090	.0230	.0080	.0110	0	.0270	.0360	.0350	.0130	.0110	.0330	.0200	0	0	≥	.03767
Threonine (lb)	.0070	.0060	.0042	.0031	.0132	.0092	.0268	.0250	.0200	.0040	.0150	.0027	.0043	0	.0160	.0181	.0240	.0037	.0049	.0206	.0120	0	0	≥	.02445
Tryptophan (lb)	.0028	.0038	.0014	.000[illegible]	.0047	.0019	.0074	.0068	.0031	.0010	.0028	.0010	.0016	0	.0044	.0062	.0065	.0018	.0020	.0049	.0048	0	0	≥	.006608
Valine (lb)	.008	.006	.006	.004	.0190	.0130	.0340	.0320	.0270	.0050	.0230	.0050	.0070	0	.0230	.0230	.0420	.0060	.0070	.0230	.0160	0	0	≥	.02709
Digestable Energy (kcal)	1171	1171	1401	1600	1221	1620	1401	1241	1466	1641	1301	1561	1301	1121	1722	1521	1125	1581	1385	1423	628.8	0	0	≥	10110
Metabolizable Energy	1031	890	1303	1510	1160	1539	1112	1012	1393	1528	1105	1465	1211	1064	1525	1403	990.0	1335	1335	1290	581.1	0	0	≥	9480
Crude Protein	.1750	.1500	.1160	.0880	.414	.272	.6420	.6050	.6000	.1000	.5040	.0890	.1140	.0290	.3350	.4400	.6000	.1410	.1600	.4440	.6000	0	0	≥	.8590
Sodium Chloride	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.96	0	≤	8.075
Crude Fiber	.2410	.2900	.0510	.0220	.1130	.091	.010	.070	.0250	.060	.0280	.023	.0108	0	0	.0730	.0200	.0240	.0700	.02700	.0950	0	0	≤	.465
SBM Crude Protein	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.4400	0	0	0	0	0	0	0	≥	.1938
Alfalfa (D) U.B.C.R.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	.3875
Alfalfa (S) U.B.C.R.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	.3875
Barley U.B.C.R.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	6.588
Corn grain U.B.C.R.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	6.538
CSM U.B.C.R.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	.3375
DDG U.B.C.R.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	.3875

Table B-4. Swine Ration Formulation (concluded)

Fishmeal (A) U.B.C.R.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	.3875
Fishmeal (M) U.B.C.R.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	.3875
Oats U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	≤	1.550
Meat-Bone Meal U.B.C.R.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	≤	.3875
Milo U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	≤	6.588
Molasses U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	≤	.3875
Soybean Meal U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	≤	1.550
Tankage U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	≤	.3875
Wheat (Hard) U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	≤	6.588
Wheat (Mid) U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	≤	.7750
Yeast U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	≤	.2325
Vitamin Ratio	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-50	≥	0
Alfalfa (D) U.B.S.	.800	-.2000	0	0	-.2000	-.2000	-.200	-.200	0	0	-.2000	0	0	-.2000	0	-.200	-.2000	0	-.200	-.200	-.200	0	0	≤	0
Alfalfa (S) U.B.S.	-.2000	3000	0	0	-.2000	-.2000	-.2000	-.2000	0	0	-.2000	0	0	-.2000	0	-.2000	-.2000	0	-.2000	-.2000	-.2000	0	0	≤	0
Cottonseed Meal U.B.S.	-.2000	-.2000	0	0	.8000	-.2000	-.2000	-.2000	0	0	-.2000	0	0	-.2000	0	-.2000	-.2000	0	-.2000	-.2000	-.2000	0	0	≤	0
DDG U.B.S.	-.2000	-.2000	0	0	-.2000	.8000	-.2000	.-2000	0	0	-.2000	0	0	-.2000	0	-.2000	-.2000	0	-.2000	-.2000	-.2000	0	0	≤	0
Fishmeal (A) U.B.S.	-.2000	-.2000	0	0	-.2000	-.2000	.8000	-.2000	0	0	-.2000	0	0	-.2000	0	-.2000	-.2000	0	-.2000	-.2000	-.2000	0	0	≤	0
Fishmeal (M) U.B.S.	-.2000	- 2000	0	0	-.2000	-.2000	-.2000	.8000	0	0	-.2000	0	0	-.2000	0	-.2000	-.2000	0	-.2000	-.2000	-.2000	0	0	≤	0
Meat-Bone Meal U.B.S.	-.3000	- 3000	0	0	-.3000	-.3000	-.3000	-.3000	0	0	.7000	0	0	-.3000	0	-.3000	-.3000	0	-.3000	-.3000	-.3000	0	0	≤	0
Molasses U.B.S.	-.05	- 05	0	0	-.0500	-.0500	-.0500	-.0500	0	0	-.0500	0	0	.9500	0	-.0500	-.0500	0	-.0500	-.0500	-.0500	0	0	≤	0
SBM U.B.S.	-.85	- 85	0	0	-.85	-.85	-.85	-.85	0	0	-.85	0	0	-.85	0	.1500	-.85	0	-.85	-.85	-.85	0	0	≤	0
Tankage U.B.S.	-.30	- 30	0	0	-.30	-.30	-.30	-.30	0	0	-.30	0	0	-.30	0	-.30	7000	0	-.30	-.30	-.30	0	0	≤	0
Wheat Mids U.B.S.	-.20	- 20	0	0	-.20	-.20	-.20	-.20	0	0	-.20	0	0	-.20	0	-.20	-.20	0	.8000	.20	-.20	0	0	≤	0
Yeast U.B.S.	-.05	- 05	0	0	-.05	-.05	-.05	-.05	0	0	-.05	0	0	-.05	0	-.05	-.05	0	-.05	.95	-.05	0	0	≤	0
Linseed Meal U.B.S.	-.20	- 20	0	0	-.20	-.20	.-20	-.20	0	0	-.20	0	0	-.20	0	-.20	-.20	0	-.20	-.20	.80	0	0	≤	0
Feed Intake (lb)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	=	7.75
Lysine (lb)	.0073	.0060	.0040	.0024	.0171	.0060	.0510	.0570	.010	.0040	.0260	.0022	.0040	0	.0260	.0293	0380	.0040	.0069	.0323	.0110	0	0	≥	.01696
Linseed Meal U.B.C.R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	≤	.3875

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report presents results of econometric estimations and mathematical simulations of markets for joint feed products of motor ethanol. The major issues considered are the nature of current market price relationships, effects on prices, including feed substitutes prices, and effects of demands for increased use of distillers' grains and gluten meal. The econometric section shows that soybean meal was by far the dominant force in the pricing of the two products. However, neither one could be adequately explained without the inclusion of corn in the estimating equations. Later research shows that this was due to the importance of both feeds for metabolizable energy as well as for protein in livestock diets. Current ration formulations would require some discounting of the value of the protein content of the two feeds. Careful siting of the ethanol facilities, and flexible design of the plants so that a maximum number of products may be extracted from the feedstock, seem necessary. Finally, the analysis indicates that substitution in animal diets of these joint products for the corn or milo used originally requires that additional energy be supplied to the animal by some type of forage crop. This implies that additional land may be required for energy production, for such marginal crops as hay and alfalfa, rather than for row crops.

17. Document Analysis

a. Descriptors Ethanol ; Production ; Feed Byproducts ; Economic Aspects ; Market ; Econometrics ; Simulations ; Domestic Animals ; Swine ; Foul ; Cattle ; Feedlots

b. Identifiers/Open-Ended Terms

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