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Estimating Regional Demand for Feed Barley:

A Linear-Programming Approach

D. Demcey Johnson

Beena Varghese

ɪartment of Agricultural Economics • Agricultural Experiment Station
North Dakota State University • Fargo, ND 58105-5636

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Abstract

The regional demand for feed grains is not directly observable. This study uses a programming model to derive a demand schedule for feed barley. The model is applied to a major barley producing region (North Dakota and Minnesota) and an important feed deficit region (California). Direct and cross-price elasticities are evaluated, and sensitivity analysis shows the potential impact of improved barley varieties on regional demand.

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Highlights

Market demand schedules are usually estimated with regression models. However, that is not possible in the case of regional demand for feed grains. While regional price data are available, quantities are not; USDA only estimates feed use on a national basis, and then only indirectly. Although regional demand for feed grains would be of clear interest to merchandisers and market analysts, the data necessary for econometric modelling are not available.

This paper develops a methodology for estimating regional demand for feed grains. The application is to feed barley, a crop of major importance in the Northern Plains for which there have been few previous demand studies.

Recent policy changes in Canada have heightened interest in regional barley demand. Canadian exports of barley to the United States (formerly controlled by the Canadian Wheat Board) have been deregulated. In addition, significant changes have been proposed for Canada's grain transportation system, which will have the effect of lowering barley prices in the Prairie Provinces and encouraging southward movements. These changes are likely to have differential impacts across U.S. regions, depending on freight rates and market conditions. In this context, an ability to evaluate demand at various barley prices is a prerequisite for economic analysis.

For purposes of evaluating regional demand, a least-cost feed model based on linear programming is specified. The model incorporates five classes of livestock (beef cattle, hogs, sheep, dairy, and poultry) and 39 individual animal diets. Using known animal numbers and observed feedstuff prices, the model is used to derive barley demand schedules in a major barley producing region (North Dakota and Minnesota) and an important feed-deficit region (California).

Results suggest that barley demand is highly price elastic. Barley demand also shows extreme sensitivity to the price of corn, a close substitute. In both regions, dairy cattle account for a large share of the market potential for feed barley. Hogs represent a large share of potential demand in Minnesota and North Dakota, while beef cattle are of greater relative importance in California.

One advantage of the modelling approach is that it permits detailed analysis of barley characteristics. Individual characteristics are shown to have different implicit values across livestock classes. Under base-case assumptions, net energy for lactation is shown to be the most valued barley attribute for dairy cows, while protein and total digestible nutrients are highly valued for medium-frame steers. These results are potentially relevant to market-development efforts, particularly in view of trends toward increased specificity in grain merchandising.

Another application is to the analysis of barley breeding programs. For illustrative purposes, the model is used to show how regional demand would shift in response to enhanced protein or lysine content. Such simulations provide a basis for evaluating the prospective demand for new barley varieties under given assumptions about livestock numbers and prices of substitutes.

Estimating Regional Demand for Feed Barley: A Linear-Programming Approach

D. Demcey Johnson and Beena Varghese*

I. Introduction

Market-level demand schedules are usually estimated with econometric models. Indeed, demand analysis has become almost synonymous with the application of regression models to available data. The limitations of such analyses are well known. For a variety of reasons, models estimated with historical data can be of questionable value for forward-looking demand analysis. Parsimony is usually seen as a virtue in regression models, despite the loss of explanatory power that can result from omitting variables. In practice, modelers end up restricting the list of substitutes, whose prices are often collinear, to preserve degrees of freedom or ensure the significance of estimated parameters.

Another more basic difficulty applies to regional demand for feed grains. While regional price data are observable, quantities are not. USDA only estimates feed use on a national basis--and then only indirectly, based on estimated production, trade, seed and industrial use, and stocks. Estimates of regional demand for feed grains would be of clear interest to merchandisers and market analysts, but the data necessary for econometric modelling are not available.

In this paper we develop estimates of regional demand for feed barley using linear programming (LP). Several classes of livestock are combined in a least-cost feed model. Using known animal numbers and observed prices of substitutes, we derive barley demand schedules in a major barley producing region (North Dakota and Minnesota) and an important feed-deficit region (California). Although the applications are specific, the methodology is general and has a number of appealing features. It incorporates a large amount of market information, provides insight into microeconomic determinants of demand, and facilitates the analysis of situations never before observed.

The paper is organized as follows. In the next section we provide background for the analysis and an overview of the LP model. Estimates of regional demand in North Dakota and Minnesota by livestock class are presented in the third section. Through use of shadow prices, we measure the value of individual barley characteristics in specific animal rations. Next, we provide estimates of price elasticities for North Dakota and Minnesota, and contrast these with estimates derived from national data. In the fifth section, we present results of some simulations designed to show how alternative barley breeding programs, e.g., to enhance protein or lysine content, would affect regional demand. In the sixth section, we extend the analysis to the California market. The paper concludes with a short summary and discussion of implications.

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*Assistant professor and former graduate research assistant, respectively, Department of Agricultural Economics, North Dakota State University, Fargo.

II. Background and Overview of the LP Model

North Dakota and Minnesota together account for about 40 percent of U.S. barley production. A large share of annual production in the region (typically 50-70 percent) is sold for malting purposes. The distinction between "malting" and "feed" barley is based on the quality standards of maltsters, and is of small concern for this study.[1] Because the feed market provides a potential outlet for all production (and an effective price floor for malting barley), the characteristics of feed demand are of broad interest.

Recent policy developments provide some additional motivation for the analysis. First, a marketing loan program is now in place for barley and other feed grains under terms of "GATT Trigger" provisions of the 1990 Budget Reconciliation Act. This makes it possible (although not yet likely) for barley prices to fall below official support rates.[2] Second, pressure has increased for Canada to sell barley into the U.S. market.[3] The withdrawal of Canadian Wheat Board control over exports to the United States in August, 1993 will allow a larger volume of barley to enter U.S. markets, with uncertain consequences for prices.[4] Third, significant changes have been proposed for Canada's grain transportation system. Over four years, existing rail subsidies will be replaced by direct payments to Canadian grain producers.[5] This should have the effect of lowering prices in the prairie provinces while encouraging southward grain movements. Changes in Canadian policies are likely to have differential impacts across U.S. regions, depending on freight rates and market conditions. However, a methodology for evaluating regional demand (at various barley prices) is a prerequisite for detailed spatial analysis.[6]

Assessments of regional demand are also crucial to market development efforts. Market potential cannot be discussed meaningfully without reference to price. However, estimating a demand schedule can be problematic, given data limitations. A merit of our approach is that it relies on current market information (essentially, feedstuff prices and

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[1]Many producers in North Dakota and Minnesota plant barley in hopes of meeting malting standards, e.g., for percent of plump kernels. Barley sold for malting purposes earns a market premium, usually in the range of 25 to 50 cents per bushel. Malting and feed barley have similar feed values.

[2]$1.40 per bushel in the 1993/94 marketing year.

[3]U.S. export subsidies have raised U.S. domestic prices while displacing Canada from some foreign export markets. With reduced trade barriers under the U.S.-Canada Free Trade Agreement, this provides an inducement for Canada to export to the United States.

[4]Carter and Schmitz et al. discuss the implications of Canadian deregulation, i.e., withdrawal of the Wheat Board's "single seller" status for export barley.

[5]See "Agriculture Canada proposes reform of grain transport system," *Milling and Baking News*, July 6, 1993, p. 45.

[6]A forthcoming study by Johnson and Wilson applies a spatial equilibrium analysis to North American barley flows.

livestock inventories) rather than historical data for estimating regional demand schedules. Our approach also yields insights into some of the technical determinants of demand. In particular, it permits us to quantify the values that buyers attach to individual quality attributes. This is an area of growing importance in grain merchandising, as evidenced by the increased use of premiums and discounts for individual characteristics in both wheat and feedgrains.[7]

The analysis is normative in that it is based on an optimization model (specifically, a linear programming problem), rather than observed behavior. The objective is to minimize the cost of feeding livestock, using regional animal numbers and feedstuff prices as model parameters. The minimization is subject to a set of constraints on animal nutrition. By systematically varying the price of barley (holding other parameters constant) and re-solving the LP problem, we derive an entire demand schedule.

A similar approach was used by Konyar and Knapp in their study of California alfalfa demand, and Watson in her study of demand for sunflower meal. While those authors made use of specialized commercial software for least-cost diet formulation, we developed our LP model in its entirety. This forced us to strike our own balance between comprehensiveness and simplicity, particularly where animal categories are concerned.[8] Technical parameters are drawn from National Research Council publications and also reflect extensive consultations with experts in animal nutrition at NDSU's Department of Animal and Range Sciences.

Mathematically, the least-cost problem has the form:

$$\underset{\substack{x_j \\ j=1,\ldots n}}{Minimize} \quad \sum_{j=1}^{n} p_j x_j$$

$$Subject\ to \quad \sum_{j=1}^{n} A_{ij} x_j \geq k_i \qquad i=1,\ldots,m$$

$$x_j \geq 0 \qquad j=1,\ldots,n$$

[7]See Wheat and Wilson, "Tailoring Grains for a Perfect Fit," *Feedstuffs*, May 13, 1991.

[8]Since the nutritional requirements of animals vary by weight class and stage of the reproductive cycle, a broad spectrum of diets should be included in the regional model. However, diets must be weighted within the model, and state-level inventories provide only broad information about the distribution of animals within livestock classes. See appendix for details.

where p_j and x_j denote the price and quantity of ingredient j, A is a matrix of technical parameters, and k_i is a constraint constant. The solution is a set of ingredients that minimizes the cost of satisfying all constraints. It is standard to formulate this kind of problem for individual livestock rations. However, our model incorporates a number of different livestock categories, each with a distinctive set of nutritional constraints. The constraint constants are also scaled to reflect the requirements of a regional livestock population.

Five different livestock classes are incorporated in the model: beef cattle, hogs, sheep, dairy cattle, and poultry. Within each class are several individual diets, so that the model accounts for varying nutritional requirements at different stages of animal development and the reproductive cycle. There are 6 diets for beef cattle, 5 for swine, 7 for sheep, 7 for dairy cows, and 14 for poultry (8 chickens and 6 turkeys). A more detailed listing is provided in the appendix. Livestock classes and individual diets are weighted according to 1992 animal inventory numbers published by state Agricultural Statistics Services and the *1992 Feedstuffs Reference Issue*. Adjustments are made for months on feed as appropriate.

Lists of potential feed ingredients vary by livestock class. For example, hays and silage are suitable for ruminants, but not for hogs or poultry. A comprehensive list of ingredients and prices is given in Table 1.

Prices are representative of North Dakota and Minnesota and are based on published market quotes (from end-March, 1993) and industry sources.[9] Corn silage, which is not widely traded, is priced according to a convenient rule of thumb.[10] Nutritional attributes of feedstuffs are taken from the *United-States Canadian Tables of Feed Composition* and some industry sources.

For each animal diet, nutritional requirements are based on National Research Council recommendations. For livestock classes other than poultry, requirements are specified in terms of levels of nutrients, e.g., kcal per day or pounds of protein, subject to constraints on maximum daily intake. Poultry diets are specified in terms of concentrations, e.g., kcal of metabolizable energy per kilogram of feed, with feed intake fixed. Constraints for minimum energy, protein, calcium, and phosphorus apply for all animals.[11] Hogs and poultry require specific amino acids and have limited tolerance for fiber. Dairy cows require minimum levels of acid-detergent and neutral-detergent fiber in their diets.

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[9]Published price quotes are from selected issues of *Feedstuffs*, *Agweek*, and *Farm and Ranch Guide*.

[10]Price of silage ($/ton) equals six bushels of corn plus $5.

[11]We ignore requirements for other minerals and vitamins, which are largely irrelevant for our analysis of barley.

Table 1: Ingredients and Base-Case Prices (End-March, 1993), North Dakota and Minnesota

Ingredient	International Feed Number ‡	Price	Potential Use †
Alfalfa	1-00-063	$65/ton	C,S,D
Barley	4-00-549	*	C,H,S,D,P
Brome Hay	1-00-888	$50/ton	C,S,D
Corn	4-02-935	$1.87/bu	C,H,S,D,P
Corn Silage	3-28-250	$16.2/ton	C,S,D
Corn Gluten Meal	5-28-242	$300/ton	P
Dical. Phosphate	6-01-080	$500/ton	C,H,S,D,P
Fish Meal	5-02-009	$460/ton	P
Limestone	6-02-632	$4.30/cwt	C,H,S,D,P
Molasses	4-00-668	$76/ton	C,H,S,D,P
Oats	4-03-309	$1.30/bu	C,H,S,D,P
Sorghum	4-04-383	$2.60/bu	C,H,S,D,P
Soybean Meal	5-20-612	$176/ton	C,H,S,D,P
Soybean Oil	4-07-983	$.20/lb	C,H,S,D,P
Sunfl. Meal (28%)	n.a.	$83/ton	C,S,D
Synth. Lysine	n.a.	$0.90/lb	H,P
Synth. Methionine	n.a.	$1.63/lb	H,P
Tallow	4-08-127	$0.13/lb	C,H,S,D,P
Wheat	4-05-211	$3.40/bu	C,H,S,D,P
Wheat Straw	1-05-175	$24/ton	C,S,D

† C: beef cattle; H: hogs; S: sheep; D: dairy cattle; P: poultry.
* Varied incrementally in model simulations. Actual feed barley prices were in the $1.65 to 1.75 range, depending on location.
‡ Numbers used to identify feeds in NRC publications.
n.a. not available.

Based on the advice of nutrition experts, the model imposes a number of constraints on intake of individual ingredients for selected animals. Grains are not allowed to exceed 80 percent of cattle rations, while specific limits on barley intake are imposed for hogs and poultry. Barley is not allowed to exceed 20 percent of poultry rations because of high levels of beta-glucans, which cause dehydration and sticky droppings. The significance of this constraint for market-level demand is assessed in Section V.

Additional details are provided in the appendix, and complete model specifications are available from the authors.

III. Base-case Simulations and Analysis of Barley Characteristics

In our base-case simulations, the price of barley is varied by 5 cent increments between $1.10 and $1.90 per bushel, while prices of all other ingredients are held constant. The model is solved at each barley price, yielding a derived demand schedule for barley. Results for each livestock class are shown in Figures 1 and 2. In Figure 1, the indicated percentages represent weighted averages (barley as percent of ration) within livestock classes. Figure 2 shows aggregate demand for barley (million bushels) by livestock class.

Barley enters the average dairy ration at a relatively high price and expands to about 40 percent of the ration at lower price levels (Figure 1). Beef rations show a more pronounced shift into barley at prices below $1.40/bu. Barley comprises about 80 percent of average rations for both hogs and sheep at prices below $1.50/bu. For hogs, the dramatic rise in barley use at $1.55/bu reflects displacement of corn in the ration. Proportional changes are less pronounced for poultry due to constraints on barley intake. (See appendix tables A-11 through A-15 for detailed summaries of some representative diets.)

Figure 2 shows the relative importance of different livestock classes in regional demand. At a barley price of $1.70/bu, the simulations indicate potential demand for dairy cattle of 50 million bushels. At prices below $1.60, hogs represent the largest potential demand for barley, in excess of 140 million bushels. It should be stressed that these estimates are based on *ceteris paribus* assumptions, with prices of corn and other substitutes fixed at base-case levels. The model also ignores a number of factors which may limit the responsiveness of livestock producers and feed manufacturers to changing relative prices in the short run--a point to which we return in Section V.

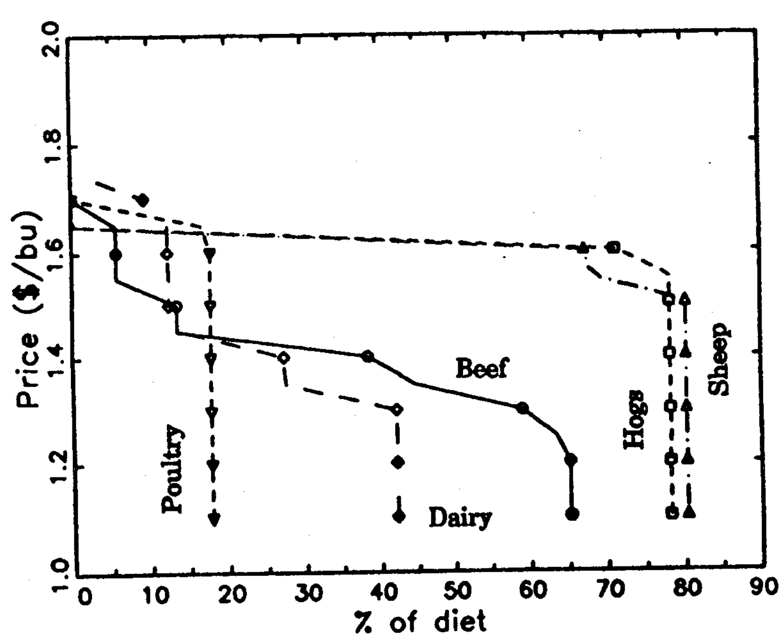

Figure 1. Barley as Percent of Diet by Livestock Class, Base-case Assumptions, North Dakota and Minnesota

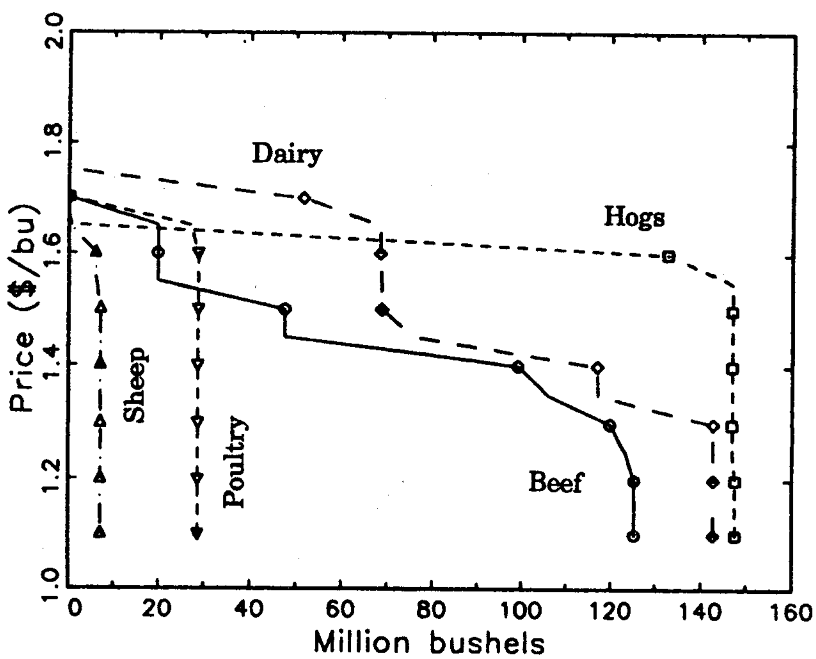

Figure 2. Aggregate Barley Demand by Livestock Class, Base-case Assumptions, North Dakota and Minnesota

One of the advantages of the least-cost model is that it can be used for detailed analysis of ingredient values.[12] In Table 2, the value of barley ($/bu) is divided into the values of its physical attributes, i.e., contribution toward satisfying constraints, for selected animals. The computations are based on simulations with barley priced at $1.65 per bushel, roughly the average regional price observed at the end of March, 1993. Values associated with individual constraints carry both positive and negative signs; negative values indicate an implicit cost or penalty.

For medium-frame steers, the value of barley lies in its protein content, total digestible nutrients (TDN), and net energy (NE) for gain. Under base-case assumptions with barley priced at $1.65/bu, the protein contained in a bushel of barley is worth $.614; TDN content $.584; and NE for gain $.362. Limits on the steer's intake of corn silage account for an additional $.088 of barley value.

[12]This is along lines suggested by Ladd and Martin. From the Lagrangian of the least-cost feed problem, the relevant first-order condition is:

$$P_j \geq \sum_i \lambda_i A_{ij}$$

where P_j is an ingredient price, λ_i is the shadow price of the i-th constraint (attribute), and A_{ij} is the "marginal yield" of the i-th attribute. When positive amounts of the ingredient are used in the ration, an equality holds.

Table 2: Decomposition of Barley Value ($/bu) in Selected Diets With Barley Priced at $1.65/bu

Animal	Constraint †	Value ($/bu)	Total Value ($/bu)
Medium-frame steer, 600 lbs.	min protein	.614	1.650
	min TDN	.584	
	min NE gain	.362	
	max corn silage	.088	
	min calcium	.003	
Hog, 50-100 kg.	min ME	.952	1.638
	min protein	.289	
	min lysine	.202	
	min phosphorus	.191	
	min calcium	.003	
Lactating ewe, 50 kg., suckling singles	min TDN	1.134	1.646
	min protein	.521	
	max DM intake	-.012	
	min calcium	.003	
Lactating dairy cow, 1300 lbs., 4% milkfat, yield 93 lbs/day	min NE lactation	2.940	1.650
	max DM intake	-2.061	
	min protein	.710	
	min AD fiber	-.210	
	min phosphorus	.208	
	max corn silage	.058	
	min calcium	.006	
Turkey, 12-16 weeks old	fixed feed intake	2.129	1.650
	min lysine concent.	-.253	
	min methionine conc.	-.108	
	min protein concent.	-.085	
	max barley concent.	-.017	
	max fiber concent.	-.003	
	min calcium concent.	-.013	

† TDN: total digestible nutrients; NE: net energy; DM: dry matter; AD: acid detergent fiber.

In diets for market hogs, the metabolizable energy (ME) in barley is worth $.952; protein content is worth $.289; lysine content $.202; and phosphorus content $.191. The sum of attribute values is $1.638. Under base-case assumptions, that is the maximum price that would induce use of barley in the hog diet. Similarly, in the lactating ewe diet, the sum of attribute values is slightly less than the market price for barley.

For the lactating dairy cow, the most highly valued barley attribute (at $2.940/bu) is net energy for lactation. Protein content ($.710) and phosphorus content ($.208) are additional sources of value. Significant costs (negative values) are associated with constraints on dry matter (DM) intake and acid-detergent (AD) fiber. Although barley has a higher fiber content than corn, it is substantially below the cow's dietary requirements.

In the turkey diet, values associated with all barley attributes (other than the feed intake constraint) are nonpositive. Poultry diets are formulated to satisfy concentration ratios, with feed intake fixed. Because barley has a lower concentration of lysine, methionine and protein than the turkey diet requires, a penalty applies to each of these barley attributes. The constraint on barley intake, reflecting high beta-glucan content, accounts for a small additional penalty.

IV. Regional Demand and Price Elasticities

The regional demand schedule is the summation of derived demand schedules for 39 individual livestock categories, using 1992 animal inventory numbers and estimated time on feed as scaling factors. Table 3 presents a breakdown of demand by livestock class. Dairy cattle account for all of barley demand at a price of $1.70 per bushel. A six-fold increase in demand occurs as price is lowered to $1.50, with hogs accounting for most of the increase. Beef demand expands considerably at lower price levels (below $1.45/bu), while poultry demand is stable.

Estimated price elasticities of demand are given in Table 4. These should be interpreted with caution as they reflect all base-case assumptions of the least-cost feed model. Elasticities are based on the arc formula, with arbitrary price intervals used in the calculations.[13] The direct price elasticity is largest (as expected) at higher price levels, near the "intercept" of the regional demand schedule. Cross-price elasticities for corn and meal are also large, indicating important possibilities for substitution in livestock rations. The cross-price elasticity for hay turns negative at lower prices, indicating a switch to a complementary price relationship.

[13]Direct price elasticities are based on a centered 10 cent price arc. Cross price elasticities are based on a centered 10 percent price arc, i.e., with alternative feedstuffs priced 5 percent higher, and 5 percent lower, than assumed in the base case.

Table 3: Barley Demand in North Dakota and Minnesota by Livestock Class, Various Prices, Base-case Assumptions

Price ($/bu)	Total Demand (mil bu)	Demand by Class (mil bu) Beef	Hogs	Sheep	Dairy	Poultry
1.75	0.0	0.0	0.0	0.0	0.0	0.0
1.70	51.6	0.0	0.0	0.0	51.6	0.0
1.65	115.3	19.9	0.0	0.0	68.4	27.1
1.60	255.6	19.9	132.7	5.9	68.4	28.7
1.55	270.3	19.9	147.0	6.0	68.7	28.7
1.50	299.0	47.5	147.0	7.1	68.7	28.7
1.45	306.3	47.6	147.0	7.1	75.9	28.7
1.40	398.9	99.1	147.0	7.1	117.0	28.7
1.35	405.8	106.0	147.0	7.1	117.0	28.7

Table 4: Direct and Cross Price Elasticities of Barley Demand, North Dakota and Minnesota, Base-case Assumptions

Price ($/bu)	Direct Price Elasticity	Cross Price Elasticities with respect to: Corn	Oats	Hay †	Meal ‡
1.65	-21.9	14.7	3.4	0.9	7.2
1.55	-2.4	1.6	-0.0	0.2	0.0
1.45	-4.1	2.8	-0.0	-0.3	0.5
1.35	-1.5	1.4	-0.0	-0.8	0.6

† Alfalfa and brome hay combined.
‡ Soybean and sunflower meal combined.

For comparison purposes, we also derived price elasticities from a regression model using national data. National barley feed use was estimated as a function of the average feed barley price, average corn price, and lagged feed use. Data from the 1967 to 1992 marketing years were utilized; Figures 3 and 4 show price relationships between barley and corn (basis Minneapolis) in those years.[14]

[14]The ratio of feed barley to corn price has been higher than average since 1986, when export subsidies for barley were first introduced under the Export Enhancement Program (EEP). To the extent that EEP has promoted U.S. barley exports (and raised the barley price relative to corn), it has necessarily reduced domestic feed use.

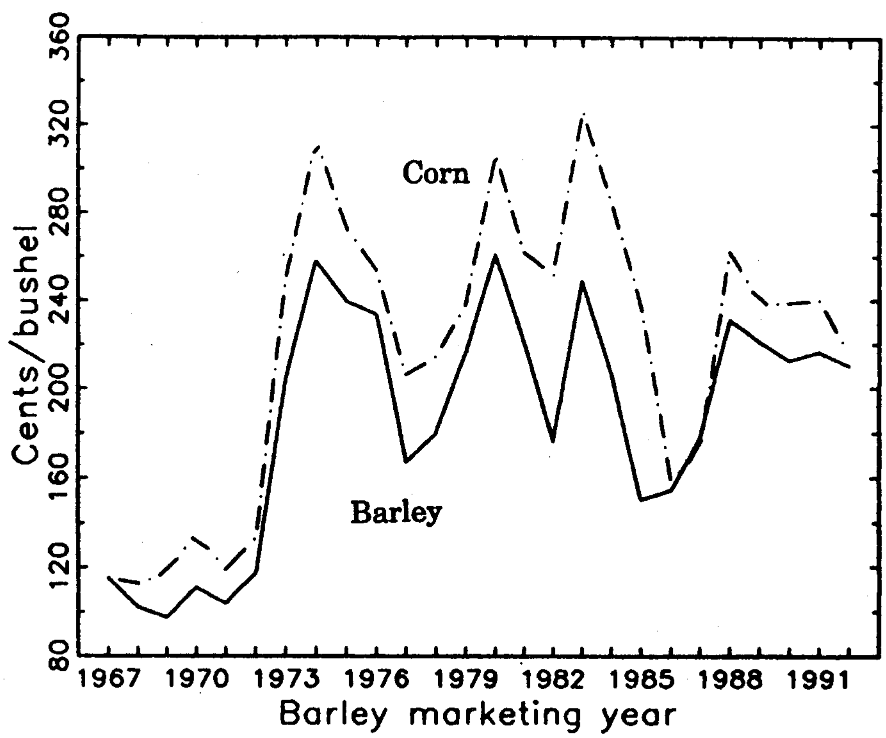

Figure 3. Average Feed Barley and Corn Prices, Minneapolis, 1967-92

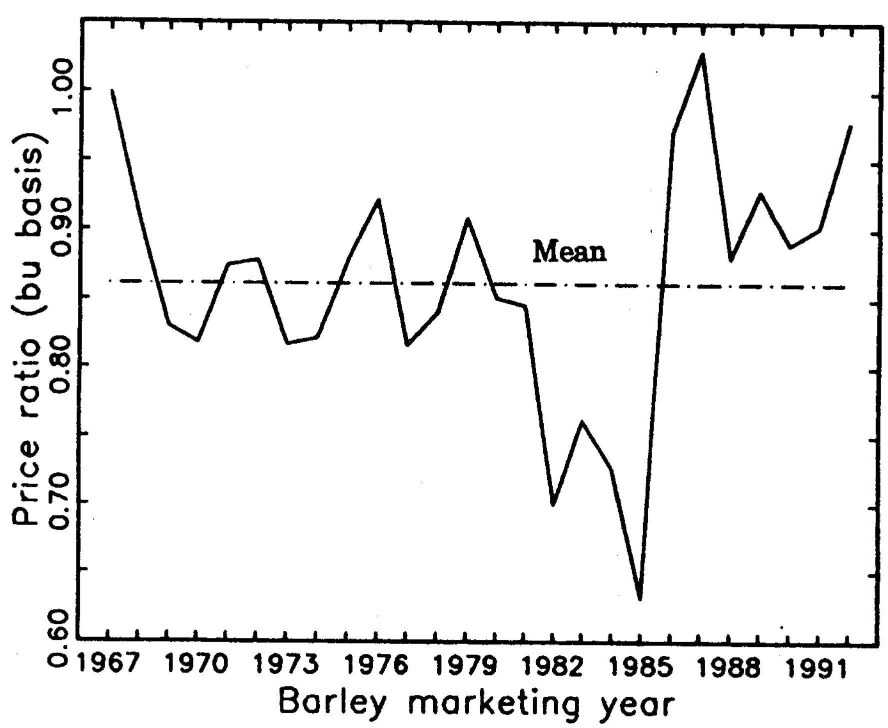

Figure 4. Average Feed Barley/Corn Price Ratio, Minneapolis, 1967-92

Variables in the regression are defined as follows:

BFU_t Barley feed use in marketing year t (million bushels)
PB_t Feed barley price, June-May average, Duluth (cents/bu)
PC_t Corn price, June-May average, Minneapolis (cents/bu)

Data are from USDA *Feed Situation and Outlook* and *Grain Market News* (Minneapolis), various issues. Regression results are as follows (t-statistics in parentheses):

$$BFU_t = \underset{(4.226)}{158.3} \; - \underset{(-4.945)}{1.296 \cdot PB_t} \; + \underset{(4.145)}{.852 \cdot PC_t} \; + \underset{(4.990)}{.547 \cdot BFU_{t-1}}$$

Observations : 25
Adj. R-sq. : .772
Durbin's h : -.556

All coefficients are highly significant. Using regression coefficients and mean values of BFU and prices, we obtained the elasticities shown in Table 5.

Table 5: Price Elasticities of National Feed Use Derived From Regression Model

	Direct Price Elasticity	Cross Price Elasticity (Corn)
Short term:	-1.1	0.8
Long term:	-2.3	1.8

Based on the regression results, national demand for feed use is price-elastic and shows a strong response to corn. However, the empirical (regression-based) elasticities are substantially smaller than synthetic estimates derived from the least-cost model, particularly under realistic pricing assumptions, with barley trading at 15 to 25 cents/bu discounts to corn.

The least-cost model may overstate the price sensitivity of regional feed use. In the short term, livestock producers may resist changing ration formulations for technical reasons, e.g., to avoid acidosis in cattle, or because existing grain stocks and limited storage capacity raise the costs of switching feedgrains. Many livestock producers in North Dakota and Minnesota are also grain producers. Much of the regional hog inventory is in southern Minnesota, where producers are likely to have their own supplies of corn on hand. Much of North Dakota's beef industry is in the western part of the state where more feed barley is grown. These details are obscured in regional price averages which, in any case, take no account of the discrepancy between market prices and values of grain produced and fed on farm.

In defense of our approach, several points bear emphasis. The least-cost model incorporates more specific market information, and a more comprehensive list of feed substitutes, than would be standard in a regression analysis. More importantly, regression analyses of feed use are restricted to national data, which is of uncertain reliability. National feed use is not measured directly, but as a residual in USDA's supply-demand balance. The choice of the price variables (for regression analysis) is also open to question.[15] National aggregates and price averages can be of limited relevance for many types of applied market research. In the case of barley, regional demand schedules have numerous potential applications--not least, to analysis of interregional trade flows--but are impossible to estimate except in the context of a normative model.

V. Sensitivity Analysis

The variety of detailed assumptions embedded in the least-cost model allows many potential areas for sensitivity analysis. Here we present results from four sets of model simulations. First, we illustrate the impact of alternative price assumptions. We then show hypothetical shifts in regional demand that would result from enhanced characteristics, i.e., higher levels of protein and lysine, and lower levels of beta-glucans.

Under base-case assumptions, feedstuffs were priced at levels observed at the end of March, 1993. To indicate the sensitivity of our results to the choice of base period, we also solved the model with prices from five months earlier (end-October, 1992). The alternative prices are shown in Table 6. Corn and other grains are priced lower than in the base case. Alfalfa and brome hay are substantially lower, while soybean and sunflower meal are higher.

Figure 5 shows the impact of alternative pricing assumptions on aggregate demand in North Dakota and Minnesota. Evaluated with October prices, the demand schedule lies below and to the left, apparently because corn and other grain substitutes are priced lower than the base case. At higher barley price ranges (above $1.55/bu), both demand schedules are extremely elastic. For both base periods, demand is effectively saturated at prices below $1.30/bu.[16]

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[15]Prices received by producers are computed nationally, but do not reflect prices paid at the point of feed use. Prices in a major market (such as Minneapolis) may misrepresent nationwide relationships between barley and feed substitutes.

[16]At such low barley prices, the model indicates levels of demand above regional production (about 172 million bu in 1992, including both malting and feed barley). Given regional supplies of corn and other grains, the notion of saturation is fairly tenuous.

Table 6: Prices From End-October 1992, North Dakota and Minnesota

Ingredient	Price	Percent Higher or Lower than Base Case
Alfalfa	$35/ton	-46.1
Barley	*	n.a.
Brome Hay	$25/ton	-50.0
Corn	$1.75/bu	-6.4
Corn Silage	$15.5/ton	-4.4
Corn Gluten Meal	$280/ton	-6.7
Dical. Phosphate	$500/ton	0.0
Fish Meal	$495/ton	+7.6
Limestone	$4.30/cwt	0.0
Molasses	$76/ton	0.0
Oats	$1.20/bu	-7.7
Sorghum	$2.50/bu	-3.4
Soybean Meal	$189/ton	+7.4
Soybean Oil	$.20/lb	0.0
Sunfl. Meal (28%)	$90/ton	+8.4
Synth. Lysine	$1.16/lb	+28.8
Synth. Methionine	$1.63/lb	0.0
Tallow	$0.13/lb	0.0
Wheat	$3.20/bu	-5.9
Wheat Straw	$20/ton	-16.7

* Varied incrementally in model simulations.
n.a. not applicable.

The remainder of this section focuses on technical characteristics of barley. Specifically, we use the model to estimate the demand for improved barley varieties. Figure 6 shows a demand shift associated with higher protein content. The solid line represents the regional demand schedule under base-case assumptions (13.5 percent protein), and the dashed line represents the shifted schedule (14.5 percent protein). In general, higher protein content produces an outward shift in the demand schedule. This is not surprising given the values attached to barley's protein content in cattle and hog rations (see Table 2).

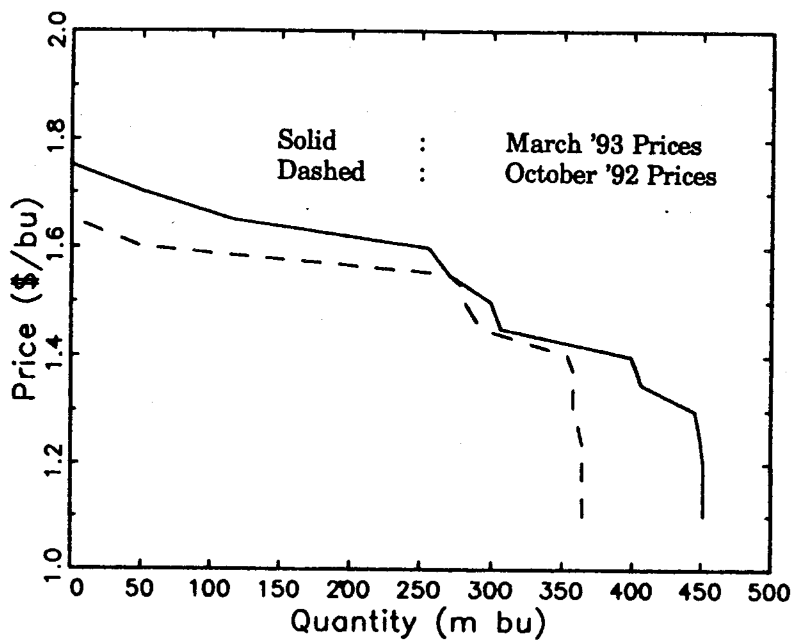

Figure 5. Demand for Feed Barley in North Dakota and Minnesota Under Alternative Pricing Assumptions

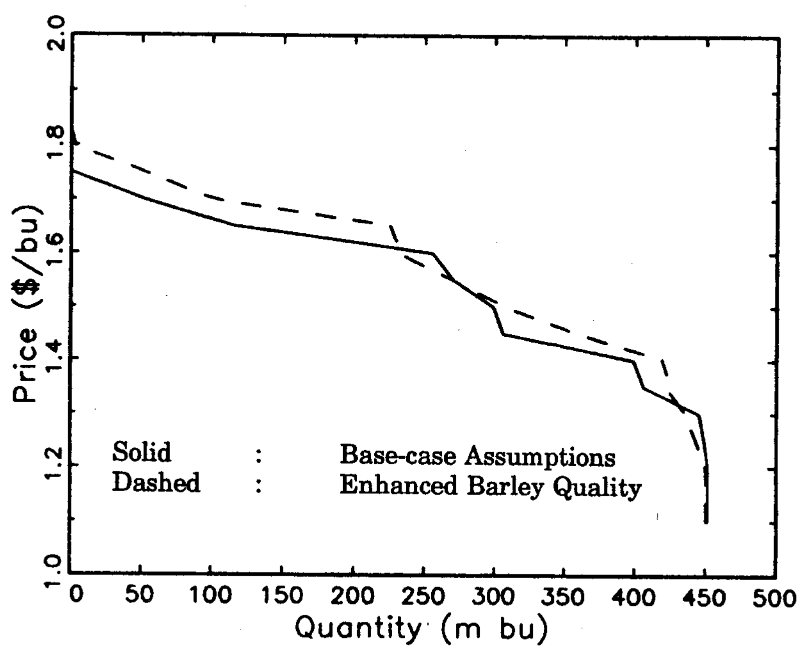

Figure 6. Impact of Higher Protein Content on Regional Demand

Figure 7 shows the shift associated with 25 percent higher lysine content than assumed in the base case. Lysine represents a binding constraint for both hogs and poultry. Evidently, an increase in lysine content could have a sizable impact on regional demand. Figure 8 shows the effect of relaxing the constraint on barley intake for poultry (from 20 percent of total dry matter, to 40 percent). This is equivalent to reducing the beta-glucan content of barley. Results suggest that demand would shift only at lower price levels.

Simulations of this type provide a convenient way to assess the implications of alternative barley breeding programs. Of course, they only address the demand side. The development of varieties with enhanced feeding characteristics does not ensure adoption by producers. Further, market premiums would only emerge if accompanied by refinements of the merchandising and handling system, such as separate storage facilities and identity-preserved shipments.

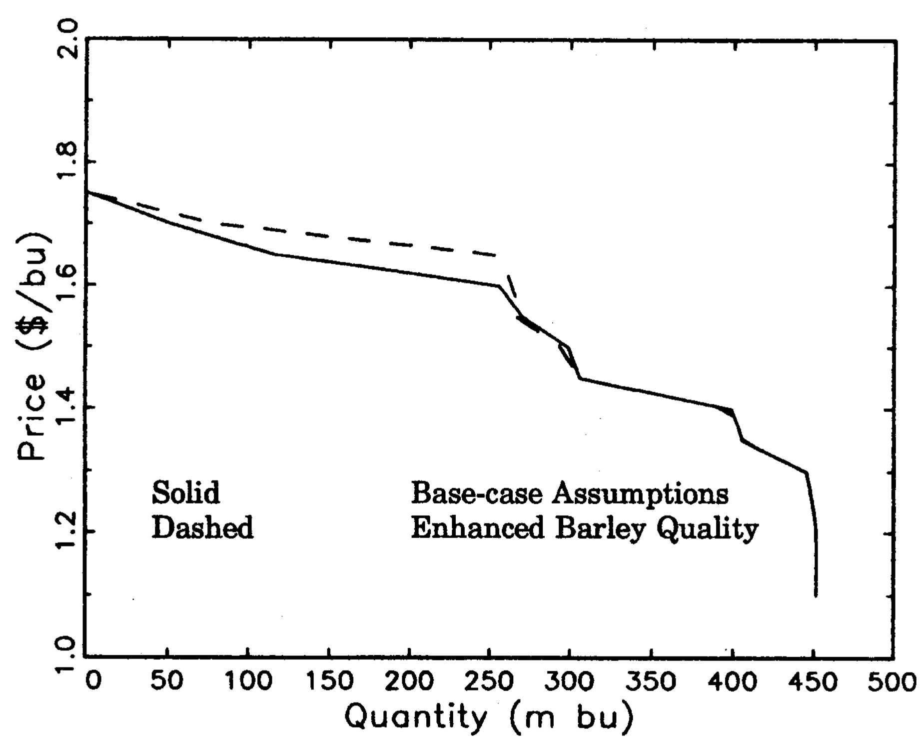

Figure 7. Impact of Higher Lysine Content on Regional Demand

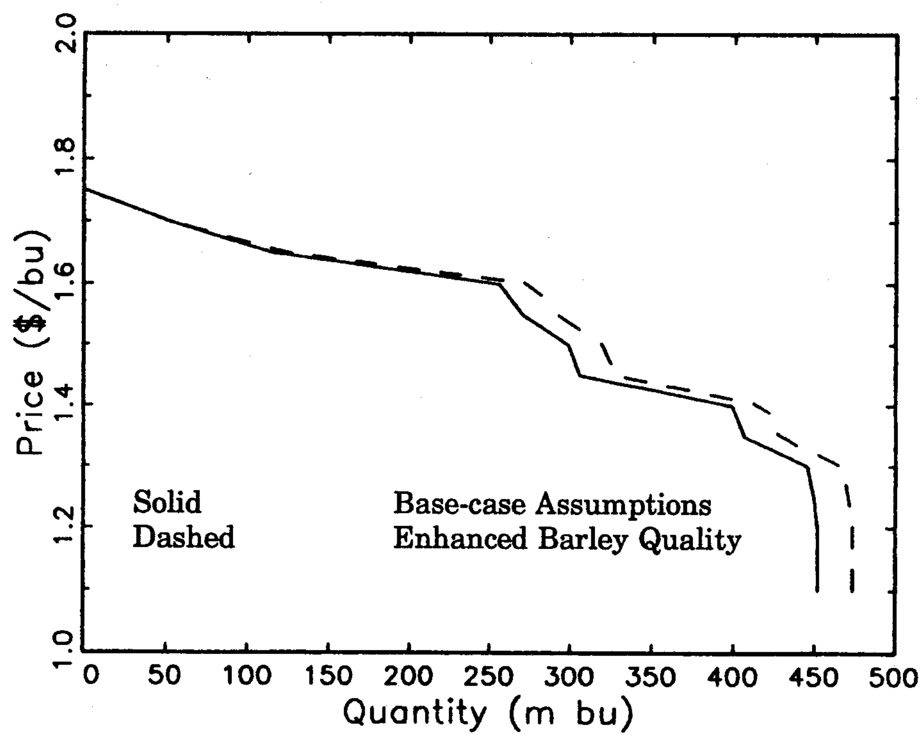

Figure 8. Impact of Reduced Beta-glucan Content on Regional Demand

VI. Demand for Feed Barley in California

In this section we extend the analysis to California, a major feed-deficit region. California is important for several reasons. It has long been a focus of market development efforts for Northern barley, because transportation costs tend to make barley competitive with corn in this market. Moreover, the size of the California market was a point of contention in Canada in the context of recent debate over deregulation of barley exports.[17] Advocates of a continental barley market pointed to California as a promising (and hitherto underutilized) market for Canadian barley--a view challenged by the Canadian Wheat Board. Missing from that debate was any explicit, quantitative assessment of how regional market size depends on barley price.

[17]The study by Carter estimates California's 1992 feed grain deficit (consumption less state production) at about 5.1 million metric tons or over 230 million bushels in terms of barley equivalent.

To evaluate market potential in California, we use 1992 livestock inventory numbers with selected adjustments for time on feed. Prices for feedstuffs are based on market quotations from end-March 1993 (Table 7). Several new feedstuffs are included, e.g., rice bran, dehydrated beet pulp, almond hulls, and cottonseed meal. Other feedstuffs that were appropriate for North Dakota and Minnesota, e.g., brome hay and sunflower meal, are omitted from the California ingredient list.

Table 7: Ingredients and End-March 1993 Prices, California

Ingredient	International Feed Number	Price	Potential Use †
Alfalfa	1-00-063	$95/ton	C,S,D
Almond Hulls	4-00-359	$79/ton	C,S,D
Barley	4-00-549	*	C,H,S,D,P
Corn	4-02-935	$3.19/bu	C,H,S,D,P
Corn Silage	3-28-250	$26/ton	C,S,D
Corn Gluten Meal	5-28-242	$340/ton	P
Cottonseed Meal	5-01-621	$192/ton	C,H,S,D,P
Dical. Phosphate	6-01-080	$300/ton	C,H,S,D,P
Dehy. Beet Pulp	4-00-669	$107/ton	C,H,S,D,P
Feather Meal	5-03-795	$285/ton	C,H,S,P
Fish Meal	5-02-009	$335/ton	P
Limestone	6-02-632	$1.79/cwt	C,H,S,D,P
Meat & Bone Meal	5-00-387	$275/ton	C,H,S,D,P
Molasses	4-00-668	$90/ton	C,H,S,D,P
Oats	4-03-309	$2.66/bu	C,H,S,D,P
Rice Bran	4-03-928	$100/ton	C,H,S,D,P
Soybean Meal	5-20-612	$221/ton	C,H,S,D,P
Synth. Lysine	n.a.	$1.16/lb	H,P
Synth. Methionine	n.a.	$1.63/lb	H,P
Tallow	4-08-127	$.13/lb	C,H,S,D,P
Wheat	4-05-211	$3.84/bu	C,H,S,D,P
Wheat Straw	1-05-175	$24/ton	C,S,D

† C: beef cattle; H: hogs; S: sheep; D: dairy cattle; P: poultry.
* Varied incrementally in model simulations.
n.a. not available.

Prices of corn, wheat, and oats are substantially higher in California than in North Dakota and Minnesota (Tables 1 and 7). However, the availability of alternative feedstuffs, such as rice bran, may mitigate some of the impact of high corn prices on California barley demand.

Results of model simulations for California, broken down by livestock class, are shown in Figures 9 and 10. These are based on numerous solutions of the regional least-cost model, with barley price changing at 5 cent increments. Note that the vertical scale is different than in earlier figures. In California, barley enters livestock rations at a higher price (relative to the Midwest) due to higher-priced substitutes.

Based on Figure 10, dairy cattle appear to represent the greatest "market potential" for barley in California. There is also substantial demand for barley in beef cattle rations at lower price levels (below $2.60/bu) under our base-case assumptions. Hogs and sheep are of minor aggregate importance despite the high proportion of barley in their diets. Demand for barley in poultry rations is significant only at low price levels.

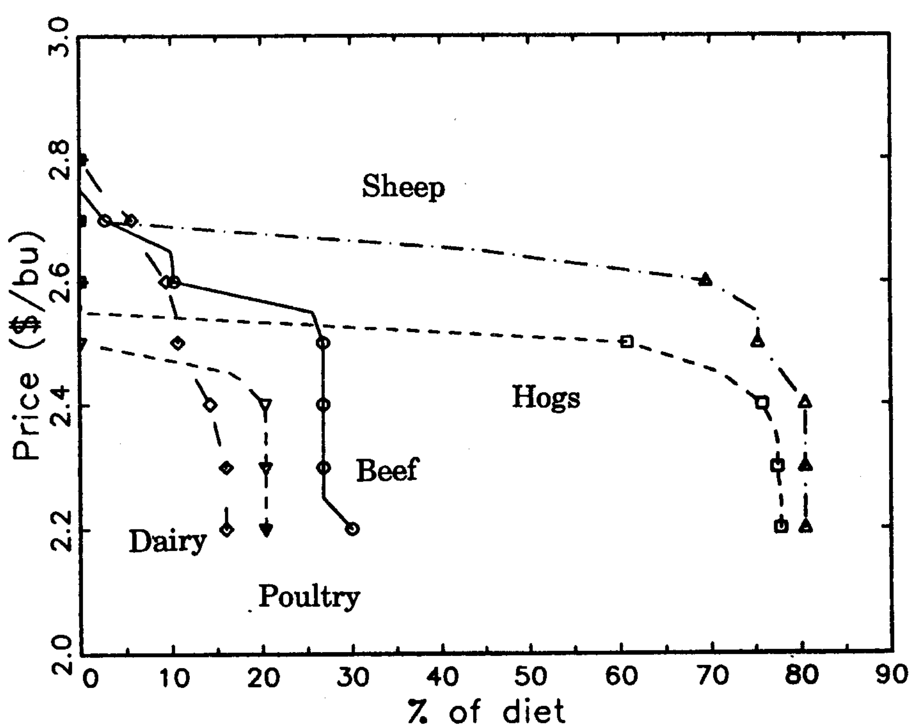

Figure 9. Barley as Percent of Diet by Livestock Class, Base-case Assumptions, California

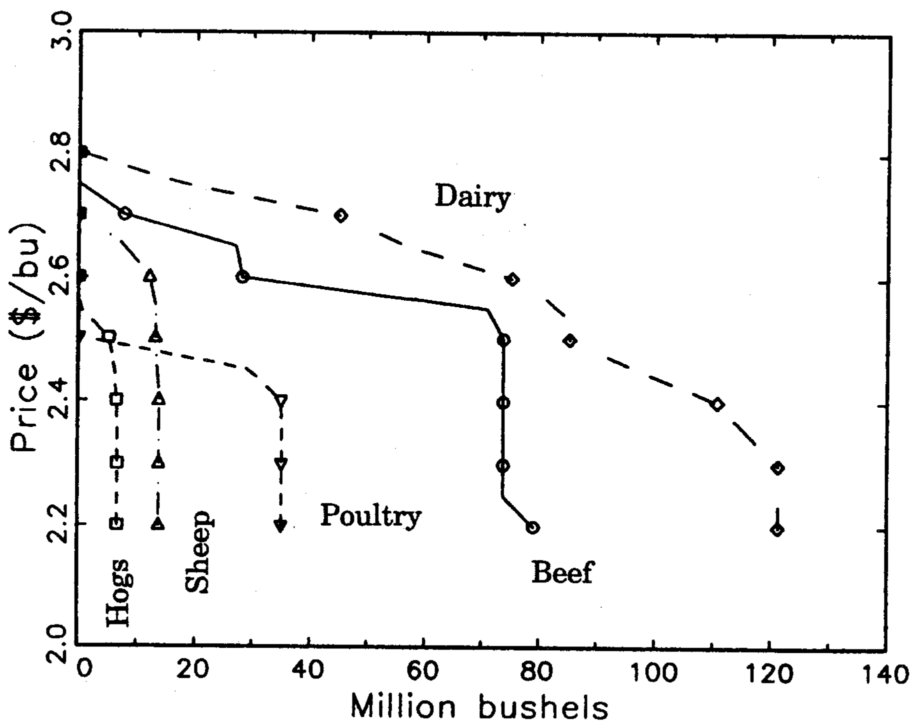

Figure 10. Aggregate Barley Demand by Livestock Class, Base-case Assumptions, California

These results obviously depend on the prices of substitute feedstuffs. For purposes of illustration, the prices of corn and rice bran were varied by 5 percent (up and down) relative to their base-case levels. Figures 11 and 12 show how the California demand for barley shifts in each case.

Although estimated as a stepwise schedule (by virtue of the LP formulation), it is convenient for some purposes to represent regional demand as a function of prices. A simple *ad hoc* method is to fit a regression to synthetic data generated by the least-cost model. A linear approximation of the California demand schedule, estimated with data displayed in Figures 11 and 12, is given by:[18]

$$QB = 425.5 - 572.7 \cdot PB + 229.7 \cdot PC + 4.490 \cdot PRB$$

where QB is the quantity of barley demand (million bushels); PB is the price of barley ($/bu); PC is the price of corn ($/bu); and PRB is the price of rice bran ($/ton).

We use this equation and base-case prices of substitutes to derive the price elasticities shown in Table 8.

[18]Observations with barley quantity in excess of 240 million bu were excluded from the data set. Statistics from the regression do not hold much interest, although the overall fit is quite good (adjusted R-square .954).

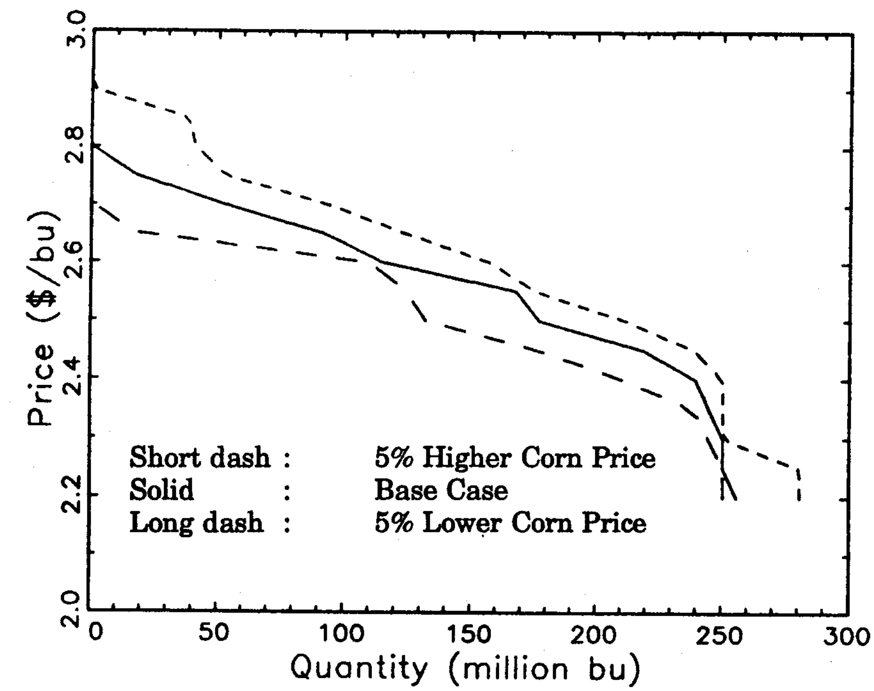

Figure 11. Shifts in California Demand due to Higher/Lower Corn Price

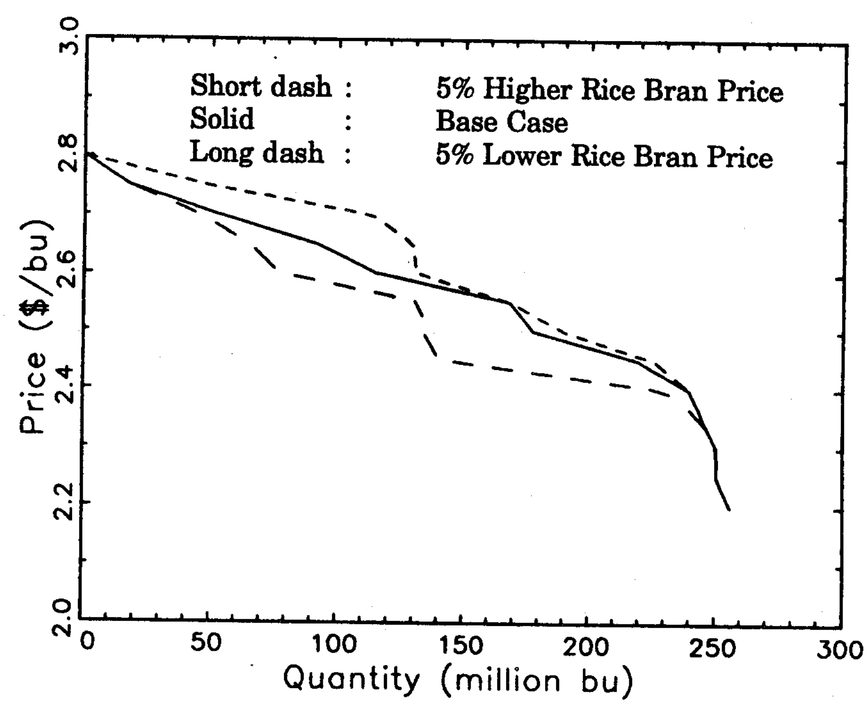

Figure 12. Shifts in California Demand due to Higher/Lower Rice Bran Price

Table 8: Price Elasticities for California Barley Demand Based on Linearized Demand Schedule

Quantity Demand	Direct Price Elasticity	Cross-Price Elasticities	
		Corn	Rice Bran
40	-39.2	18.3	11.2
120	-12.4	6.1	3.7
200	-7.0	3.7	2.2

Based on estimates from the linearized schedule, barley demand in California is extremely elastic, even at a level of 200 million bushels, equivalent to about 85 percent of the estimated feedgrain deficit for 1992. In addition, the results indicate that demand is highly sensitive to prices of corn and rice bran. Presumably, other important cross-price effects would be revealed in a more exhaustive set of simulations.

VII. Summary and Implications

This paper has presented a methodology for estimating the regional demand for feed barley. A least-cost feed model, incorporating five classes of livestock and 39 individual animal rations, was used to derive a synthetic demand schedule. The model was applied to North Dakota and Minnesota, a major barley producing region, and California, an important feed-deficit region.

A detailed analysis of barley characteristics was applied to selected rations. Individual characteristics were shown to have different implicit values across livestock classes. Net energy for lactation was the most valued barley attribute in the dairy ration, while protein content was most highly valued for the medium-frame steer. Metabolizable energy was highly valued in hog rations, along with protein, lysine, and phosphorus content. These results challenge the view (which undergirds official support prices for feedgrains relative to corn) that the "feed value" of barley is substantially the same as its "energy value."

The derived regional demand schedules are highly segmented due to the nutritional constraints of different livestock classes. However, the existence of a close substitute, corn, makes barley demand extremely elastic within normal price ranges. In North Dakota and Minnesota, barley demand displays a strong cross-price response to soybean and sunflower meal, important sources of dietary protein.

Additional simulations illustrated how enhancing protein and lysine content, or reducing beta-glucans, would shift the demand schedule for feed barley. This type of analysis provides a flexible basis for simulating demand-side responses to changes in quality attributes--something clearly relevant to the design of barley breeding programs.

The model can be easily adapted to other regions. Animal numbers and ingredient prices are known at least approximately by state, and additional feedstuffs can be included as appropriate. Because the model does not rely on historical data, it may be particularly useful as a tool for measuring market potential under arbitrary price assumptions.

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Appendix

This appendix provides additional background on the least-cost model and detailed descriptions of some representative livestock diets. Tables A-1 through A-5 provide a listing of animal diets incorporated in the model. Accompanying these tables are notes indicating how individual diets are weighted within the model, based on livestock inventory numbers and estimated time on feed. In tables A-6 through A-10, the nutritional constraints imposed for each livestock class are summarized. Results of base-case simulations are provided in tables A-11 through A-15 for five representative diets.

For individual diets, nutritional constraints are based on daily requirements per animal[19] estimated by the National Research Council. Constraint constants are then multiplied by scaling factors in order to reflect the annual requirements of a regional livestock population. For example, consider the protein constraint for medium-frame steers (diet C5 in Table A-1). An individual steer requires 1.42 lbs of protein on a daily basis. There are 771,000 steers within the region (based on livestock inventories), and they spend an average of 5 months on feed. This translates into an annual requirement of 1.42 x 365 x (5/12) x 771,000 = 166,503,870 lbs of protein. Similar calculations, with different scaling factors, apply to other animals.

Several categories of livestock (e.g., lactating dairy cows) are represented by more than one diet. In such cases, the relevant inventory number (or alternatively, time on feed) is apportioned across diets, based on advice received from various industry experts.

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[19]Weekly requirements in the case of poultry diets.

Table A-1: Beef Cattle Diets in the Least-Cost Model

Diet	Description and Reference
C1	Dry pregnant cow, 1200 lbs, last third of pregnancy (NRC 1984b, p. 84)
C2	Medium-frame heifer calf, 600 lbs, 1.5 lb daily gain (NRC 1984b, p. 82)
C3	Medium-frame heifer calf, 900 lbs, 1.5 lb daily gain (NRC 1984b, p. 82)
C4	Bull, 1300 lbs, 1.5 lb daily gain (NRC 1984b, p. 85)
C5	Medium-frame steer, 600 lbs, 1.5 lb daily gain (NRC 1984b, p. 77)
C6	Medium-frame steer, 900 lbs, 2.5 lb daily gain (NRC 1984b, p. 78)

Weighting Scheme for Beef Diets

Weights are based on published state cattle inventories. "Beef cows and heifers that have calved" are allocated to diet C1. "Beef replacement heifers over 500 lbs" are divided equally between C2 and C3. "Bulls over 500 lbs" are allocated to C4. "Other heifers over 500 lbs" and "steers over 500 lbs" are added together; their combined number is divided between C5 and C6 in proportions that vary by state to reflect the importance of cattle finishing operations. The assumed percentages (C5/C6) are 90/10 for North Dakota, 50/50 for Minnesota, and 30/70 for California. Months on feed for diets C1 through C6 are, respectively, 4, 6, 4, 4, 5, and 11.

Table A-2: Hog Diets in the Least-Cost Model

Diet	Description and Reference
H1	Growing hogs, 10-20 kg. liveweight (NRC 1988a, pp. 50-51)
H2	Growing hogs, 20-50 kg. liveweight (NRC 1988a, pp. 50-51)
H3	Growing hogs, 50-110 kg. liveweight (NRC 1988a, pp. 50-51)
H4	Bred gilts, sows and adult boars (NRC 1988a, p. 52)
H5	Lactating gilts and sows (NRC 1988a, p. 52)

Weighting Scheme for Hog Diets

Weights are based on published state hog and pig inventories. "Market hogs and pigs under 60 lbs" are allocated to diet H1. "Market hogs and pigs from 60-119 lbs" are allocated to diet H2. "Market hogs and pigs over 120 lbs" are allocated to diet H3. "Hogs and pigs kept for breeding purposes" are divided between diets H4 and H5; lactating gilts and sows (diet H4) are assumed to represent one sixth of the total breeding stock. All pigs and hogs are on feed for 12 months.

Table A-3: Sheep Diets in the Least-Cost Model

Diet	Description and Reference
S1	Lambs finishing, 4-7 months old, 40 kg. (NRC 1985, p. 47)
S2	Replacement ram lambs, 80 kg. (NRC 1985, p. 47)
S3	Replacement ewe lambs, 60 kg. (NRC 1985, p. 47)
S4	Flushing ewe, 80 kg., 2 weeks prebreeding and first 3 weeks breeding (NRC 1985, p. 45)
S5	Nonlactating ewe, 80 kg., first 15 weeks gestation (NRC 1985, p. 45)
S6	Ewe, last 4 weeks gestation, 80 kg. (NRC 1985, p. 45)
S7	Ewe, first 6-8 weeks lactation suckling singles, 80 kg. (NRC 1985, p. 45)

Weighting Scheme for Sheep Diets

Weights are based on published state sheep inventories. "Sheep and lambs on feed" are allocated to diet S1. "Stock sheep, wethers and rams" are allocated to diet S2. "Stock sheep, ewe lambs" are allocated to diet S3. "Stock sheep, ewes, one year and older" are allocated to diets S4 through S7, with variations for months on feed. For diets S1 through S7, months on feed are, respectively, 6, 8, 8, 1, 4, 1, and 2.

Table A-4: Dairy Diets in the Least-Cost Model

Diet	Description and Reference
D1	Lactating cow, 1300 lbs, 4% milkfat, 47 lbs milk/day (NRC 1988b, pp. 144, 147)
D2	Lactating cow, 1300 lbs, 4% milkfat, 70 lbs milk/day (NRC 1988b, pp. 144, 147)
D3	Lactating cow, 1300 lbs, 4% milkfat, 93 lbs milk output/day (NRC 1988b, pp. 144, 147)
D4	Dry pregnant cow, 1300 lbs (NRC 1988b, pp. 143-144)
D5	Large-breed growing heifers, 300 lbs, 1.7 lb daily gain (NRC 1988, pp. 139, 147)
D6	Large-breed growing heifers, 600 lbs, 1.7 lb daily gain (NRC 1988b, pp. 139, 147)
D7	Large-breed growing heifers, 900 lbs, 1.7 lb daily gain (NRC 1988b, pp. 139, 147)

Weighting Scheme for Dairy Diets

Weights are based on published state dairy cow inventories. "Milk cows and heifers that have calved" are allocated to D1 through D4 in the following proportions: 25% to D1, 34% to D2, 25% to D3, and 16% to D4. "Milk replacement heifers" are divided equally among diets D5, D6 and D7. Months on feed for diets D1 through D7, respectively, are 12, 12, 12, 12, 10, 10, and 10.

Table A-5: Poultry Diets in the Least-Cost Model

Diet	Description and Reference
P1	Growing layers, 0-6 weeks (NRC 1984a, pp. 12-13)
P2	Growing layers, 6-14 weeks (NRC 1984a, pp. 12-13)
P3	Growing layers, 14-20 weeks (NRC 1984a, pp. 12-13)
P4	Laying layers (NRC 1984a, p. 12)
P5	Breeding layers (NRC 1984a, p. 12)
P6	Broilers, 0-3 weeks (NRC 1984a, p. 13)
P7	Broilers, 3-6 weeks (NRC 1984a, p. 13)
P8	Broilers, 6-8 weeks (NRC 1984a, p. 13)
P9	Turkeys, 0-4 weeks (NRC 1984a, p. 17)
P10	Turkeys, 4-8 weeks (NRC 1984a, p. 17)
P11	Turkeys, 8-12 weeks (NRC 1984a, p. 17)
P12	Turkeys, 12-16 weeks (NRC 1984a, p. 17)
P13	Turkeys, 16-20 weeks (NRC 1984a, p. 17)
P14	Turkeys, 20-24 weeks (NRC 1984a, p. 17)

Weighting Scheme for Poultry Diets

Inventories of layers are from state statistical sources. "Hens and pullets of laying age" are allocated to diet D4. Layers are on feed for 12 months. Because detailed information on growing layers was unavailable, they are assigned zero weight. For broilers and turkeys, weights are based on annual state production as published in *1992 Feedstuffs Reference Issue*. Annual production of broilers is allocated to diets P6 through P8, with 1 month attributed to each diet. Similarly, annual production of turkeys is allocated to diets P9 through P14, with 1 month attributed to each diet.

Table A-6: List of Nutritional Constraints for Beef Diets

Minimum calcium in grams/day
Minimum phosphorus in grams/day
Maximum dry matter intake in lbs/day
Minimum protein in pounds/day
Minimum metabolizable energy in mcal/day
Minimum total digestible nutrients in lbs/day
Minimum net energy for maintenance in mcal/day
Minimum net energy for gain in mcal/day
Maximum grains as percent of dry matter
Maximum wheat as percent of grain intake
Maximum wheat straw as percent of dry matter
Maximum brome hay as percent of dry matter
Maximum molasses as percent of dry matter
Maximum corn silage as percent of dry matter

Table A-7: List of Nutritional Constraints for Hog Diets

Maximum intake of dry matter in grams/day
Minimum metabolizable energy in kcal/day
Minimum protein in grams/day
Minimum arginine intake in grams/day
Minimum histidine intake in grams/day
Minimum isoleucine intake in grams/day
Minimum leucine intake in grams/day
Minimum lysine intake in grams/day
Minimum methionine intake in grams/day
Minimum phenylalanine and tyrosine intake in grams/day
Minimum threonine intake in grams/day
Minimum valine intake in grams/day
Minimum linoleic acid intake in grams/day
Minimum phosphorus intake in grams/day
Maximum barley as percent of dry matter
Maximum lipids as percent of dry matter
Maximum fiber as percent of dry matter

Table A-8: List of Nutritional Constraints for Sheep Diets

Maximum dry matter intake in kg/day
Minimum total digestible nutrients in kg/day
Minimum digestible energy in mcal/day
Minimum metabolizable energy in mcal/day
Minimum protein in grams/day
Minimum calcium in grams/day
Minimum phosphorus in grams/day
Maximum grains as percent of dry matter
Maximum wheat as percent of grains

Table A-9: List of Nutritional Constraints for Dairy Diets

Maximum dry matter intake in lbs/day
Minimum net energy for lactation in mcal/day
Minimum net energy for maintenance in mcal/day
Minimum net energy for growth in mcal/day
Minimum crude protein in lbs/day
Minimum acid detergent fiber as percent of dry matter
Minimum neutral detergent fiber as percent of dry matter
Minimum calcium in lbs/day
Minimum phosphorus in lbs/day
Maximum grains as percent of dry matter
Maximum wheat as percent of grain intake
Maximum wheat straw as percent of dry matter
Maximum brome grass as percent of dry matter
Maximum molasses as percent of dry matter
Maximum corn silage as percent of dry matter

Table A-10: List of Nutritional Constraints for Poultry Diets

Minimum feed intake in lbs/day, dry matter basis
Minimum metabolizable energy concentration, kcal/kg of feed intake
Minimum protein concentration, percent of feed intake
Minimum calcium concentration, percent of feed intake
Minimum phosphorus concentration, percent of feed intake
Minimum lysine concentration, percent of feed intake
Minimum methionine concentration, percent of feed intake
Maximum barley as percent of dry matter
Maximum lipids as percent of dry matter
Maximum fiber as percent of dry matter

Table A-11: Composition of Ration and Binding Constraints for Medium-Frame Steer (600 lbs), Various Barley Prices

Barley Price ($/bu)	Ingredients in Ration and Percent	Binding Constraints
1.10-1.35	barley (80.3)	max grains as % DM
	wheat straw (18.7)	min TDN in lbs/day
	limestone (0.9)	min calcium in g/day
	sunfl. meal (0.2)	min protein in lbs/day
1.40	barley (70.1)	min TDN in lbs/day
	wheat straw (27.5)	min NE for gain in mcal/day
	sunfl. meal (1.6)	min protein in lbs/day
	limestone (0.8)	min calcium in g/day
1.45-1.65	corn silage (72.9)	max corn silage as % DM
	barley (17.0)	min TDN in lbs/day
	wheat straw (6.6)	min NE for gain in mcal/day
	sunfl. meal (3.3)	min protein in lbs/day
	limestone (0.3)	min calcium in g/day
1.70-1.90	corn silage (73.0)	max corn silage as % DM
	corn (15.9)	min TDN in lbs/day
	wheat straw (5.6)	min NE for gain in mcal/day
	sunfl. meal (5.6)	min protein in lbs/day
	limestone (0.3)	min calcium in g/day

Table A-12: Composition of Ration and Binding Constraints for Market Hog (50-100 kg), Various Barley Prices

Barley Price ($/bu)	Ingredients in Ration and Percent	Binding Constraints
1.10-1.55	barley (90.3)	max barley as % DM
	corn (8.3)	min ME in kcal/day
	limestone (1.1)	min calcium in g/day
	synth. lysine (0.2)	min lysine in g/day
	dicalcium phos. (0.2)	min phosphorus in g/day
1.60	barley (76.9)	min protein in g/day
	corn (14.9)	min ME in kcal/day
	limestone (1.1)	min calcium in g/day
	synth. lysine (0.2)	min lysine in g/day
	dicalcium phos. (0.2)	min phosphorus in g/day
1.65-1.90	corn (90.2)	min ME in kcal/day
	soybean meal (8.1)	min protein in kcal/day
	limestone (1.0)	min calcium in g/day
	synth. lysine (0.2)	min lysine in g/day
	dicalcium phos. (0.6)	min phosphorus in g/day

Table A-13: Composition of Ration and Binding Constraints for Lactating Ewe (80 kg, Suckling Singles), Various Barley Prices

Barley Price ($/bu)	Ingredients in Ration and Percent	Binding Constraints
1.10-1.60	barley (80.4)	max grains as % DM
	sunfl. meal (14.4)	min protein in g/day
	brome hay (4.4)	min TDN in kg/day
	limestone (0.8)	min calcium in g/day
1.65-1.90	brome hay (60.8)	min TDN in kg/day
	corn (24.7)	max DM intake in kg/day
	sunfl. meal (14.2)	min protein in g/day
	limestone (0.3)	min calcium in g/day

Table A-14 Composition of Ration and Binding Constraints for Lactating Dairy Cow (1300 lbs, Yield 93 lbs/day), Various Barley Prices

Barley Price ($/bu)	Ingredients in Ration and Percent	Binding Constraints
1.10-1.40	corn silage (52.8)	min NE lactation in mcal/day
	barley (25.6)	max DM intake in lbs/day
	brome hay (11.3)	min AD fiber as % DM
	soybean meal (9.5)	min protein in lbs/day
	limestone (0.8)	min calcium in lbs/day
	dicalcium phos. (0.2)	min phosphorus in lbs/day
1.45-1.70	corn silage (73.0)	max corn silage as % DM
	barley (25.5)	min NE lactation in mcal/day
	soybean meal (9.5)	max DM intake in lbs/day
	brome hay (2.4)	min AD fiber as % DM
	limestone (0.7)	min protein in lbs/day
	sunfl. meal (0.4)	min calcium lbs/day
	dicalcium phos. (0.1)	min phosphorus in lbs/day
1.75-1.90	corn silage (73.1)	max corn silage as % DM
	corn (12.7)	min NE lactation in mcal/day
	soybean meal (9.3)	max DM intake in lbs/day
	brome hay (3.8)	min AD fiber as % DM
	limestone (0.8)	min protein in lbs/day
	sunfl. meal (0.5)	min calcium in lbs/day
	dicalc. phos. (0.2)	min phosphorus in lbs/day

Table A-15 Composition of Ration and Binding Constraints for Turkey (12-16 Weeks Old), Various Barley Prices

Barley Price ($/bu)	Ingredients in Ration and Percent	Binding Constraints
1.10-1.65	corn (47.3)	Fixed feed intake in g/day
	barley (20.3)	max barley as % DM
	soybean meal (17.0)	min protein as % DM
	oats (13.5)	max fiber as % DM
	limestone (1.8)	min calcium as % DM
	synth. lysine (0.1)	min lysine as % DM
	synth. methionine (0.0)	min methionine as % DM
1.65-1.90	corn (60.5)	Fixed feed intake in g/day
	oats (19.4)	min protein as % DM
	soybean meal (18.2)	max fiber as % DM
	limestone (1.7)	min calcium as % DM
	synth. lysine (0.1)	min lysine as % DM
	synth. methionine (0.0)	min methionine as % DM
	dicalcium phos. (0.0)	min phosphorus as % DM