Demand for Feed Ingredients by U.S. Formula Feed Manufacturers

By Karl D. Meilke[1]

In 1969, formula feed manufacturers utilized 23.1 percent of all the feed grains and wheat fed to livestock. Estimates of aggregate demand by the mixed feed industry for corn, oats, barley, grain sorghum, and wheat are presented. As expected, all of the feed grains have elastic demands. Grain sorghum has the highest direct price elasticity (–5.42), followed by corn (–4.81), oats (–3.82), and barley (–2.75). The direct price elasticity of wheat is estimated to be –0.85. The location of feed manufacturers is found to play an important role in the demand for feed ingredients.

Keywords: Barley, Corn, Demand, Demand elasticity, Demand functions, Feed grains, Grain sorghum, Livestock feeding, Oats, Wheat.

Use of feed grains by formula feed manufacturers in the United States has been increasing for at least the past 20 years. In 1949, 10.2 million tons of feed grains and 1.3 million tons of wheat were utilized by the formula feed industry (*8*). This represented less than 11 percent of the total feed grains and wheat fed in 1949. By 1969 (the latest year for which these data are available) the formula feed industry was consuming 31.5 million tons of feed grains and 0.8 million tons of wheat, or 23.4 percent of the total feed grains and wheat fed to livestock (*6*). The total amount of the individual feed grains fed and the percentages used in formula feed for 1949 and 1969 are shown in table 1.

The mix of feed grains used by formula feed manufacturers has also changed since 1949 when 6.9 million tons of corn, 0.6 million tons of grain sorghum, 0.8 million tons of barley, 1.9 million tons of oats, and 1.3 million tons of wheat were used in manufactured feeds (*8*). By 1969, 19.8 million tons of corn, 7.6 million tons of grain sorghum, 2.4 million tons of barley, 1.7 million tons of oats, and 0.8 million tons of wheat were utilized in formula feeds (*6*, p. 17). The use of corn and barley tripled while the use of grain sorghum increased 10 times and the use of oats held steady.

There are three basic types of formula feeds, each with different requirements for ingredients. They are complete feed, supplement feed, and premix (*6*, p. 2). Complete feeds contain all the nutrients needed in the nonroughage portion of an animal's diet. Complete feed is the major user of feed grains and is the dominant type of feed manufactured in States deficit in the production of feed grains. Supplement feed is combined with other feed ingredients to improve the nutritive balance in an animal's diet. Supplements are produced heavily in feed grain surplus States where they are mixed with farmers' home-grown grain. Supplements contain large amounts of high protein ingredients as well as vitamins and minerals. Premixes are formulations of one or more microingredients, such as vitamins, trace minerals, or drugs, mixed with a carrier. The premix is used to distribute microingredients evely throughout a formula feed. Premixes are heavy users of all the microingredients, and their production is centered in the Corn Belt.

Feed manufacturers are expected to be more responsive than individual livestock producers to changes in the price of individual ingredients. This is because the large amounts of feed mixed by feed processing firms enables them to expend considerable resources in the assessment of the relative prices of the various ingredients and of interstate price differentials. Also, the individual livestock producer is unlikely to sell home-grown grain and then repurchase some other feed grain unless relative prices are very favorable.

Linear programming has been widely adopted by the formula feed industry and is used to

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Table 1. Use of feed grains and wheat by U.S. formula feed manufacturers, 1949 and 1969

Crop	Crop year 1949			Calendar year 1969		
	Total amount fed	Amount used in formula feed	Formula feed use/ total feed use	Total amount fed	Amount used in formula feeds	Formula feed use/ total feed use
	Mil. tons	*Mil. tons*	*Percent*	*Mil. tons*	*Mil. tons*	*Percent*
Corn	79.4	6.9	8.7	99.8	19.8	19.8
Grain sorghum	1.8	0.6	33.3	17.6	7.6	43.2
Oats	19.1	1.9	9.9	11.6	1.9	16.4
Barley	3.3	0.8	24.2	5.6	2.4	42.8
Wheat	3.3	1.3	39.4	5.8	0.8	13.8
Total	106.9	11.5	10.7	140.4	32.5	23.1

Sources: *The Formula Feed Industry, 1969: A Statistical Summary*, U.S. Dept. Agr., Statis. Bul. 485. *Feed Consumed by Livestock: Supply and Disposition of Feeds, 1949–50 by States*, U.S. Dept. Agr., Statis. Bul. 145.

determine least-cost rations. With the aid of linear programming, feed processors can vary the composition of their mixed feeds within limits set by nutritional constraints. As early as 1956, Mighell pointed out that the expansion of the formula feed industry would have a stabilizing influence in feed grain markets by tending to keep the prices of alternative feeds more nearly in line with their marginal feed substitution values (*13*).

A large formula feed industry has two implications for grain marketing. First, an increase in the level of substitution between grains reduces the extent to which the price of a single grain can be set independently of the prices of other feeds, should this ever be desirable from a policy point of view. Second, geographic variations in the prices of ingredients could result in considerable increases in interstate grain shipments.

This model is an attempt to show how the aggregate feed manufacturing industry reacts to changes in the prices of the major feed ingredients. Linear programming can indicate how a cost-minimizing firm should adjust its ingredient use to obtain a least-cost ration under a certain set of specific nutritional constraints, but it cannot indicate how industry demand will change, given the different types of formula feed produced.

This study has at least two purposes. They are (1) to indicate the relative degree of substitution among the feed grains, and (2) to show how price variations may affect the ingredient needs of the formula feed industry under different ingredient price and growth assumptions.

Objectives

This study provides estimates of the demand by formula feed manufacturers for corn, oats, barley, grain sorghum, and wheat. The study answers the following types of questions:

(1) What are the direct and cross price elasticities among the different feed grains?

(a) What effect would a high price for one of the major feed grains, perhaps as the result of a poor crop, have on the demand for it and the other feed grains?

(2) What effect does location play in the demand for feed grains?

(3) How will the expansion of the formula feed industry affect the demand for feed ingredients?

(4) Do different types of formula feed have different ingredient needs?

There is no published information available that estimates the aggregate response of feed manufacturers to ingredient price changes. Likewise, although the feed grains have always been assumed to be very close substitutes, no one has been able to estimate the relevant cross elasticities of demand. This study should fill a part of this knowledge gap.

Data

The quantity data used in this analysis come from a survey of feed mills conducted by the Economic Research Service (*6*). The survey was an attempt at a complete census of all U.S. feed mills producing over 1,000 tons of formula feed

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in 1969. The survey was conducted under the authority of the Defense Production Act of 1950, as amended, and response to the questionnaire was mandatory. Of the feed milling establishments surveyed, 7,267 produced over 1,000 tons of formula feed in 1969. The sample was expanded by approximately 9 percent to allow for unusable questionnaires and firms that may have been missed by the survey. Therefore, the final compilation of data represented the responses of 7,917 feed processing establishments.

Feed ingredient usage was reported by 4,833 firms that mixed some primary feed in 1969. A primary feed is defined to be a feed processed from the ground up, although it may contain a premix used at a rate of less than 100 pounds per ton of finished feed (*6*, p. 2).

Prices paid for feed ingredients were not collected along with the quantity data in the survey of feed mills. Therefore, before any demand analysis can be undertaken, prices have to be obtained. The only comprehensive set of price data collected, by State, is published by the Statistical Reporting Service and relates to the prices received by farmers for feed grains (*20*). The farm price in different States reflects the transportation differentials between States and any premium or dockage due to quality differences. The farm price for the feed grains is calculated by taking a simple average of the monthly prices received by farmers during calendar year 1969. The monthly prices reflect the cost of storing grain from one month to the next. Feed manufacturers purchase grain steadily throughout the year and do not store ingredients for long periods. Data in the feed mill survey indicate that feed manufacturers maintain slightly more than 30 days inventory of grain (*6*, p. 45). Hence, it is not necessary to weight prices more heavily in some months than others in computing average farm prices.

A study by the U.S. Department of Agriculture also indicated that seasonality in the production of manufactured feed was not great. Production varied from a peak of 8 percent above average in April to 6 percent below average in August (*23*, pp. 30-34).

Since the price data are collected at the farm level, the published prices have to be adjusted to reflect the wholesale price. The margin between the prices received by farmers (farm price) and the prices paid by feed manufacturers (wholesale price) includes charges for handling, assembling, and blending of the grain ingredients. The farm prices of feed grains are adjusted to reflect wholesale prices by adding a margin for the assembly function. The margin is computed from data collected by the U.S. Department of Agriculture on the cost of handling grain at country and terminal elevators in six regions of the United States (*16*).[2]

For some States, prices received by farmers for feed grain are not reported. In these States estimates of the prevailing wholesale prices during 1969 were obtained from private trade sources.[3]

The Model

A single-equation demand function for each of the feed ingredients is estimated using ordinary least squares. Identification of the demand curve is possible, using single-equation methods, if we assume that feed manufacturers consider the major feed ingredient prices as fixed. If feed manufacturers consider feed grain prices fixed, the supply facing a particular firm is perfectly elastic and the regression of quantity on prices provides parameter estimates of the demand curves (*10*, p. 509).

The demand curves for the feed ingredients are obtained using cross section data collected from feed manufacturers for 47 States for calendar year 1969 (*6*, pp. 16-20). None of the major feed ingredients were used in all of the 47 States surveyed. The number of observations for a particular ingredient varies from 45 for corn and oats to 43 for barley, 39 for wheat, and 32 for grain sorghum.

[2] In computing the marketing margin, grain received at the feed mill by truck is assumed to come from a country elevator where it is also received by truck. Eighty percent of the grain received at a feed mill by rail is assumed to originate from a country elevator, and 20 percent from a terminal market where the grain is received by rail from a country elevator. The margin between farm and wholesale prices varies from a low of 3.8 cents per bushel in North Dakota to a high of 6.8 cents per bushel in several Northeastern States.

[3] It is well known that if the independent variables in a multiple regression analysis contain measurement error, the ordinary least squares estimates of the coefficients are biased and inconsistent. In this portion of the study, the chance of measurement error in the price variables is fairly high. For this reason, the estimates of the demand parameters should be interpreted as providing only estimates of the general magnitude for the true demand parameters. J. Johnston, *Econometric Methods* (New York: McGraw-Hill, 1963), pp. 148-176.

The same two basic demand equations are estimated for each of the feed grains. They are:

$$(1) \quad \log Q_i = \log a + b \log P_i + c \log PF_i + d \log CF_i + e \log L_i + f\, CC_i/CF_i + u$$

and

$$(2) \quad \log Q_i = \log a + b \log (P_i/PF_i) + c \log CF_i + d \log L_i + e\, CC_i/CF_i + u$$

where

Q_i = quantity of feed ingredient Q used in State i

P_i = price per ton of feed ingredient Q in State i

PF_i = weighted average price per ton of the other feed grains used in State i

CF_i = quantity of complete formula feed mixed in State i

L_i = a ten-one variable used to indicate the location of State i

The choice of variables to include in each equation is based on derived demand theory and data limitations. The theory of derived demand for feed inputs is developed by King (*9*) and will not be reproduced here. In general the demand for an input depends on the price of the input, the price of other inputs, and the price of the output. In this study the inputs are the feed grains and the output is complete formula feed. Unfortunately it is impossible to calculate a representative price for formula feed in each State. Therefore the quantity of complete formula feed mixed in each State is included as an independent variable in each equation. This variable performs two roles: (1) it accounts for differences in feed grain usage, because of the size of the formula feed industry in each State, and (2) it picks up some of the influence of the excluded price variable assuming price and quantity move in an inverse relationship.[4] The inclusion of the quantity puts certain restrictions on the estimated elasticities. In particular, the demand for each ingredient is estimated assuming the quantity produced, rather than the price of the output, remains constant.

[4] The use of the quantity of feed mixed in the demand equation can be compared to using the number of animal units in a demand function for all feed grains. For example see, R. J. Foote (*5*).

Theoretically, we would expect the sign of the coefficient on P_i to be negative and the sign on PF_i to be positive. We would expect both the direct and cross price elasticities to be greater than one because of the availability of close substitutes.

The sign of CF_i should be positive and close to one. A coefficient of one implies that the use of a feed ingredient varies in direct proportion with the amount of feed produced. In some equations the coefficient for CF_i is constrained to equal one.

For most ingredients, the increased production of certain types of formula feed has a greater impact on their use than the increased production of other types of feed. For this reason the proportion of cattle feed produced in each State is used as a demand shifter. Multicollinearity between CC_i/CF_i and CF_i was not a problem.

L_i is a location variable that indicates whether a State is in the Eastern, Western, or Midwestern region of the United States. Figure 1 indicates the boundaries of the three regions. In general, the West contains States that are deficit in the production of corn but surplus in the production of one or more of the other feed grains. The Midwest contains the Corn Belt States, which are all surplus corn-producing States. The East contains States that are generally deficit in the production of all the feed grains, although there are a few exceptions. For example, North Carolina is a surplus corn-producing State. The location variable is included in the analysis to pick up two possible influences. First, feed manufacturers may be reluctant to use ingredients that are unfamiliar to their customers. This is especially true if the formula feed is sold with an "open label."[5] Second, the location variables may pick up some of the nonfeed costs of using ingredients shipped long distances. For example, North Carolina feed manufacturers may not use barley because delivery from the Northwest is uncertain and because of the extra cost involved in locating distant sources, even though the price of barley, including transportation charges, may be slightly cheaper than corn.

Equation (2) is similar to equation (1) except that relative prices are used instead of absolute prices. This form of the equation constrains the

[5] An open label lists the ingredients included in the formula feed.

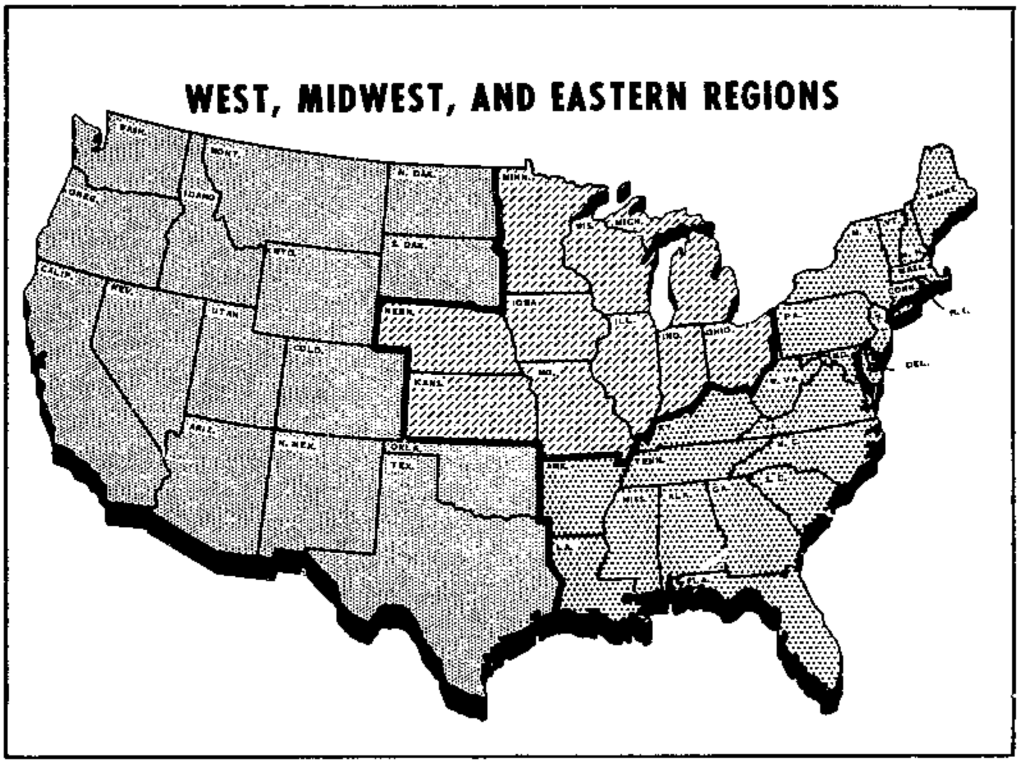

Figure 1

direct and cross price elasticities to be equal.

All of the demand equations are estimated using data converted to logarithms, except for the ratio of CC_i to CF_i. Logarithmic equations are preferred when (1) the relationships between the variables are believed to be multiplicative rather than additive; (2) the relations are believed to be more stable in percentage than in absolute terms; and (3) the unexplained residuals are believed to be more uniform over the range of the independent variables when expressed in percentage rather than absolute terms (*4*, pp. 37-38). In this analysis it is felt that the independent variables affect the dependent variables jointly, rather than additively; therefore, log-log demand curves are estimated. If an additive relationship is used for the prices of the various grains in the demand equation, it implies that the effect of a change in the price of corn, for example, on the quantity of corn used would be independent of the price of other feed grains. It seems more realistic to assume that the effect of a change in the price of corn is greater when the prices of the other grains are relatively high and their usage low than when the other grains are relatively cheap and their usage high. This amounts to assuming a declining marginal rate of substitution between corn and other grains. It is one way of arguing for the constant elasticity assumption which is implicit in a multiplicative model.

A word of caution should be given concerning the interpretation of the elasticities calculated in this study. The estimates given below are based on geographic variation in grain prices. This price variation, over space, allows the estimation of cross demand effects that are impossible to detect in time series data, because of the tendency of feed grain prices to move together over time.[6] Therefore the ceteris paribus assumption imposed in estimating the demand curves, namely that the price of one feed grain varies while the prices of the other feed grains are constant, is not likely to be met over time. Hence, the demand elasticities for any individual feed are much larger when holding the prices of

[6] For a discussion of the problem of estimating the cross demand relationships among the feed grains using time series data, see K. W. Meinken (*12*).

other feed grains constant than when allowing the prices of all feed grains to vary together.[7] Consequently, the elasticities calculated in this study are most applicable in determining how the use of a particular feed ingredient will vary when a change in freight rates or cropping patterns makes it more or less expensive relative to other feed grains in a State.

Empirical Analysis: Feed Grains and Wheat

Corn. In 1969, 96.8 percent of the 4,717 feed establishments that used some feed grain reported using corn (*6*, p. 16). Corn is the feed grain against which all other feed grains are measured. It is unexcelled in feeding poultry, and because of its net energy value, corn is one of the best feeds for use in broiler rations. A large percentage of corn is included in most of the high energy mashes for broilers. It is an excellent feed for dairy cattle but is generally used as only a part of the concentrate mixture, frequently being mixed with oats. Corn is also a good beef cattle feed and unsurpassed for growing and fattening pigs (*15*, pp. 415-522).

The statistical estimates of the demand for corn are presented below. The *t* values of the estimated coefficients are in parentheses below the coefficients. Since all of the variables have been converted to logarithms, the coefficients can be interpreted directly as elasticities.

$$(3)\quad QC_i = 2.8 - \underset{(5.13)}{7.01}PC_i + \underset{(4.67)}{5.01}PFC_i + \underset{(11.01)}{1.05}CF_i$$

$$R^2 = 0.77$$

$$(4)\quad QC_i = 5.3 - \underset{(4.71)}{4.81}PC_i + \underset{(2.04)}{1.47}PFC_i + \underset{(18.00)}{0.99}CF_i - \underset{(9.40)}{0.59}\,West - \underset{(3.10)}{0.26}\,Mwst$$

$$R^2 = 0.93$$

$$(5)\quad QC_i = -0.57 - \underset{(4.50)}{5.14}PC_i/PFC_i + \underset{(10.70)}{1.06}CF_i$$

$$R^2 = 0.74$$

where

QC_i = quantity of corn used in State i (1,000 tons)
PC_i = price per ton of corn in State i
PFC_i = average price per ton of all feed grains except corn in State i
CF_i = quantity of complete formula feed mixed in State i (1,000 tons)
$West$ = a zero-one variable equal to one for Western States and zero for all other States
$Mwst$ = a zero-one variable equal to one for Midwestern States and zero for all other States

Equation (3) is the simplest formulation of the demand curve for corn. All of the coefficients are significant at the 5 percent level, and the equation explains 77 percent of the variation in the dependent variable. The direct price elasticity in equation (3) is −7.0, and the cross price elasticity is 5.0. Equation (3) predicts a 1 percent change in the use of corn in response to a 1 percent change in the production of complete formula feed.

Equation (4) is the same as equation (3) except that two location variables have been added. The major effect of this adjustment is to lower the direct and cross price elasticities to −4.81 and 1.47, respectively. Holding all other variables constant, States will use less corn than those in the Midwest or the East. According to equation (4) a change in the price of corn will have about three times the effect on the quantity of corn used as will a similar change in the average price of the other feed grains.[8]

In equation (5) the two elasticities are constrained to be equal, and the estimated elasticity is found to be −5.14.[9]

Grain sorghum. Grain sorghum was utilized by 62.0 percent of the feed processing firms

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[7] For a detailed analysis of the demand for feed grains over time, see K. D. Meilke (*11*).

[8] Due to the close correlation among the location variables and the type of feeds mixed in the different regions, it was difficult to determine whether the different rates of use were due to the difference in the type of feed mixed or location. If the difference is due to the type of feed mixed, then increases in the production of poultry feed will have a much larger effect on the use of corn than increases in the production of other types of feed.

[9] If the location variables are added to equation (5), the estimated elasticity falls to approximately one-half of that found in equation (5).

reporting ingredient usage in 1969 (*6*, p. 16). Grain sorghum is well liked for fattening cattle and produces nearly as rapid gains as corn. The feeding value of grain sorghum is close to that of corn for poultry, when used in well balanced rations. If a large proportion of grain sorghum is used in a broiler ration, it will produce white skinned and shanked birds. Grain sorghums are excellent in feeding swine (*15*, pp. 453-456).

Four demand curves for grain sorghum were fitted statistically and are presented below:

$$(6)\quad QGS_i = -4.98 - \underset{(2.32)}{7.50PGS_i} + \underset{(2.10)}{9.12PFGS_i} + \underset{(3.42)}{0.93CF_i} + \underset{(2.60)}{0.87Mwst} + \underset{(5.55)}{1.64West}$$

$$R^2 = 0.61$$

$$(7)\quad QGS_i = -2.42 - \underset{(2.35)}{7.48PGS_i} + \underset{(3.91)}{0.99CF_i} + \underset{(2.78)}{0.76Mwst} + \underset{(5.65)}{1.60West}$$

$$R^2 = 0.60$$

$$(8)\quad QGS_i = -\underset{(1.53)}{4.90} - \underset{(1.53)}{5.42PGS_i} + \underset{(1.46)}{6.77PFGS_i} + \underset{(3.71)}{1.04CF_i} + \underset{(1.35)}{0.88CC_i/CF_i} + \underset{(1.92)}{0.68Mwst} + \underset{(2.65)}{1.18West}$$

$$R^2 = 0.63$$

$$(9)\quad QGS_i = -2.78 - \underset{(1.54)}{5.35PGS_i/PFGS_i} + \underset{(4.21)}{1.09CF_i} + \underset{(1.41)}{0.90CC_i/CF_i} + \underset{(2.00)}{0.59Mwst} + \underset{(2.65)}{1.14West}$$

$$R^2 = 0.63$$

where

QGS_i = quantity of grain sorghum used by formula feed manufacturers in State i (1,000 tons)

PGS_i = price per ton of grain sorghum in State i

$PFGS_i$ = average price per ton of all feed grains except grain sorghum in State i

$West$ = a zero-one variable equal to one for the Western States and zero for all other States

$Mwst$ = a zero-one variable equal to one for the Midwestern States and zero for all other States

CC_i/CF_i = cattle feed produced as a percentage of total complete feed mixed in State i

CF_i = quantity of complete formula feed manufactured in State i (1,000 tons)

All of the coefficients in equations (6) and (7) have the correct sign and the *t*-values for all of the variables are over 1.64, the critical value for a one-tailed test of significance at the 5 percent level.

The direct and cross price elasticities for grain sorghum are both quite high, indicating the demand for grain sorghum is very elastic. This seems reasonable since the price of grain sorghum is such that it can compete with corn in the Midwest and barley in the West. The cross price elasticities are slightly larger than the direct price elasticities in equations (6) and (8).

The coefficients on the location variables show that grain sorghum is used more intensively in the West and Midwest than in the East.

All of the equations indicate that the demand for grain sorghum will increase about 1 percent for every 1 percent increase in the production of complete formula feed. An increase in the proportion of complete cattle feed mixed, holding total production constant, will also cause the demand for grain sorghum to increase.

Oats. Oats were utilized by 86 percent of the formula feed manufacturers in 1969 (*6*). Oats can be used as a part of the ration for swine, but because of a high fiber content, they are too bulky to be the chief concentrate. Oats are very desirable in poultry rations because of certain special characteristics, such as the tendency to prevent picking and cannibalism. Oats also improve the growth and feather development of chicks while helping to prevent mortality. Oats have a higher value for dairy cows in comparison with corn than would be expected on the basis of total digestible nutrients. Dairymen commonly include some ground oats in the concentrate mixture for dairy cattle (*15*, pp. 427-431).

Equations (10) through (13) are the demand curves estimated statistically for oats.

$$(10)\ QO_i = 3.76 - \underset{(2.63)}{3.82}PO_i + \underset{(0.50)}{0.85}PFO_i + \underset{(8.75)}{0.83}CF_i + \underset{(2.60)}{0.65}CC_i/CF_i - \underset{(2.15)}{0.34}West + \underset{(0.51)}{0.08}Mwst$$

$$R^2 = 0.75$$

$$(11)\ QO_i = -1.24 - \underset{(2.05)}{3.07}PO_i/PFO_i + \underset{(8.19)}{0.81}CF_i + \underset{(2.40)}{0.63}CC_i/CF_i - \underset{(1.05)}{0.15}West + \underset{(2.96)}{0.34}Mwst$$

$$R^2 = 0.72$$

$$(12)\ QO_i = 3.51 - \underset{(2.93)}{4.32}PO_i + \underset{(0.69}{1.21}PFO_i + 1.0CF_i - \underset{(2.68)}{0.69}CC_i/CF_i - \underset{(2.29)}{0.37}West + \underset{(0.20)}{0.03}Mwst$$

$$R^2 = 0.43$$

$$(13)\ QO_i = -1.76 - \underset{(2.35)}{3.57}PO_i/PFO_i + 1.0CF_i + \underset{(2.48)}{0.67}CC_i/CF_i - \underset{(1.19)}{0.17}West + \underset{(2.56)}{0.30}Mwst$$

$$R^2 = 0.36$$

where

QO_i = quantity of oats used by formula feed manufacturers in State i (1,000 tons)

PO_i = price per ton of oats in State i

PFO_i = average price per ton of all feed grains except oats in State i

$West$ = a zero-one variable equal to one for the Western States and zero for all other States

$Mwst$ = a zero-one variable equal to one for the Midwestern States and zero for all other States

CC_i/CF_i = cattle feed produced as a percentage of total complete feed mixed in State i.

All of the variables in equations (10) through (13) have the correct signs, and equation (10) explains 75 percent of the variation in the dependent variable. The coefficient on the *PFO* variable in both equations (10) and (12) is not statistically significant.

The estimated cross demand elasticities of 0.85 in equation (10) and 1.21 in equation (12) are much smaller than the cross demand elasticities estimated for corn or grain sorghum. This is probably due to the fact that the price of oats, in most States, is much higher in relation to feeding value than the prices of other feed grains. Just the same, oats are utilized in nearly every State because of the special characteristics mentioned earlier. To make it profitable to use oats as a major item in livestock ratios, the price of other feed grains would have to increase considerably. All of the equations indicate that complete cattle feed is a heavy user of oats.

Equations (12) and (13) differ from (10) and (11) in that the coefficient of CF_i is constrained to equal one. This change increases the estimates of the demand elasticities.

Wheat. Wheat was used by 68 percent of the feed manufacturing establishments in 1969 (*6*). In only three States did the amount of wheat used by formula feed manufacturers account for more than 10 percent of the total grain used in the State. Wheat is about equal in feeding value to corn for dairy cows and a good substitute for corn or barley in fattening cattle. It is slightly superior to corn in feeding swine. Poultry prefer wheat to all other grains, and a limited amount is often included in poultry rations to increase their palatability and to furnish variety (*15*, pp. 437-440).

Presented below are the estimated demand curves for wheat.

$$QW_i = -6.70 - \underset{(0.43)}{0.85}PW_i + \underset{(2.49)}{3.27}PFW_i + \underset{(6.57)}{0.90}West + \underset{(4.47)}{0.66}Mwst + \underset{(6.16)}{0.76}CF_i \quad (14)$$

$$R^2 = 0.69$$

$$QW_i = -1.83 - \underset{(2.20)}{2.72}PW_i/PFW_i + \underset{(6.73)}{0.80}CF_i + \underset{(6.68)}{0.92}West + \underset{(4.39)}{0.58}Mwst \quad (15)$$

$$R^2 = 0.67$$

$$QW_i = -4.63 - \underset{(0.92)}{1.83}PW_i + \underset{(2.31)}{3.15}PFW_i + 1.0CF_i + \underset{(7.48)}{1.00}West + \underset{(4.19)}{0.65}Mwst \quad (16)$$

$$R^2 = 0.65$$

$$QW_i = -2.46 - \underset{(2.24)}{2.83}PW_i/PFW_i + 1.0CF_i + \underset{(7.54)}{1.00}West + \underset{(4.44)}{0.60}Mwst \quad (17)$$

$$R^2 = 0.65$$

where

- QW_i = quantity of wheat utilized by formula feed manufacturers in State i (1,000 tons)
- PW_i = price per ton of wheat in State i
- PFW_i = average price per ton of all feed grains except wheat in State i
- $West$ = a zero-one variable equal to one for Western States and zero for all other States
- $Mwst$ = a zero-one variable equal to one for Midwestern States and zero for all other States.

The estimate of the direct price elasticity from equation (14) for wheat is −0.85, while the cross price elasticity is estimated to be 3.27. The reason for the large cross price elasticity in comparison with the direct price elasticity can be partially explained by the fact that wheat prices have often been supported at levels that remove it from competition with the feed grains. Consequently, wheat prices are probably not included in many feed manufacturers' linear programming models unless the price of feed grains is very high.

When the price of feed grains increases, the cost of the feed manufacturer's rations also increases. This signals the feed processor to try to find alternative nutrient sources that are cheaper, and wheat will probably be considered. On the other hand, when the price of wheat falls into the range where it is competitive with the feed grains, there is no increase in the cost of the manufacturer's output to signal the need for action. Hence, the feed manufacturer may not shift from feed grains to wheat as quickly in response to a change in the price of wheat as he would to a change in the price of feed grains. More wheat is fed in the West and Midwest than in the East, as evidenced by the large coefficients on the location variables.

In equations (16) and (17) the coefficient of the CF variable is constrained to equal one. This modification results in a somewhat higher direct price elasticity of −1.83 and a cross price elasticity of approximately the same size as that found in equation (14). When the relative price of wheat is used in the demand functions, the estimated elasticity is approximately −2.80.[10]

Barley. In 1969 the use of barley as a feed ingredient was reported by 67 percent of the feed manufacturing establishments (*6*). The use of barley is especially important in the Western States. Feeding trials have shown that fattening cattle will gain just as rapidly on ground barley, fed as the only grain, as on shelled corn. For dairy cattle, barley is as good as corn when composing 40 to 60 percent of the ration. Barley is a good feed for hogs, but it needs to be ground where corn does not. For poultry, barley is less palatable than corn, and due to the hulls, the growth of chicks is decreased if more than 30 percent of ground barley is used in a chick starter or more than 15 percent in a ration for broilers (*15*, pp. 446-450).

Four demand equations are fitted statistically for barley.

[10] The CC_i/CF_i variable was included in the demand equation in preliminary runs. Its estimated coefficient was not statistically significant, and its exclusion caused only a small change in the estimated elasticities.

$$(18)\ QB_i = -3.33 - \underset{(1.48)}{2.75PB_i} + \underset{(1.96)}{3.88PFB_i} +$$

$$\underset{(4.78)}{0.64CF_i} + \underset{(2.90)}{0.93CC_i/CF_i} + \underset{(6.16)}{0.95West}$$

$$R^2 = 0.75$$

$$(19)\ QB_i = -1.45 - \underset{(1.73)}{3.13PB_i/PFB_i} + \underset{(4.76)}{0.64CF_i} +$$

$$\underset{(2.82)}{0.90CC_i/CF_i} + \underset{(6.18)}{0.95West}$$

$$R^2 = 0.74$$

$$(20)\ QB_i = -4.55 - \underset{(1.30)}{2.59PB_i} + \underset{(1.78)}{3.81PFB_i} +$$

$$1.0CF_i + \underset{(2.79)}{0.96CC_i/CF_i} + \underset{(6.23)}{1.02West}$$

$$R^2 = 0.75$$

$$(21)\ QB_i = -2.54 - \underset{(1.54)}{3.00PB_i/PFB_i} + 1.0CF_i +$$

$$\underset{(2.70)}{0.93CC_i/CF_i} + \underset{(6.25)}{1.02West}$$

$$R^2 = 0.74$$

where

QB_i = quantity of barley used in feed manufacturing in State i (1,000 tons)
PB_i = price per ton of barley in State i
PFB_i = average price per ton of all feed grains except barley in State i
$West$ = a zero-one variable equal to one for Western States and zero for all other States
CF_i = quantity of complete formula feed manufactured in State i (1,000 tons)
CC_i/CF_i = cattle feed produced as a percentage of total complete feed mixed in State i.

Equations (20) and (21) differ from equations (18) and (19) in that the coefficient of the CF_i variable is constrained to equal one. In general, this constraint has little effect on the estimated coefficients. All of the variables in the demand functions have the correct signs, but the PB variable in equations (18) and (20) and the price variable in equation (21) are not statistically significant at the 5 percent level.

The estimated direct and cross price elasticities from equation (18) are −2.75 and 3.88, respectively. If the two elasticities are constrained to be equal, as in equation (19), the estimated elasticity is −3.13. The demand for barley is much stronger in the West than in the rest of the country. Barley demand also increases when the percentage of cattle feed mixed increases. The estimated equations explain about 75 percent of the variation in the amount of barley used in formula feeds.

Summary

Statistical information gathered about corn, oats, barley, sorghum, and wheat is summarized in table 2 and table 3.

According to the analysis, the use of grain sorghum is the most responsive to changes in its own price and to changes in the price of the other feed grains. In terms of direct price elasticities, corn, oats, barley, and wheat follow grain sorghum in degree of responsiveness to changes in their own price. The cross price elasticity of grain sorghum use with respect to

Table 2. Direct and cross price elasticities calculated for corn, oats, barley, grain sorghum, and wheat

Commodity	Equation number	Elasticity with respect to:	
		Own price	Price of all other feed grains
Corn	(4)	− 4.81	1.47
Grain sorghum	(8)	− 5.42	6.77
Oats	(10)	− 3.82	0.85
Wheat	(14)	− 0.85	3.27
Barley	(18)	− 2.75	3.88

Table 3. Estimated elasticities when the direct and cross demand elasticities are constrained to be equal

Commodity	Equation number	Price elasticity
Corn	(5)	− 5.14
Grain sorghum	(9)	− 5.35
Oats	(11)	− 3.07
Wheat	(15)	− 2.72
Barley	(19)	− 3.13

the price of other feed grains is nearly twice as large as that for barley and wheat. The cross price elasticity of corn is lower than that of wheat and barley but is still greater than one. Oats are the only feed grain with a cross price elasticity of less than one.

The elasticity estimates in this study provide an upper bound for the true direct and cross price elasticities for the total feed use of the individual grains and wheat. The typical livestock producer, especially one who produces his own feed, will not be as responsive to price changes as formula feed manufacturers.

Location plays an important role in the demand for all of the feed grains. Grain sorghum, wheat, and barley are used more intensively in the West than in the Midwest or East. More oats are utilized in the Midwest and more corn in the East than would be expected on the basis of interstate price differentials.

The demand for barley, oats, and grain sorghum is affected by the proportion of total complete feed production accounted for by cattle feed. When location and total production are held constant, an increase in the proportion of cattle feed mixed will increase the demand for barley, oats, and grain sorghum.

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