Demand Estimation for Agricultural Processing Co-products

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ABSTRACT

Co-products of processing agricultural commodities are often marketed through private transaction rather than through public markets or those in which public transaction information is recorded or available. The resulting lack of historical price information prohibits the use of positive time series techniques to estimate demand. Demand estimates for co-products are of value to both livestock producers, who obtain them for use in livestock rations, and processors, who must sell or otherwise dispose of them. Linear programming has long been used, first by researchers and later as a mainstream tool for nutritionists and producers, to formulate least cost livestock rations. Here it is used as a normative technique to estimate step function demand schedules for co-products by individual livestock classes within a region. Regression is then used to smooth step function demand schedules by fitting demand data to generalized Leontief cost functions. Seemingly unrelated regression is used to estimate factor demand first adjusted for data censoring using probit analysis. Demand by individual livestock classes is aggregated over the number of livestock within a region. Species important to demand for each co-product are identified and own price elasticity for individual livestock classes and all livestock are estimated.

INTRODUCTION

Agricultural co-products result from the processing of an agricultural commodity into a consumable or industrial product. When their use is limited to livestock rations, identifying their economic value in this role provides an estimate of demand. This information is important for both livestock producers, who purchase and use co-products, and processing companies, who generate and dispose of them or give or sell them to livestock producers. Use of co-products may reduce feed cost and improve profitability of a livestock operation and, when directed to their highest value use, increase their value to processors.

Co-products are increasing in importance to livestock producers throughout the United States. Feed costs, which comprise one of the largest expenses in livestock production, can be reduced by using regionally produced co-products in rations (Kubic and Stock; Schroeder). Further fueling interest in the use of co-products in North Dakota livestock rations is an increase in their availability in the region. However, even when regionally abundant, the use of co-products in livestock rations can be low when information about their nutritional and economic value is limited (Schroeder).

Distance between a processing plant and the farm and the physical characteristics of available co-products (e.g., moisture content) affect their availability and cost to livestock producers, and their appropriateness as a ration ingredient. Creating co-product demand schedules that reflect the value of co-products for use in rations of various livestock in specific regions is thus warranted. This information will also help buyers and sellers make decisions which guide co-products to their highest value use. And, when co-products are or can be an important contributor to net return, the information may also influence tactical decisions of processing firms, such as co-product pricing, and even more strategic decisions such as plant location and characteristics of the primary product.

Use of Co-products in North Dakota Livestock Rations

Meeting animal nutritional needs is fundamental to ensuring optimal growth and production. When regionally available, high nutrient co-products can be used to reduce feed cost without sacrificing the nutrient value of the ration. North Dakota and bordering counties in western Minnesota are home to many firms which process agricultural commodities, including sugarbeets, wheat, durum, and potatoes. Processing plants of American Crystal and Min-Dak Farmers cooperatives located throughout the Red River Valley of Northwestern Minnesota and Eastern North Dakota process sugarbeets from nearly 600,000 acres. Sugarbeet processing results in a wet (22 to 28 percent dry matter) pulp co-product which may be dried to 90 to 92 percent dry matter. Beet pulp is not high in protein but offers at least 85 percent of the energy value of corn and 95 percent of the energy value of barley and is an excellent source of calcium (Schroeder).

Wheat middlings result from the milling of flour or semolina from wheat and durum. They typically contain 17 to 18 percent crude protein, above that provided by most feed grains but below that offered by high protein oil seed meal co-products, such as soybean meal (Dhuyvetter, Hoppe, and Anderson). Wheat middlings are also a good source of crude fiber and phosphorus. The increased number of regional wheat and durum processing plants has increased the availability of wheat middlings and the interest in feeding this product to livestock (Dhuyvetter, Hoppe, and Anderson).

Potato waste is high in energy (85 percent total digestible nutrients, TDN), is easily digestible, and contains a moderate amount of protein (8 percent). It is often used as a substitute for corn or corn silage in livestock rations. When transportation distance is relatively short, potato waste can serve as an inexpensive ration ingredient, especially for beef and dairy diets (Schroeder). Processors are generally located in close geographic vicinity to the livestock operations which serve as the main consumers of this co-product because of its high moisture content.

PURPOSE

Although the aforementioned and other co-products are often directed to use in livestock rations, little information is available about their economic value in this or other roles. Co-products are, in general, marketed through private transactions wherein processors attempt to maximize sales revenues or dispose of a predetermined quantity. They are rarely marketed through public markets or those in which public transaction information is recorded or available. The resulting lack of historical price information prohibits the use of time series techniques to estimate demand. An alternative method is required. The purpose of this paper is to propose such a method and present an empirical application, the estimation of demand for sugarbeet pulp, wheat middlings, and potato waste by livestock in the Central Crop Reporting District of North Dakota.

DEMAND ESTIMATION

Two methods commonly used to estimate demand are econometrics, a positive approach, and primal optimization, a normative approach (Konyar and Knapp). The two methods are quite distinct, in part because they use different information. If historic data is available, employing a positive approach allows for estimates based on observed rather than simulated data (Agharya-Madnani). However, available data is sometimes not adequate to use econometrics to estimate demand for some products in the feed industry and the use of historic data alone may ignore the impact of changes in technology and management practices (Konyar and Knapp). Alternatively, use of a normative approach allows for estimates based on events that have not yet occurred (Konyar and Knapp; Johnson and Varghese).

Because its use does not require historic price data, the normative approach is particularly appropriate for estimating demand for new products or those on which little or no historical data is available. Another advantage of a normative demand estimation technique for feed ingredients is that its use facilitates consideration of individual groups of animals (*e.g.*, within a particular production stage). Thus, it allows livestock to which co-products offer the highest value to be identified.

Linear programming has long been used by nutritionists and practitioners to formulate least cost rations, and by researchers to evaluate the effect of ration composition and other management and marketing practices on the profitability of farm enterprises (*e.g.*, see Brennen and Hoffman). It accommodates complex problems with multiple constraints and results in specific information about the value of individual feed ingredient characteristics (*e.g.*, protein content) and the cost of imposed constraints. More refined estimates of feeds as components of least cost rations and of their contribution to the nutrient requirements of individual animals result than when other normative estimation techniques are used (Peeters and Surry).

Use of linear programming to obtain detail about the role of various livestock classes in comprising demand for a feedstuff requires specific information such as nutritional characteristics of individual ration components, characteristics of and nutrient requirements for individual animals, number of animals, and current prices for the product for which demand is being estimated as well as for other feedstuffs available to the animal in the region of interest. Caution must also be exercised in interpreting elasticities calculated from resulting demand schedules. Their step-wise nature can result in elasticities between zero, where quantity demanded does not change in response to price changes, and infinity, where there exists a range of quantities demanded at a single price. This problem can be corrected by regressing the data generated from solving least cost rations into smooth cost functions from which curvilinear demand schedules can be derived. This so-called 'pseudo-data approach' has been employed to estimate demand for various feeds (*e.g.*, see Mickinzie et al.; Peeters; Peeters and Surry). However, its use has been criticized because bias can be introduced into demand estimates and the smoothing process may result in demand schedules which violate one or more nutritional constraints (Peeters and Surry). Shonkwiler and Yen developed a two-step estimation procedure for censored limited dependent variables to correct for the former. This technique is described in more detail in the methods section.

METHODS

A system of demand equations for three co-products, sugarbeet pulp, potato waste, and wheat middlings, are developed for the Central Crop Reporting District of North Dakota. Each co-product is available from processing firms in this or an adjacent district. Estimating co-product demand as that for livestock rations is appropriate because there are limited alternative markets for the co-products in question. Each of the major classes of livestock including beef cattle, dairy cattle, sheep, and swine are raised in the Central Crop Reporting District. Demand by poultry is not included because of their low numbers in the district.

Lack of historic market transaction information for the co-products under consideration necessitated the use of a normative estimation technique. Linear programming was chosen because the problem involves multiple resources and numerous constraints. Least cost rations for different species of animals in different growth stages and with varying levels of performance (*i.e.*, various livestock classes) are first estimated. Solving for least cost rations under varying prices results in step function demand schedules for individual animals represented by each livestock class. Regression is then used to smooth demand schedules. Estimating smooth conditional factor demands for each co-product involves the use of a functional form of the generalized Leontief cost function which imposes substitutions among feed ingredients. A two-step procedure proposed by Shonkwiler and Yen is first used to correct for bias introduced by data censoring. Aggregating demand from individual animals within the district provides an estimate of regional demand.

Livestock Classes and Nutritional Requirements. Species are separated into livestock classes according to size or age (*e.g.*, 900 vs. 1120 lb steer), production (*e.g.*, dairy cow producing 66 versus 88 lb milk per day), or production stage (*e.g.*, gestating versus lactating sow). Table 1 specifies the nineteen classes used to represent livestock in the district. Each class of livestock represented has unique nutrient requirements and consumes a ration consistent with modern livestock production systems. Nutrition required by livestock and that provided by each feedstuff were obtained from National Research Council guidelines and modified for use based on advice by specialists in the Animal and Range Science Department at North Dakota State University. Specialists include Dr. Greg Lardy and Dr. Marc Bauer (beef and dairy), Dr. Roger Haugen (sheep), and Dr. Robert Harrold (swine). Details on animal nutritional requirements and constraints and feedstuff nutritional values are available from the authors.

Table 1. Livestock Classes

Species	Classification	Description
Beef Cattle	C1	900 lb feedlot steer
	C2	1,120 lb feedlot steer
	C3	1,200 lb beef cow, 20 lb peak milk[a], 3 months since calving
	C4	1,200 lb beef cow, 20 lb peak milk, 11 months since calving
	C5	1,400 lb beef cow, 20 lb peak milk, 3 months since calving
	C6	1,400 lb beef cow, 20 lb peak milk, 11 months since calving
Dairy Cattle	D1	1,320 lb dairy cow, 66 lb milk per day
	D2	1,320 lb dairy cow, 88 lb milk per day
Sheep	S1	Flushing[b] 150 lb ewe
	S2	Gestating[c] 150 lb ewe
	S3	Lactating[d] 150 lb ewe
	S4	Growing 50 lb lamb
	S5	Finishing 80 lb lamb
Swine	H1	22 to 44 lb growing hog
	H2	44 to 110 lb growing hog
	H3	110 to 176 lb growing hog
	H4	176 to 265 lb growing hog
	H5	Gestating sow, 386 lb, 12 piglet litter
	H6	Lactating sow, 386 lb, 12 piglet litter

a. Peak Milk - maximum milk production per day
b. Flushing- feeding for gain of weight before breeding season to increase lambing percentage
c. Gestating- animal that is carrying unborn young
d. Lactating- animal that is nursing young

Ingredient Classifications and Prices. Feed ingredients available to livestock rations represent those commonly used in North Dakota. The nutrient value of each feed depends on the animal consuming it and other ingredients in the ration. Digestive systems are uniquely different for ruminants (beef, dairy, and sheep) and monogastrics (swine). Ration ingredients are classified as roughages or concentrates. Three roughages made available to rations were alfalfa, prairie hay, and corn silage. Roughages are limited to use in ruminant diets. Concentrates made available to livestock rations include cereal grains (corn, barley, and oats), supplements, and co-products.

Twenty years of historic prices (1980 to 1999) were used to represent the cost of ration ingredients. Weighted average annual prices of barley, corn, alfalfa, prairie hay, and oats, all commonly grown and abundant in North Dakota, were obtained from the North Dakota Agricultural Statistics Service. The per ton price of corn silage is represented as eight times the per bu price of corn (Hendrix). A simple average of weekly soybean meal prices obtained from Feedstuffs Magazine represents annual price. Prices of the aforementioned traditional feed ingredients were represented using a single vector of prices for each year. Prices of supplements including salt, vitamin premix, selenium, trace mineral, dical, and limestone were fixed at recent prices because of the lack of available historic price records and because their price does not influence demand for other feed ingredients. These ingredients are used in fixed quantities.

Little historic market information is available about the co-products of sugarbeet pulp, potato waste and wheat middlings. A range of prices, represented by a low, medium and high price, was used for each. The range of prices was determined by trial and error. Multiple iterations were solved to identify price levels at which each co-product entered as a least cost ration ingredient. Range of price levels at which each co-product comprises a portion of the ration is anchored by the low and high prices. Least cost rations were identified for each livestock class using 540 feed ingredient price combinations; twenty-seven possible combinations of co-product prices (three prices of each of three co-products, $3^3 = 27$), each with twenty one-year price vectors representing price of traditional feeds.

Linear Programming Model. Aggregate demand for each co-product was estimated as that comprising least cost rations of all animals within the region. The General Algebraic Modeling System (GAMS) was used to solve for least cost rations (Brooke, et al.) The least-cost ration problem is mathematically stated as:

$$\textit{Minimize} \quad \sum_{i=1}^{n} r_i x_i$$

$$\textit{Subject to} \;\; a_i x_i \geq b_t, \; j = 1, \ldots\ldots, m \;\; \textit{and}\; x_i \geq 0$$

Where r_i and x_i are the price and amount of feed input i, respectively. The cost function denotes the minimum cost of producing a specified level of output as defined by the production stage and performance level of the animal represented. This minimum level of output is guaranteed by specified constraints and is considered fixed. Constraints are unique to each livestock class, where a_i is the amount of the nutrient available from ingredient i and b_t is the nutrient level requirement for the animal, and m represents the number of constraints. Additional conditions of the model imposed are that x_i is positive and estimated factor demands are homogeneous of degree zero in factor prices. Solving least cost rations using the described price vectors results in 540 points on a demand schedule for each ingredient in the ration.

Demand Smoothing

A generalized Leontief functional form is applied to the normative responses estimated from the linear programming model to estimate smooth demand functions for each co-product (Diewert). The generalized Leontief cost function is specified as:

$$C = C(r, y) = y \; \Sigma_i \; \Sigma_j \beta_{ij} \; r_i^{1/2} r_j^{1/2}$$

Where y is the constant level of output specified by each livestock class, and the cost function is homogeneous of degree one and is non-negative, and results in the derivation of positive factor demands. Cross symmetry imposed between ingredient prices allows for ingredient substitution.

Probit Adjustment. Least cost rations frequently did not include one or more feed ingredients. Because factor demands must be positive, a 'zero' observation imposes a restriction on the error term, it must be greater than $-\beta x_i$. Demand estimation will be biased if this restriction is not considered (Pindyck and Rubinfeld). The two-step estimation procedure for systems of equations with limited dependent variables proposed by Shonkwiler and Yen is used to correct for bias introduced by data censoring. Probit analysis provides weights for estimating equations.

The probit estimator is represented as :

$$\begin{aligned} Prob(Y=1) &= \beta' x \varphi(t) dt \\ &= \Phi(\beta' x) \end{aligned}$$

where f is the probability density function, F is the cumulative probability that an observation of 'one' will be observed given the observations on x, and Prob (Y=1) is the probability that the feed will enter the ration at a non-zero level. Estimation identifies values of b that best fit observed levels of the feed to be either 'zero' (Y=0) or positive (Y=1), conditional upon values of the exogenous variables, x_i. The results of the probit are used to weight individual demand functions in the system estimation to give consistent parameter estimates (*i.e*, 'zero' observations are properly accounted for).

Factor Demand Estimation. Adjusted individual factor demand equations consistent with the generalized Leontief approximation of the cost function are estimated using seemingly unrelated regression (TSP). Factor demands are:

$$x_i = \Phi(z'\alpha) f(r,\beta) + \delta \varphi(z'\alpha)$$

for feeds exhibiting a large number of 'zero' observations, and

$$x_i = f(r,\beta)$$

for feeds with few or no 'zero' observations. The significance of delta indicates that data censoring was necessary to correct for bias originating from the large number of 'zero' observations.

Individual factor demands were derived using Shephard's Lemma. They are represented as:

$$f(r,\beta) = y\left(\beta_{ij} + \sum_j \beta_{ij} \left(\frac{r_j}{r_i}\right)^{1/2} \right)$$

Conditional factor demand for ingredient i is a function of the level of output and relative input prices. All ingredients are represented in the equation but only factor demands for the three by-products are extracted.

Demand for least cost rations of nineteen livestock classes were solved in GAMS but the smoothing procedure was used for only nine. Quantity of co-products comprising least cost rations of the remaining livestock classes did not change with price. The nine livestock classes for which the demand estimate was smoothed were beef cows (C3 to C6), dairy cows (D1 and

D2), and ewes (S1 to S3). Adjustments were made in feeds available to beef cows and lactating ewes prior to demand smoothing. Barley and soybean meal were removed from beef cow diets because these feeds were not, in general, present in the least cost ration. Forages were combined for beef cows because they tended to enter and exit the ration as blocks without substitution. As a result, forages were not mixed and there was insufficient variability to conduct a probit analysis. Alfalfa, prairie hay, and corn silage were combined into a single variable (FORAGES). The variable was then weighted by use of each forage to ensure proper accounting of the individual feeds. Beet pulp and potato waste were eliminated prior to estimating the ration for lactating ewes because neither entered the least cost ration.

Demand Aggregation

Once derived for all nineteen livestock classes, co-product factor demands are aggregated into demand by individual species and by all livestock. Co-product demand from each animal unit within a livestock class is first multiplied by the number of district animals it represents and the number of days within the specific period of time for which demand is estimated, one year. Animal inventories within the Central Crop Reporting District were obtained from the North Dakota Agricultural Statistics Service.

RESULTS AND CONCLUSIONS

When competitively priced with more traditional feedstuffs, sugarbeet pulp, wheat middlings, and potato waste will comprise part of least cost rations in North Dakota. The unique characteristics of each co-product influence their value in meeting livestock nutrient requirements. Identification of those livestock classes most important in the demand for a specific co-product will facilitate efforts by processors to target and educate producers and may influence decisions such as co-product pricing, processing and plant location. Alerted to the value of co-products in the rations of their livestock, producers may more carefully consider their inclusion as a means to reduce feed cost.

Demand Estimation

A system of demand equations was estimated for individual livestock classes for each co-product. An example, the demand equation for co-products by 1,200 lb beef cows, three months since calving, is shown in Table 2. Ingredients in this system's parameters and those for other classes of beef cows include only forages and the co-products, sugarbeet pulp, wheat middlings, and potato waste. Cereal grains and soybean meal did not enter least cost rations for beef cows. Ingredients included in least cost dairy cow rations were the three co-products and corn, barley, soybean meal, corn silage, and alfalfa. Neither oats nor prairie hay entered the ration. Ingredients included in the demand system parameters for ewe rations include all three co-products, alfalfa, prairie hay, and soybean meal. No cereal grains or corn silage entered least cost ewe rations. Sugarbeet pulp and potato waste were not included in the demand system parameters for lactating ewes because these co-products were part of the least cost ration less than eight percent of the time.

Table 2. Estimated parameters for system of equations of C3, 1,200 lb beef cow, 3 months since calving[a, b]

Parameter	Estimate	Standard Error	T value	P value[c]
$\beta_{BP,BP}$	-16.872	1.860	-9.066	[.000]
$\beta_{BP,W}$	7.177	0.693	10.353	[.000]
$\beta_{BP,P}$	4.680	1.318	3.550	[.000]
$\beta_{BP,F}$	15.013	1.067	14.065	[.000]
$\delta 1$	-2.134	0.881	-2.422	[.015]
$\beta_{W,W}$	-28.24	1.091	-25.881	[.000]
$\beta_{W,P}$	20.93	1.069	19.577	[.000]
$\beta_{W,F}$	16.463	0.809	20.333	[.000]
$\delta 2$	2.632	0.810	3.250	[.001]
$\beta_{P,P}$	-66.106	5.188	-12.740	[.000]
$\beta_{P,F}$	20.48	1.266	16.165	[.000]
$\delta 3$	-8.426	2.757	-3.055	[.002]
$\beta_{F,F}$	-28.219	1.399	-20.162	[.000]

Model Statistics

	Beet Pulp	Wheat Middlings	Potato Waste
Standard Error	2.8	2.79	7.01
R-Squared	.609	.765	.920
LM Heteroscedasticity Test[d]	29.1	.406	24.5

a. $_F$ is a single variable representing the weighted presence of alfalfa, corn silage, and hay in the least cost ration.
b. Parameters in the demand estimation include β_{BP} = Sugarbeet Pulp, β_P = Potato Waste, β_W = Wheat Middlings, β_A = Alfalfa, β_H = Prairie Hay, β_S = Corn Silage, β_C = Corn, β_B = Barley, β_O = Oats, β_{SM} = Soybean meal, β_F = Forages. The delta parameter adjusts the error term for data censoring.
c. The two-tailed t-statistic is used to measure significance.
d. High LM Heteroscedasticity test statistics were expected because error terms were not normally distributed. The system of equations was estimated using seemingly unrelated regression.

Demand equations for ten livestock classes (feedlot beef cattle, lambs and swine) did not need to be estimated. Solving for least cost rations resulted in a vertical or nearly vertical demand curve for each co-product within a livestock class. The perfect or near perfect inelasticity of co-product demand resulted from the importance of one or more nutrient constraints. High energy requirements for growing beef, concentrate limits for growing lambs, and high protein requirements for swine constrained the diets to the inclusion of specific feeds and limited the inclusion of co-products.

Co-product Demand

Demand for each co-product is expressed tabularly and discussed holding constant prices of all other feeds available for use in livestock rations. Prices of traditional feeds are fixed at their twenty-year average and of the other co-products at the mid-range price.

Sugarbeet Pulp. Beef cattle, especially cows and heifers with calves, are the main consumers of sugarbeet pulp although this co-product is included in the ration for all species considered over a wide price range. As is also true for wheat middlings and potato waste, the importance of beef cows to the composition of aggregate demand is because of their large population within the region relative to other livestock. Elasticity of aggregate demand for beet pulp by all district livestock varies over the range of prices considered. Demand elasticity is particularly interesting for this co-product because the market is imperfectly competitive and availability of the product can, to some extent, be adjusted to meet market conditions. Members of the three sugar cooperatives in Southern Minnesota and the Red River Valley of Eastern North Dakota and Northwestern Minnesota produce approximately fifty percent of the nation's sugarbeets. The combined quantity of beet pulp produced by these three cooperatives is marketed jointly through a shared cooperative, Midwest AgriCommodities. Today, more than seventy percent of the dried beet pulp they produce is sold to customers in Japan and Western Europe which the remainder is sold in relatively more forage-rich domestic markets. Dried beet pulp can be stored but because Midwest AgriCommodities strategically maintains a presence in three distinctly separate markets, quantity available in any one can be adjusted by shifting product between markets.

Demand for sugarbeet pulp by district livestock is elastic at prices of less than $62 per ton; inclusion in rations is relatively price responsive. For example, quantity demanded at a price of $40 per ton (100,810 tons) is nearly twice that demanded at a price of $50 per ton (52,000 tons) (η decreases from -2.86 to -2.65 within this price range). Specifically, demand by beef cows is elastic over this range [demand by feedlot beef cattle is limited by an intake constraint and is constant over the range]. Demand by ewes and dairy cattle is inelastic over a wider range of prices [demand by lambs is limited by an intake constraint and is constant]. Demand is inelastic only at prices less than $45 and $37 per ton, respectively, but becomes quite elastic at higher prices. In fact, demand by the primary consumers, beef cows, drops to less than 1,000 tons at prices higher than $60 and to zero at prices higher than $68. At prices between $70 and $80, quantity demanded is only comprised of that from beef feedlot animals.

In 1999, the average local price of sugarbeet pulp was $65 per ton. At this price, quantity demanded by livestock in the Central Crop Reporting District is low. The elastic nature of demand for beet pulp at current prices is important. For example, quantity demanded doubles when price is reduced from its current level of $65 per ton to $45 per ton. And, at a price of $40 per ton, 100,000 tons of beet pulp is demanded by local livestock. If transportation costs are ignored, at this price, ruminants in the Central Crop Reporting District alone would demand approximately fifteen percent of the sugarbeet pulp produced annually by all seven processing plants in the adjacent region. Strong demand by local livestock at slightly lower than current prices may prove important should price drop in overseas markets.

Wheat Middlings

Wheat middlings are abundant throughout North Dakota with approximately five wheat processing plants in operation. There is one plant in the Central Crop Reporting District (Carrington). The price of wheat middlings in the state generally ranges from $35 to $55 per ton although a broader price range was considered here.

Wheat middlings are a good source of protein compared to other concentrates commonly used in North Dakota livestock rations, such as corn and barley, and enter rations as a substitute for these feeds at various prices. Demand is elastic over the range of prices considered because demand for inclusion in beef cow rations is price responsive. Elasticity increases at higher prices. Quantity demanded over the price range considered is constant for beef and lamb feeders and for swine, and is inelastic for dairy cows and ewes.

Even at prices higher than those generally found in the region, all species continue to consume wheat middlings as part of their least cost ration, but at relatively low levels. At prices higher than $65 per ton, quantity demanded by beef cows rapidly moves toward zero and dairy cows become the most important consumers. Although beef cow rations are the highest value feed use for wheat middlings within the typical price range found in North Dakota, other species demand a notable amount of this feed ingredient proportionate to their specified diet. Wheat middlings can be an important ingredient in dairy diets in particular. However, the proportion of a dairy cow or sheep ration that can be comprised of wheat middlings cannot exceed 24 percent. The influence of this constraint on demand for wheat middlings by these species is reflected in the relatively consistent quantity demanded by each over a wide range of prices. Demand by these species is inelastic (η ranges from -.47 to -.44 for dairy cows and from -.37 to -.30 for ewes). The inelastic nature of demand by individual dairy cows over a wide range of prices is an important result. Quantity demanded by dairy cows, even at higher prices, will increase nearly proportionate with increases in the herd size.

The Dakota Growers Pasta Company located in Carrington produces approximately 90,000 tons of middlings per year (Dakota Growers Pasta Company, 2000). Livestock in the Central Crop Reporting District alone will use this quantity when prices are at or lower than approximately $45 per ton. [Demand by beef cattle alone will exhaust the quantity of wheat middlings produced by the regions pasta plant at a price of $40 per ton.] Because wheat middlings can be an important component of livestock rations, even at higher prices, and their value differs by livestock class, diversified market opportunities exist for processors. Educating livestock producers that most highly value this co-product will be beneficial. In particular, all producers should be made aware of the role of wheat middlings as a strong substitute for feed grains and soybean meal because of its high energy and protein content. And, at higher prices, the district's dairy producers should specifically be targeted.

Potato Waste

Although characterized by a relatively consistent downwards slope, the shape of the demand curve for potato waste is not consistent with the generalized Leontief functional form used to estimate demand systems. Specifically, it is concave at higher prices. This results from the method used to correct for bias introduced by data censoring. The problem is not crucial because the demand curve is always downward sloping and is convex over most of the price range considered.

Potato waste is important in beef cow rations at prices up to $13 per ton and in dairy cow rations to prices of $11.80 per ton. Because potato waste is a high moisture ingredient (e.g., 20 lb as fed equals 4.6 lb of dry matter), animals have to consume a large quantity to meet their nutritional requirements. These large ruminants have the ability to do so. Demand by individual dairy cows is similar to that by individual beef cows at lower prices and is always greater at prices higher than $5.80 per ton. However, aggregate demand is much more dependent on the district's beef cow population because it exceeds that of dairy cows by a 20:1 ratio. Sheep, specifically flushing and gestating ewes, demand small amounts of potato waste and the co-product does not enter the ration for feedlot beef cattle and lambs because these animals cannot consume enough of the high moisture ingredient to meet their nutrient requirements. Swine are unable to efficiently digest this feed.

The aggregate demand schedule for potato waste is inelastic at prices lower than $7 per ton and elastic at higher prices. The elastic region reflects the price responsiveness of use of potato waste as a least cost ration ingredient in beef cow rations. Demand for potato waste by dairy cows is much less sensitive to changes in price and is in fact inelastic over the entire price range. This co-product is cost effective in fulfilling the nutrient requirements of dairy cows over a wide price range. However, the high moisture content of this feed limits the quantity that can be fed. The high moisture content of potato waste also limits its inclusion in ewe rations. Demand for use in ewe rations is also inelastic over the range of prices.

Practically, livestock markets for potato waste must be in close proximity to a potato processing plant. Its high moisture content limits the distance it can be economically transported. In addition to transportation difficulties, the high moisture content of this co-product can create storage problems. The cold winters in North Dakota require special equipment to prevent freezing such as lined delivery trucks. Because its physical characteristics limit the market for potato waste, yet it must be disposed of, negotiation of transactions between suppliers and producers is important. Armed with an estimate of its value as a component of livestock rations, market participants are better prepared to negotiate a fair price.

The district's only potato processor, Avico USA, produces approximately 52,000 tons of potato waste a year, well below the quantity demanded for district livestock rations over the price range considered. And, as prices fall, quantity demanded increases quickly. Although that from beef cows comprises 80 to 90 percent of quantity demanded, at higher prices demand from the district's dairy cows becomes important. Dairy herds located nearby a potato processing plant may provide an excellent market for locally produced potato waste, even at higher prices. Close proximity to a potato processing plant would allow a producer building or expanding a dairy operation to take advantage of the potato waste as a feed, particularly if a price below its value as a feed ingredient and a long term contract can be negotiated. At this time, potato waste base price is as low as $7 per ton. At this price, it could be transported up to 95 miles to beef cow operations, where the farm gate cost would equal $13 per ton including the $6 transportation cost, and up to 80 miles to dairy operations, where the farm gate cost would be $11.80 per ton.

Concluding Comments. Local livestock can be an important market for co-products produced in and nearby the Central Crop Reporting District of North Dakota. Distinct differences in the level and nature of co-product demand (*e.g.*, price elasticity) over a range of prices and, particularly, between species, increases the value of information about such to processors and producers.

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