Spring 2006

Demand Estimation for Agricultural Processing Coproducts

Cheryl Wachenheim
North Dakota State University, Fargo, ND

Patrick Novack
North Dakota State University, Fargo, ND

Eric DeVuyst
North Dakota State University, Fargo, ND

David Lambert
North Dakota State University, Fargo, ND

Great Plains Research 16 (Spring 2006):85-94

DEMAND ESTIMATION FOR AGRICULTURAL PROCESSING COPRODUCTS

Cheryl J. Wachenheim
Patrick Novak
Eric A. DeVuyst
and
David K. Lambert

Department of Agribusiness and Applied Economics
Box 5636
North Dakota State University
Fargo, ND 58105-5636
cwachenh@ndsuext.nodak.edu

ABSTRACT—Coproducts of processing agricultural commodities are often marketed for use as livestock feed through private transaction. The resulting lack of historical price information prohibits the use of positive time series techniques to estimate demand. Linear programming is used as a normative technique to estimate step function demand schedules for coproducts by individual livestock classes. Seemingly unrelated regression is used to smooth demand schedules by fitting demand data to generalized Leontief cost functions. Estimates are adjusted for data censoring using probit analysis. Aggregate quantity demanded of sugarbeet pulp, wheat middlings, and potato waste is relatively responsive to price changes (i.e., demand is elastic) but less so for specific species and at higher prices for sugarbeet pulp (i.e., demand is inelastic).

Key Words: coproducts, demand estimation, econometrics, linear programming, livestock feeding

INTRODUCTION

Agricultural coproducts result from the processing of an agricultural commodity into a consumable or industrial product. When they can substitute for other ingredients in rations, coproducts are of value to livestock producers. Information about their value is important not only to producers but to existing and new processing firms as they make tactical decisions, such as coproduct pricing, and strategic decisions such as plant location and the form of coproducts produced.

Coproducts in general are marketed through private transactions wherein processors attempt to maximize sales revenues or dispose of a predetermined quantity. The resulting lack of publicly available historical price information can impede use of coproducts by livestock producers and prohibits the use of time series techniques to estimate demand.

This paper presents an alternative to time series techniques used to estimate demand for agricultural coproducts. The demonstrated technique can be applied to unique local situations to reflect the type and availability of coproducts, of other feeds and their prices, and the number and type of livestock in the area. The technique is demonstrated by estimating demand for three agricultural coproducts originating from livestock producers in one Crop Reporting District (CRD) of North Dakota.

BACKGROUND

Two methods commonly used to estimate demand are econometrics, a positive approach, and primal optimization, a normative approach. If price and quantity data are available, the positive approach allows for estimates based on observed rather than simulated data (Madnani and Acharya 1988). However, data are sometimes not available or the use of historic data may mask changes in technology and management practices (Konyar and Knapp 1986). The normative approach provides price and quantity information under explicit assumptions of optimizing behavior and can provide expected demand and supply conditions when transparent markets do not exist (Johnson and Varghese 1993). The normative approach is particularly appropriate for estimating demand for new constraints. Specific nutrient requirements and constraints imposed on the intake of particular feeds by individual classes of livestock are available from http://agecon.lib.umn.edu/cgi-bin/detailview.pl?paperid=2434.

Ingredient Classifications and Prices

Feed ingredients available to livestock rations represent those common in North Dakota. The nutrient value of each feed depends on the animal consuming it and other ingredients in the ration. 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 coproducts.

We used historic prices from a 20-year period (1980 to 1999) to represent the cost of ration ingredients. Weighted average annual prices of barley, corn, alfalfa, prairie hay, and oats were obtained from the North Dakota Agricultural Statistics Service (USDA 2000). The per ton price of corn silage is represented as eight times the per bushel price of corn (Hendrix 1996). A simple average of weekly soybean meal prices obtained from *Feedstuffs* magazine represents annual price. Prices of the 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 coproducts we considered. We used a range of prices, represented by a low, medium, and high price, for each. The range of prices was determined by trial and error. Multiple iterations were solved to identify price levels at which each coproduct entered as a least-cost ration ingredient. Range of price levels at which each coproduct 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; 27 possible combinations of coproduct prices (three prices of each of three coproducts, $3^3 = 27$), each with 20 one-year price vectors representing price of traditional feeds.

Least-Cost Ration Determination

Least-cost rations were estimated using linear programming for different species of animals in different growth stages with varying levels of animal performance and under varying feed prices. Resulting step function demand schedules formed the basis for estimating a system of continuous demand functions. Resulting estimated demands are homogeneous of degree zero in feed prices and permit substitutions among feed ingredients. Since the range of prices used in the derivation of least-cost rations resulted in solutions in which many feed ingredients did not enter the ration, numerous cases arose in which the endogenous variable was zero. Shonkwiler and Yen's (1999) procedure to correct for censoring was used in the system estimation. Finally, aggregating demand from individual animals within the district provided an estimate of district demand.

Linear Programming Model. Aggregate demand for each coproduct 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. 1998). The least-cost ration problem is:

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

subject to

$$\sum_{i=1}^{n} a_{ki} x_i \geq b_k, \; k = 1, \ldots, m \tag{2}$$

$$x_i \geq 0$$

where r_i and x_i are the price and amount of feed input i, respectively. The objective function minimizes the ration cost of producing a specified level of output as defined by the production stage and performance level of the animal represented. The m constraints are unique to each livestock class, where a_{ki} is the amount of nutrient k available from ingredient i, and b_k is the nutrient-level requirement for the animal. Solving least-cost rations using the described price vectors results in up to 540 points on a demand schedule for each ingredient in the ration.

Demand Smoothing. A generalized Leontief functional form was applied to the normative responses estimated from the linear programming model to estimate smooth demand functions for each coproduct (Diewert 1971). Demand equations consistent with a generalized Leontief cost function are:

$$x_i\left(y,r\right) = y\left(\beta_{ii} + \sum_{j} \beta_{ij} \left(\frac{r_j}{r_i}\right)^{1/2}\right) \tag{3}$$

where x_i is quantity of ingredient i demanded, y is output level (e.g., milk production, animal gain), r_i and r_j are the prices of feed ingredients i and j, and β's are the parameters to be estimated.

Least-cost rations frequently did not include one or more feed ingredients. A large number of zero observations in the endogenous variable result in biased parameter estimates if not corrected (Pindyck and Rubinfeld 1997). The first step in Shonkwiler and Yen's (1999) correction procedure involves a probit analysis to determine the probability of observing a zero or positive level of the individual feed in the ration given a set of explanatory variables (i.e., feed prices):

$$\text{Prob}\left(Y=1\right)=\int_{\infty}^{a'r}\phi\left(t\right)dt=\Phi(t) \tag{4}$$

where ϕ is the probability density function, Φ is the cumulative distribution function, and $t = \alpha' r$, the estimated relationship between prices r and the likelihood that a feed will enter the ration. Estimation identifies values of α that best fit observed levels of the feed to be either zero ($Y = 0$) or positive ($Y = 1$), conditional upon values of the exogenous prices. The results of the probit are used to weight individual demand functions in the system estimation to give consistent parameter estimates:

$$x_i=\Phi\left(\alpha' r\right)x_i\left(y,r\right)+\delta_i\Phi\left(\alpha' r\right) \tag{5}$$

The statistical significance of δ indicates whether data censoring was necessary to correct for bias originating from the large number of zero observations.

Demand schedules for least-cost rations of 19 livestock classes were solved in GAMS but the smoothing procedure was used for only nine. Coproducts demanded for 10 of the livestock classes did not change with price. The nine livestock classes for which demands were 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 typically not present in the least-cost ration. Alfalfa, prairie hay, and corn silage were combined into a single variable (FORAGES) for beef cows because they tended to enter and exit the ration as blocks without substitution. As a result, the data matrix was singular, preventing solution of the probit model. Sugarbeet pulp and potato waste were eliminated prior to estimating the ration for lactating ewes because neither entered the least-cost ration.

Demand Aggregation

Coproduct factor demands were next aggregated across livestock classes and livestock inventory. Coproduct demand for each animal unit within a livestock class was first multiplied by the number of animals within the district and the number of days in a year represented by the production stage of the individual livestock class. Animal inventories within the Central CRD were obtained from the North Dakota Agricultural Statistics Service (USDA 1999). There were approximately 122,000 cows and heifers, 14,700 feedlot cattle, 10,000 ewes, 10,700 growing lambs, 1,100 sows, 6,900 growing pigs, and 6,100 dairy animals in the district. Animal numbers within each livestock class were represented as a portion of animal inventory within the species it represents. The portion represents the number of days an individual animal is best represented by the livestock class over the production period (e.g., year or time in the feedlot). For example, a growing beef steer reaches market weight in 210 days. For 90 days the animal is characterized as a 408 kg feeder (represented by the C1 livestock class). The remaining 120 days, the animal is characterized as a 508 kg feeder (represented by the C2 livestock class). It was assumed that production systems operate on a round turn basis for production periods of less than one year (e.g., a feeder steer marketed at 210 days is replaced). Animal inventory numbers were considered constant over the year in the Central CRD.

RESULTS AND DISCUSSION

Demand Estimation

We estimated a system of demand equations, which included each feed and coproduct, for individual livestock classes. An example, the demand equation for coproducts by 508 kg beef cows, three months since calving, is shown in Table 2. (Results for all livestock classes are available from http://agecon.lib.umn.edu/cgi-bin/detailview.pl?paperid=2434.) Ingredients in this system's parameters and those for other classes of beef cows include only forages and the coproducts. Each parameter estimate in the final system of equations is significant. Coproduct demand presented is that estimated at the midrange price for other coproducts and at the 20-year average price for forages. Use of alternative prices would provide estimates based on current or forecasted prices depending on the specific objective of the demand estimation.

Least-cost dairy rations included coproducts, corn, barley, soybean meal, corn silage, and alfalfa. Coproducts,

TABLE 2
ESTIMATED PARAMETERS FOR SYSTEM OF EQUATIONS OF C3, 544 KG BEEF COW, 3 MONTHS SINCE CALVING

Parameter[a]	Estimate	Standard error	T value	P value[b]
$\beta_{BP,BP}$	-16.87	1.86	-9.07	[.000]
$\beta_{BP,W}$	7.18	0.69	10.35	[.000]
$\beta_{BP,P}$	4.68	1.32	3.55	[.000]
$\beta_{BP,F}$	15.01	1.07	14.06	[.000]
$\delta 1$	-2.13	0.88	-2.42	[.015]
$\beta_{W,W}$	-28.24	1.09	-25.88	[.000]
$\beta_{W,P}$	20.93	1.07	19.58	[.000]
$\beta_{W,F}$	16.46	0.81	20.33	[.000]
$\delta 2$	2.63	0.81	3.25	[.001]
$\beta_{P,P}$	-66.11	5.19	-12.74	[.000]
$\beta_{P,F}$	20.48	1.27	16.16	[.000]
$\delta 3$	-8.43	2.76	-3.05	[.002]
$\beta_{F,F}$	-28.22	1.40	-20.16	[.000]

Model statistics

	Beet pulp	Wheat middlings	Potato waste
Standard error	2.800	2.790	7.010
R-squared	0.609	0.765	0.920
LM heteroscedasticity test[c]	29.100	0.406	24.500

[a]Parameters in the demand estimation include β_{BP} = sugarbeet pulp, β_P = potato waste, β_W = wheat middlings, β_F = forages. The delta parameter adjusts the error term for data censoring. F is a single variable representing the weighted presence of alfalfa, corn silage, and hay in the least-cost ration.
[b]The two-tailed t-statistic is used to measure significance.
[c]High LM heteroscedasticity test statistics were expected because error terms were not normally distributed. The system of equations was estimated using seemingly unrelated regression.

alfalfa, prairie hay, and soybean meal were included in ewe rations. Sugarbeet pulp and potato waste were not included in demand system parameters for lactating ewes because they were part of the least-cost ration less than 8% of the time.

Demand equations for 10 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 coproduct within each livestock class. Coproduct demand was perfectly or near perfectly inelastic. That is, coproduct quantity demanded did not change or changed little with changes in price. This 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 coproducts.

Coproduct Demand

Demand for each coproduct is expressed tabularly and discussed holding all other feed prices constant. (Again, prices of traditional feeds are fixed at their 20-year average and of the other coproducts at the midrange price.) Demand is reported based on the farm-delivered price a producer would pay for a coproduct. It is reported on an as-fed basis. These figures can easily be converted to a dry-matter basis using the dry-matter percentages for wheat middlings (87), potato waste (23), and sugarbeet pulp (91). Demand depends on delivery costs as well as other factors related to on-farm coproduct management (e.g., storage). Consequently, estimated demand is more representative for coproducts with transportation, storage, and handling costs similar to the more traditional feeds they replace.

Sugarbeet Pulp. Beef cattle, especially cows and heifers with calves, are the main consumers of sugarbeet pulp, although this coproduct is included in the ration for all species considered over a wide price range (Table 3). Beef cows are important to the aggregate demand for sugarbeet pulp, as well as for wheat middlings and potato waste, because of the large population of beef cows within the region relative to other livestock. Demand by feedlot cattle and lambs is limited by intake constraints and is constant.

In 2000 the average local price of sugarbeet pulp was $59 per tonne. At this price, quantity demanded by livestock in the Central CRD is low. However, sugarbeets quickly become cost-effective at lower prices due to the elastic (price responsive) nature of demand. For example, quantity demanded approximately doubles when price is reduced 30% from $59 to $41 per tonne. At a delivered price of $36 per tonne, ruminants in the Central CRD alone would demand approximately 15% of the sugarbeet pulp produced annually by all seven processing plants in the adjacent district.

Strong quantity demanded by local livestock at lower prices, particularly by beef cows, may prove important

TABLE 3
DEMAND FOR SUGARBEET PULP BY LIVESTOCK IN THE CENTRAL CROP REPORTING DISTRICT OF NORTH DAKOTA

	Quantity demanded, thousand tonnes			Aggregate	
Price ($/tonne)	Beef cows	Dairy cows	Ewes	Quantity	Elasticity
36	50.96	10.40	0.24	91.52	-2.86
38	38.82	10.18	0.18	79.10	-2.98
40	28.88	9.82	0.13	68.76	-3.01
42	21.02	9.29	0.07	60.30	-2.95
44	14.94	8.57	0.04	53.47	-2.82
45	10.35	7.68	0.02	47.97	-2.65
47	6.97	6.67	0.01	43.57	-2.45
49	4.53	5.61		40.05	-2.23
51	2.79	4.57		37.28	-1.98
53	1.58	3.61		35.11	-1.71
54	0.80	2.78		33.49	-1.39
56	0.35	2.07		32.34	-1.07
58	0.06	1.51		31.49	-0.84
60	0.02	1.07		31.01	-0.50
62	0.01	0.74		30.67	-0.37
64		0.51		30.43	-0.28
65		0.34		30.25	-0.20
67		0.22		30.14	-0.14
69		0.14		30.07	-0.08

Notes: Demand for beet pulp was estimated at the mean price of all other ingredients. Mean prices ($/tonne) are 90.39 (barley), 22.05 (corn silage), 88.18 (corn), 66.14 (alfalfa), 44.09 (hay), 90.39 (oats), and 198.42 (soybean meal). Quantity demanded by feedlot beef cattle and lambs was 29.7 and .25 thousand tonnes, respectively, over the range of prices considered. Price and quantity are reported on an as-fed basis. Sugarbeet pulp considered is 91% dry matter.

should demand for sugarbeet pulp drop in other domestic or in overseas markets. If, for example, local cooperatives approve the use of genetically modified sugarbeet varieties by growers, demand for sugarbeet pulp originating from the Red River valley may fall in overseas markets.

The responsiveness of quantity of sugarbeet pulp demanded by local livestock to changes in price is also important because the market is imperfectly competitive and availability of the product can, to some extent, be adjusted as processors attempt to maximize revenues from beet pulp sales. Members of the three sugar cooperatives in southern Minnesota and the Red River valley produce approximately 50% of the nation's sugarbeets. The beet pulp produced is sold to customers in Japan, Western Europe, and the United States. Dried beet pulp could be stored to adjust quantity offered, but because a presence is strategically maintained in three distinctly separate markets, quantity available in any one can be adjusted simply by shifting product between 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 CRD. The price of wheat middlings in the state generally ranges from $32 to $50 per tonne.

Wheat middlings are a good source of protein compared to other concentrates commonly used in North Dakota livestock rations and enter rations as a substitute for corn and barley. Overall demand by district livestock is elastic (price responsive) over the range of prices considered because demand for inclusion in beef cow rations is price responsive (Table 4). 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. At prices higher than $59 per tonne, quantity demanded by beef cows rapidly moves toward zero and dairy cows become the prominent consumers. Because wheat middlings are constrained to 24% of the ration, demand by dairy cows is inelastic. Therefore, the quantity they demand, even at higher prices, will increase nearly proportionate with increases in the herd size.

The Dakota Growers Pasta Company located in Carrington, ND, produces approximately 80,000 tons of middlings per year. Livestock in the Central CRD alone will use this quantity when prices are at or lower than approximately $41 per tonne. Demand by beef cattle alone will exhaust the quantity of wheat middlings produced by the region's pasta plant at a price of $36 per tonne. 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.

Potato Waste. Potato waste is important in beef cow rations at prices up to $11.80 per tonne and in dairy cow rations to prices of $10.70 per tonne (Table 5). Because potato waste is a high moisture ingredient (e.g., 9 kg as fed equals 2.1 kg of dry matter), animals have to consume

TABLE 4
DEMAND FOR WHEAT MIDDLINGS BY LIVESTOCK IN THE CENTRAL CROP REPORTING DISTRICT OF NORTH DAKOTA

Price ($/tonne)	Quantity demanded, thousand tonnes: Beef cows	Dairy cows	Ewes	Aggregate: Quantity	Elasticity
18	257.40	15.43	1.47	278.12	
22	207.36	14.17	1.38	226.74	-1.12
25	168.48	13.20	1.31	186.81	-1.26
29	137.10	12.41	1.24	154.58	-1.42
33	111.02	11.76	1.20	127.80	-1.61
36	88.87	11.20	1.15	105.06	-1.86
40	69.82	10.73	1.12	85.49	-2.16
44	53.42	10.32	1.08	68.65	-2.51
47	39.44	9.95	1.05	54.29	-2.92
51	27.76	9.63	1.03	42.25	-3.37
54	18.20	9.33	1.01	32.37	-3.84
58	10.56	9.07	0.99	24.45	-4.32
62	5.47	8.84	0.97	19.11	-4.05
65	3.04	8.61	0.95	16.44	-2.63
69	1.19	8.41	0.93	11.92	-5.89
73	0.13	8.22	0.93	10.67	-2.17

Notes: Demand for wheat middlings was estimated at the mean price of all other ingredients. Mean prices ($/tonne) are 90.39 (barley), 22.05 (corn silage), 88.18 (corn), 66.14 (alfalfa), 44.09 (hay), 90.39 (oats), and 198.42 (soybean meal). Quantity demanded by feedlot beef cattle was 24.4 thousand tonnes, by lambs 0.53 thousand tonnes, and by all swine 0.86 thousand tonnes, over the range of prices considered. Price and quantity are reported on an as-fed basis. Wheat middlings considered are 89% dry matter.

a large quantity to meet their nutritional requirements. Large ruminants have the ability to do so. Over the price range considered, demand by individual dairy cows is always greater than that by individual beef cows. However, again, 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 coproduct does not enter the ration for feedlot beef cattle and lambs. Swine are unable to efficiently digest this feed.

TABLE 5
DEMAND FOR POTATO WASTE BY LIVESTOCK IN THE CENTRAL CROP REPORTING DISTRICT OF NORTH DAKOTA

Price ($/tonne)	Quantity demanded, thousand tonnes: Beef cows	Dairy cows	Ewes	Aggregate: Quantity	Elasticity
7.4	554.81	51.41	1.64	607.87	-1.05
8.0	510.70	49.49	1.60	561.78	-1.12
8.5	467.83	47.76	1.56	517.14	-1.26
9.1	420.12	46.18	1.51	467.82	-1.62
9.6	358.14	44.75	1.48	404.37	-2.50
10.2	276.26	43.43	1.44	321.13	-4.17
10.7	185.06	42.21	1.11	228.37	-6.47
11.2	106.22	0.49	0.31	107.02	-14.59
11.8	52.75		0.02	52.77	-14.37
12.3	22.85			22.85	-17.54
12.9	8.36			8.36	-21.52

Notes: Demand for potato waste was estimated at the mean price of all other ingredients. Mean prices ($/tonne) are 90.39(barley), 22.05 (corn silage), 88.18 (corn), 66.14 (alfalfa), 44.09 (hay), 90.39 (oats), and 198.42 (soybean meal). No potato waste comprises part of least-cost rations for feedlot cattle, lambs, or swine. Price and quantity are reported on an as-fed basis. Potato waste considered is 23% dry matter.

The aggregate demand schedule for potato waste is elastic over the range of prices considered. This reflects the price responsiveness of quantity demanded for use in beef cow rations. Demand for potato waste by dairy cows and ewes is much less sensitive to changes in price and is inelastic over the entire price range.

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. Farm-delivered potato waste from the plant near Jamestown, ND, is priced accordingly. Producers within 33 km of the plant are charged a base price that is a function of the local price for corn and barley. An additional $1.20 per loaded kilometer ($0.07/tonne) is charged for the distance over 33 km. In addition to transportation difficulties, the high moisture content of this coproduct can create storage problems. The cold winters in North Dakota require special equipment, such as lined delivery trucks, to prevent freezing. 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 produces approximately 52,000 tonnes 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. At higher prices, because demand from dairy cows becomes important, dairy herds located near a potato processing plant may provide an excellent market for locally produced potato waste. 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 price is as low as \$6.35 per tonne. At this price, it could be transported up to 158 km to beef cow operations, where the farm gate cost would equal \$11.80 per tonne including the transportation cost, and up to 133 km to dairy operations, where the farm gate cost would be \$10.70 per tonne.

Implications

Livestock producers have long made use of regionally available coproducts in their feed rations. Information about the value of these coproducts can be used by existing or potential livestock enterprises requiring an evaluation of feed cost as a component of enterprise profitability. Individual producers will benefit from consideration of the value of specific nutritional components of coproducts for their individual herds. Processors will be better prepared for decisions regarding coproduct offerings (e.g., type, amount, form).

Distinct differences in the level and nature of coproduct demand (e.g., price elasticity) over a range of prices, and particularly between species, makes flexibility in estimating demand especially important. The method for estimating demand presented and demonstrated here can be applied to a variety of livestock species and feed ingredients for which local time series data are unavailable.

ACKNOWLEDGMENTS

This research was funded through financial assistance from the North Dakota Agricultural Experiment Station. Econometric guidance from Dr. J. Scott Shonkwiler is gratefully appreciated, as is assistance in developing livestock nutrient requirement constraints from Dr. Greg Lardy, Dr. Marc Bauer, Dr. Roger Haugen, and Dr. Robert Harrold.

REFERENCES

Brennan, R.W., and M.P. Hoffman. 1989. Computer simulation of a cattle feedlot production system. *Journal of Animal Science* 67:1116-27.

Brooke, A., D. Kendrick, A. Meeraus, and R. Raman. 1998. *GAMS: A User's Guide*. Scientific Press, South San Francisco, CA.

Dhuyvetter, J., K. Hoppe, and V. Anderson. 1999. *Wheat Middlings.* North Dakota State University Extension Service Publication AS-1175. North Dakota State University, Fargo, ND.

Diewert, W.E. 1971. An application of the Shephard Duality Theorem: A generalized Leontief production function. *Journal of Political Economy* 79:481-507.

Feedstuffs. Various issues 1980 to 1999. Rural Press Limited, Minnetonka, MN.

Hendrix, K.S. 1996. *Can We Agree on What Corn Silage Is Worth in 1996?* Purdue Crop and Livestock Update. Purdue University, West Layfette, IN.

Johnson, D., and B. Varghese. 1993. *Estimating Regional Demand for Feed Barley: A Linear Programming Approach.* Agricultural Economics Report No. 303. Department of Agricultural Economics, North Dakota State University, Fargo, ND.

Konyar, K., and K. Knapp. 1986. *Demand for Alfalfa Hay in California.* Giannini Foundation Research Report Number 333. Division of Agriculture and Natural Resources, University of California, Riverside, CA.

Madnani, G.M.K., and S.S. Acharya. 1988. *Applied Econometrics for Agricultural Economists.* Himanshu Publications, Udaipur, India.

McKinzie, J.L., D.H.L. Daurlberg, and I.P. Ituerta. 1986. Estimating a complex matrix of demand elasticities for feed components using pseudo data: A case study of Dutch compound livestock feeds. *European Review of Agricultural Economics* 13:23-42.

National Research Council (NRC). 1985. *Nutrient Requirements of Sheep.* National Academy Press, Washington, DC.

National Research Council (NRC). 1989. *Nutrient Requirements of Dairy Cattle.* National Academy Press, Washington, DC.

National Research Council (NRC). 1996. *Nutrient Requirements of Beef Cattle.* National Academy Press, Washington, DC.

National Research Council (NRC). 1998. *Nutrient Requirements of Swine*. National Academy Press, Washington, DC.

Peeters, L. 1990. An E.C. Feed Grain Spatial Model for policy analysis (FIX). CARD Working Paper 90-WP61. Iowa State University, Ames, IA.

Peeters, L., and Y. Surry. 1987. A review of the arts of estimating price-responsiveness of feed demand in the European Union. *Journal of Agricultural Economics* 48:379-92.

Pindyck, R., and D. Rubinfeld. 1997. *Econometric Models and Economic Forecasts*, 4th ed. Irwin McGraw-Hill, Boston, MA.

Shonkwiler, J., and S. Yen. 1999. Two-step estimation of a censored system of equations. *American Journal of Agricultural Economics* 81:972-82.

Surry, Y. 1990. Econometric modeling of the European Community compound feed sector: An application to France. *Journal of Agricultural Economics* 41:404-21.

U.S. Department of Agriculture (USDA). 1999. *1997 Census of Agriculture*, vol. 1: Geographic Area Series. Part 34: North Dakota, State and County Data. USDA National Agricultural Statistics Service, Washington, DC.

U.S. Department of Agriculture (USDA), North Dakota Agricultural Statistics Service. 2000. *North Dakota Agricultural Statistics*. USDA National Agricultural Statistics Service, Washington, DC.

Voorhees-Watson, J.C. 1986. Synthetic demand for sunflower meal as a livestock feed ingredient. Master's thesis, Department of Agricultural Economics, North Dakota State University, Fargo, ND.

Manuscript received for review, November 2005; accepted for publication, March 2006.