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Input Quality in the Sugar Beet Industry

Michael Boland and Thomas L. Marsh

Using 23 years of data (1978–2000), this study examines seven vertically integrated sugar beet plants representing three different companies in the United States. The objective of this research is to identify the marginal costs of producing sugar beets for vertically integrated sugar beet processors as a way of determining the cost savings from higher quality sugar beets. In doing so, we account for quality differences in the sugar beet input that are used to manufacture the refined sugar output. The results quantify links between high quality sugar beets and lower processing costs.

Key words: cost function, product differentiation, production economics, sugar

Introduction

Between 1970 and 2001, 15 U.S. sugar beet processing companies closed 27 processing facilities with a total daily slicing capacity of 108,625 tons, which is approximately 40% of 2003 capacity. In addition, other plants were purchased by three producer-owned cooperatives beginning in the 1970s. These cooperatives were vertically integrated sugar beet processors. More cooperatives were formed in 1986 (Idaho), 2001 (Michigan), and 2002 (Colorado, Montana, Nebraska, and Wyoming). By 2002, sugar beet producers had vertically integrated 95% of the U.S. production. Producer-owned cooperatives included Amalgamated Sugar Company, American Crystal Sugar Company, Michigan Sugar, Minn-Dak Farmers Cooperative, Western Sugar Company, Southern Minnesota Beet Sugar Co-op, and Wyoming Sugar LLC (Brester and Boland, 2004).

Reasons for the dramatic change in the industry are, in part, driven by low profits in recent years. In the 1980s, Tate & Lyle diversified into corn sweetener production through its ownership of A.E. Staley, and expanded its sugar beet and sugar cane assets in the United States and around the world. Imperial Sugar acquired Holly Sugar and Domino Sugar to expand its cane sugar and beet sugar holdings. Other competitors engaged in similar diversification strategies. One driver of demand is price. In the mid-1990s, low world prices for sugar reduced margins. Consequently, these strategies failed and placed the firms in bankruptcy or with stressed balance sheets (Boland and Barton, 2002).

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A second driver of demand is the decline in sugar consumption in the United States in recent years due to substitution of corn sweeteners such as high fructose corn syrup for sugar. Bankruptcy and pressure from stockholders resulted in these firms seeking buyers for their sugar beet operations. Sugar beet growers were the only buyers for these assets, and through the acquisition of these assets, they vertically integrated into sugar beet processing. Jacobs (1990) reported that sugar beet processing plants were asset-specific—i.e., previous plants that had been closed were demolished and sold for scrap rather than used for other types of processing.

The objective of this research is to identify the marginal costs of producing sugar beets for vertically integrated sugar beet processors as a way of determining the cost savings from higher quality sugar beets. In doing so, we account for quality differences in the sugar beet input that are used to manufacture the refined sugar output. The results quantify links between high quality sugar beets and lower processing costs.

The results are derived using data for vertically integrated processing plants. As noted earlier, the sugar beet industry has rapidly vertically integrated over the past few years. Because the results may have implications for why this industry has vertically integrated in recent years, in the first part of the paper, we discuss the appropriate theories of vertical coordination based on organizational economics. This is followed by a discussion about quality issues in sugar beet production. Finally, the cost function and estimation results are described. While these results specifically apply to existing vertically integrated sugar beet processors, they have implications for other plants which have recently vertically integrated in Colorado, Idaho, Michigan, Montana, Nebraska, and Wyoming.

Motivation for Vertical Integration

Three alternative theories from the organizational economics literature are most often used to explain vertical coordination (Cook and Barry, 2004). These are agency theory, transactions costs theory, and contractual incompleteness, which often is referred to as property rights theory.

Agency theory explains how to best organize relationships in which one party (the principal) determines the work, which another party (the agent) undertakes (Jensen and Meckling, 1976). The agent has an incentive to shirk and the principal seeks to structure the relationship so as to avoid shirking. The theory argues that under conditions of incomplete information and uncertainty, which characterize most business settings, two agency problems arise: adverse selection and moral hazard. Adverse selection is the condition under which the principal cannot ascertain if the agent accurately represents his or her ability to do the work for which the agent is being paid. Moral hazard is the condition under which the principal cannot be sure if the agent has put forth maximal effort. Agency theory generally fits animal agriculture (e.g., broilers and swine) because it is easier to control and there is less uncertainty in management variables such as feed efficiency and environmental factors, and there is little or no seasonality (Goodhue, 2000; Allen and Lueck, 1998; Knoeber, 1989). The governance structure most often used is the corporate model because it has scale economies and lower costs of capital.

Transactions costs theory states that firms use coordination methods because there are costs of discovering, documenting, and implementing price negotiations (Williamson, 1988). Transactions costs arise when certain governance structures dictate how prices are discovered (e.g., futures markets). Specialized or idiosyncratic goods require more specialized governance structures and, if the item is traded frequently, a more complex governance structure is needed, which leads to transactions costs. In agriculture, transactions costs theory has been used to explain contracts employed for identity-preserved crops (i.e., genetically modified, organic, etc.) because these crops are specialized and it is more difficult to gain economies of scale (Sykuta and Parcell, 2003). Due to the specialized nature of these crops, the governance structure most often used is a corporation contracting with an individual farmer. However, as the costs of producing such crops decreases, a corporate form of governance may likely emerge.

Contractual incompleteness or property rights theory states that vertical coordination arises when firms seek to reduce conflicts with customers and suppliers (Grossman and Hart, 1986; Hart and Moore, 1990). Contracts always contain gaps (i.e., there is never a perfect contract), which leads to renegotiation of the contract. Under such conditions, the entity owning the commodity has bargaining power. When a commodity is more idiosyncratic, disputes are likely to be greater. Ownership is a source of power when contracts are incomplete. However, the exact form of governance (e.g., corporation, partnership, or proprietorship) does not matter, as the incentive effect due to ownership is relatively small compared to the previous two theories.

Vertical Integration and Sugar Beets

To understand which of the above theories best describes the integration that has occurred in the sugar beet industry, it is necessary to consider several aspects of sugar beet production, described below.

The value of the sugar beet crop is influenced by the estimated sucrose percentage in each ton of sugar beets. The sucrose percentage varies depending upon sugar beet variety, moisture, harvest conditions, and crop management practices such as timing of nitrogen fertilizer application. The sucrose percentage is taken from a sample for each load (or, in some cases, every other load) of a producer's sugar beets. This value represents the sucrose percentage at harvest and is the maximum sucrose percentage in a sugar beet. Once a sugar beet is harvested, the plant begins to burn sucrose as it decays and the sucrose percentage declines, implying that timing is crucial. Furthermore, sugar beets are bulky and cannot be shipped very far from the sugar beet processing plant. Consequently, spatial proximity is important and processing plants are built relatively close to production areas.[1]

Various reasons have been offered to explain vertical integration.[2] The use of contracts and transfer of revenue risk have been widely studied in recent years. Three

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[1] Sugar beets are a very profitable crop for producers relative to competing crops such as malt barley, corn, or wheat. Taylor and Brester (2005) found that the ability to grow and market sugar beets resulted in land values 20% to 30% greater than similar irrigated land in Montana.

[2] Moss and Schmitz (2002) analyzed the effects of an import quota on sugar, a key instrument in U.S. sugar policy, as a means of understanding why vertical integration has occurred. They examined economic rents for different types of firms in each segment of the sugar marketing channel, as illustrated in their figure 3 (p. 59). One implication from Moss and Schmitz is that vertical integration in the beet sugar industry results in lower average production and processing costs relative to sugar beet processors who are not integrated because vertically integrated firms are able to provide refined sugar to domestic customers and are less affected by imports or changes in the import quota (due to U.S. sugar policy) than unintegrated processors. However, our focus is on the quality aspects of sugar beets with regard to integration rather than the policy aspects.

cooperatives formed in the 1970s used an extractable sugar contract based on the actual amount of recoverable sugar from a grower's sugar beets.[3] This system provides an incentive for producers to increase the quality of their sugar beets since payments are made on actual recoverable sugar. Balbach (1998) and Sykuta and Cook (2001) suggested that the cooperative organizational structure was the reason the extractable sugar contract was used as a means of minimizing transactions costs. As these authors argued, since sugar beet growers owned the processing plants, producers could adopt the most accurate methods of measuring sucrose content (e.g., extractable sugar contract) because their ownership lessened information and monitoring costs. In doing so, they could also provide economic incentives for producers to supply sugar beets with greater sucrose content. In contrast, unintegrated processors have greater uncertainty in their knowledge of quality and supply of quality, leading to higher transactions costs.

Hueth and Melkonyan (2004) attribute the use of extractable sugar contracts to the variation in a grower's ability to control factors such as nitrogen application that are positively correlated with sugar beet ton yields but negatively correlated with sugar production within the plant. They argue that the governance structure is not linked to transactions costs.

Property rights theory is more likely a better explanation for the occurrence of vertical integration rather than the influences of transactions costs. The perishable nature of the sugar beet, coupled with management practices that impact sucrose content, hinders a plant's ability to devise a complete contract—i.e., the contract specifications laid out prior to planting are based on estimates of the crop's sucrose content whose value is not known until almost 12 months later.

Conditions frequently change from the time a contract is written until the value of the crop is known. An early frost or excessive rainfall can increase the degradation of sucrose. Wind damage or frost in the spring can reduce the volume of sugar beets. At the present time, there is no insurance for damage incurred by the sugar beets piled at the plant.[4] Therefore, these plants need to run at full capacity; ensuring prompt processing of these perishable sugar beets is essential to profitability. Vertical integration helps mitigate the inability to write a perfect contract, and adopting a cooperative governance model would lead to fewer disputes about the value of the sugar beet crop each year because the growers would own the assets.

Finally, it is important to note that vertical integration in the northern Great Plains and Michigan is fairly new. Property rights theory suggests the incentive effect of ownership is likely to be small relative to transactions costs theory and agency theory. If the effect were large, additional buyers probably would have considered purchasing the plants, or producers would have purchased them in earlier years. Although property rights theory appears to offer a good explanation as to why this vertical integration has occurred, it does not explain why such vertically integrated plants might desire high quality sugar beets.

The reasons noted above suggest the quality of a sugar beet as measured by sucrose content is an important input in a processor's cost function. Therefore, it is important to differentiate sugar beets when modeling a sugar beet processor's cost function. We

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[3] Recoverable sugar depends on both the sugar content and the quality of the beets or the level of impurities present. Measurements of the impurity levels and sugar content percentage are made from samples taken from each grower's truckloads. The percentage sugar loss to molasses is then subtracted from the percentage of sugar content.

[4] It should be noted that one of the firms in this study does use weather derivatives to manage this type of risk.

define the differentiated input as quality sugar beets and average sugar beets, and then estimate a cost function for three vertically integrated sugar beet processors. Price elasticities from this cost function provide information about how these processors use economic incentives to encourage their producer-members to deliver sugar beets with greater sucrose content.

Cost Function Literature

In general, the structural cost function literature treats product quality (e.g., sugar beets as a homogeneous input) as exogenous and unobserved in the analysis because it is unobservable in most cases. Quality is also usually assumed to be unrelated to the other endogenous variables in the analysis. This is often done because of the difficulties in collecting data on product quality, which can be quite laborious and cost-inhibiting. In many analyses, however, the assumption of exogenous, unobservable quality is incorrect because the products are differentiated on some quality attribute. This creates biases in the parameter estimates, which can lead to inaccurate inferences.

Analyzing the regulated automobile insurance industry, Braeutigam and Pauly (1986) concluded that omitted variables, such as quality, can lead to biases in estimation. Based on the findings of their study, failure to distinguish between firms operating in states where insurance prices are heavily regulated relative to states where insurance prices were not as heavily regulated led to misleading results from hypothesis tests.

In a study of New York State nursing homes, Gertler and Waldman (1992) specified a quality-adjusted cost function considering product quality as unobserved but endogenous. This function was then used to analyze the effects of price regulation and competition on nursing home costs and quality. Gertler and Waldman's model provides an advantage in that it accounts for product quality but does not require much more data than a typical cost function analysis. Two labor inputs were used in their study, where labor was differentiated based on the hourly wage rate.

Marsh (2005) investigated the flour milling industry, differentiating between wheat classes for domestic food use. Economically and statistically significant effects were found between different classes of wheat, indicating that wheat is not a homogeneous input, but rather a differentiated quality input (primarily reflecting protein content) into the milling industry.

In sugar beet processing, quality is measured by the level of sugar in a ton of sugar beets. Sugar is an observable attribute for vertically integrated firms that use a contract for an individual grower. Producers are paid a price based on sugar beet tonnage, which is then adjusted for the average level of sugar in an average ton of sugar beets. In this case, "quality" sugar is related to sugar with greater extraction rates as well as some form of differentiation. The differentiation is related to sugar quality based on its end use.

The Model

This approach assumes the existence of a unique cost function with inputs used in nonnegative quantities. A cost function for sugar beet processors can be represented as:

$$C = f(P_k, P_l, P_e, P_o, P_b, P_u, Q), \tag{1}$$

where C is the total cost of processing sugar beets, P_k is the price of capital K, P_l is the price of labor L, P_e is the price of energy E, P_o is the price of other marketing inputs O, P_b is the price of "average" sugar beets B with average sugar content, P_u is the price of "quality" sugar beets U that have above average sugar content, and Q is output or total tons processed. The standard properties of a cost function are homogeneous of degree one, nondecreasing, and concave in input prices, as well as nondecreasing and convex in Q (Shephard, 1970).

The normalized quadratic function is often used in production economics research to specify cost functions because curvature can be readily imposed and the normalization of prices ensures homogeneity (Diewert and Wales, 1987). For $m + 1$ inputs, the normalized quadratic form of equation (1) is expressed as follows:

$$(2) \qquad C = \alpha_0 + \sum_{i=1}^{m} \alpha_i p_i + \alpha_Q Q + \frac{1}{2}\left[\sum_{i=1}^{m}\sum_{j=1}^{m} \alpha_{ij} p_i p_j + \alpha_{QQ} Q^2\right] + \sum_{i=1}^{m} \alpha_{iQ} p_i Q \quad \text{for } i,j = k,l,e,o,b,u;\ i \neq j,$$

where α_0, α_i, α_Q, α_{QQ}, α_{iQ}, and α_{ij} are parameters to be estimated. In equation (2), cost and input prices are normalized by the m + 1st input price. The cost-minimizing input demand functions can be found using Shephard's lemma:

$$(3) \qquad x_i = \alpha_i + \sum_{j=1}^{m} \alpha_{ij} w_j + \sum_{i=1}^{m} \alpha_i Q,$$

where x_i is the quantity of the ith input. The input price elasticities of demand are given by:

$$(4) \qquad E_{ij} = \frac{\alpha_{ij} w_j}{x_i} \quad \text{for } i,j = k,l,e,o,b,u,$$

where E_{ij} is the price elasticity of the ith quantity demanded with respect to the jth input price. The cost elasticity of output Q is defined by:

$$(5) \qquad E_{CQ} = \left[\alpha_Q + \sum_{i=1}^{m} \alpha_{iQ} w_i + \alpha Q_{QQ}\right]\left[Q/C\right],$$

which is a measure of scale economies.

Wohlgenant (1989) and Goodwin and Brester (1995) have shown that input substitutability between raw agricultural products and other processing and marketing inputs is an important feature of the food processing industry. Therefore, it seems reasonable to convert Allen-Uzawa price elasticities to Morishima elasticities to accurately measure input substitutability (Blackorby and Russell, 1989). Morishima elasticities of substitution are calculated as:

$$(6) \qquad M_{ij} = E_{ji} - E_{ii},$$

where M_{ij} is the Morishima elasticity for the ith and jth inputs, and the E_{ji} are calculated in (4). The Morishima elasticities of substitution measure the effect of varying the input price ratio p_i/p_j in the ith direction on the input quantity ratio x_i/x_j (Blackorby and Russell, 1989). The price elasticities obtained from (4) and the substitution elasticities obtained from (6) are used to measure economic responsiveness to changes in the price of an input.

Description of the Data

The data used in this research came from seven vertically integrated sugar beet plants representing three different companies in the United States. Annual reports for these plants were obtained from the Kansas State University Arthur Capper Cooperative Center database and Lexis-Nexis for the years 1978 through 2000. Any missing data and data on the sugar beet quality variable were obtained from each plant. Thus, there are 23 years of data for each of the seven plants, or 161 total observations. These plants had become vertically integrated just prior to the beginning of this period. Individual information on input shares was obtained through details presented in the annual report and from direct follow-up with each firm. Table 1 reports the mean and standard deviation of each variable. Data on other inputs were obtained from a variety of public sources, which are described in the following paragraphs.

Production Costs and Output

Total production costs (C) were calculated by using the total cost from each firm's annual report. These included non-procurement, marketing costs, and the beet payment, which was the total payment made to producers each year. Thus, C measures all variable costs associated with processing the sugar beets. Output (Q) was measured as total tons of sugar beets.

Inputs

Inputs were aggregated into capital, labor, energy, other marketing costs, average quality sugar beet, and above average quality sugar beet categories. These inputs are described below.

Capital

Shui, Beghin, and Wohlgenant (1993) note that the implicit user cost of capital (P_k) is defined as the sum of the real rate of interest and the depreciation of capital. We used data from various public sources to construct this variable. The real rate of interest is the difference between the annual Baa bond rate reported by the U.S. Department of Commerce in its *Survey of Current Business* and the rate of change in the average annual Consumer Price Index reported by the U.S. Department of Labor's Bureau of Labor Statistics. The depreciation component is calculated by dividing plant depreciation by net property values as reported by the U.S. Department of Commerce's *Annual Survey of Manufactures* for SIC Code 2063, Beet Sugar. This variable increased until the early 1980s as interest rates were high due to inflation, and then decreased until the mid-1990s before increasing again.

Table 1. Selected Statistics for Input, Output, and Cost Variables for Seven Sugar Beet Processing Plants, 1978–2000

Variable	Unit	Average	Std. Dev.	Minimum	Maximum
Energy Price (P_e)	index	108.34	13.84	68.00	129.10
Labor Price (P_l)	$/hour	10.42	2.84	5.60	15.90
Capital Price (P_k)	%	13.93	2.28	10.83	18.70
Other Price (P_o)	index	114.79	21.15	68.00	147.30
Average Sugar Beet Price (P_b)	$/ton	38.46	8.90	17.38	60.17
Quality Sugar Beet Price (P_u)	$/ton	40.56	9.05	20.00	62.21
Total Costs (C)	$100,000s	247.56	163.04	153.99	637.33
Average Quantity (Q)	1,000 tons	4.14	2.53	7.44	10.68
Energy Share	%	5.88	0.39	5.01	6.61
Labor Share	%	7.75	0.86	5.30	9.70
Capital Share	%	4.08	1.52	1.76	7.81
Other Share	%	16.58	3.29	9.30	21.10
Average Sugar Beet Share	%	35.10	1.90	31.14	39.76
Quality Sugar Beet Share	%	30.62	2.11	24.37	36.43

Note: Shares may not sum to 100% due to rounding.

Labor

Labor expenditures included costs associated with hourly plant employees: wages, salaries, social security and payroll taxes, insurance, and health benefits. The price of labor was measured as the 12-month average of the Average Hourly Earnings of Production Workers, which was obtained from the U.S. Department of Labor/Bureau of Labor Statistics *National Employment, Hours, and Earnings* database for SIC Code 2063, Beet Sugar. These data are not seasonally adjusted, with a base year of 1982. Data for SIC 2063 were available from January 1982 to the present. Prior to 1982, the data were reported under the three-digit SIC Code 206, Sugar and Confectionary Products. This variable steadily increased over the time period of this study.

Energy

Energy costs (i.e., fuel and electricity) were not available for each plant. However, the Bureau of the Census in the U.S. Department of Commerce/Economics and Statistics Administration reports an energy index for SIC Code 2063, Beet Sugar. This variable was greater at the beginning of the time series due to high energy costs in the late 1970s and early 1980s.

Other Marketing Costs

The variable for other marketing costs is calculated as the residual between total costs and the costs of capital, labor, energy, average sugar beets, and quality sugar beets. (These latter two variables are discussed in the next section.) There is no single best method to determine what these other costs are since they are not reported individually for each firm.

Goodwin and Brester (1995) used an index developed by the U.S. Department of Agriculture's Economic Research Service. This index is comprised of costs for such items as packaging, labeling, and similar costs. It seems reasonable to use this variable as a proxy for input prices given their importance and that they are similar for refined sugar. The index was not reported for 1998 to the present in that USDA publication; however, the study's author provided the index for these years via electronic mail (Elitzak, 2000).

Sugar Beet Prices

Two variables are used to measure sugar beet prices. The first price is the observed average price paid to sugar beet producers at each plant. These are obtained from the annual reports of each firm. The second price is based on data available from the USDA's National Agricultural Statistics Service (NASS) which reports a sucrose (i.e., sugar) percentage per ton of sugar beets by county. These data are used to construct a price for quality sugar beets. The word "quality" is used here to denote sugar beets that were paid a greater price relative to the average because they had greater sucrose content. Each of the seven sugar beet plants contracted with producers in different counties, so there is no overlap in the county data. The data can be used to construct a county-level price for sugar beets that has been weighted for sucrose content. A weighted price was constructed for quality sugar beets as:

$$P_{um} = \sum_k \sum_l \left(\left(\frac{SR_{klm}}{SR_l} P_l \right) I_m(k, l) \right) \Big/ \sum_k \sum_l I_m(k, l), \tag{7}$$

where P_{um} is the price of the quality sugar beet for the mth plant (m = Plant A, Plant B, ..., Plant G), SR_{klm} is the average sucrose percentage for the kth county (1, ..., 22) in the lth state (1, 2) for the mth plant, SR_l is the average sucrose percentage reported for the lth state, and $I_m(k, l)$ is an indicator function that takes on the value of one if firm m contracted within county k in state l, and zero otherwise. The first term on the right-hand side results in a quality index weighted by sucrose percentage for each county. This index then adjusted the average sugar beet price reported for each state by USDA/NASS. The denominator accumulates the total number of counties that contract with firm m. The average sugar beet quality price reported by each plant is an average of all sugar beets and not explicitly linked to quality, while the P_{um} price for each plant is an average price weighted by the sucrose percentage which is linked to quality.

Three alternatives could be identified for price of quality sugar beets. A quality price that was greater than the firm's average price implies a premium above the price of average sugar beets because of the higher sucrose percentage. A quality price that was less than the firm's average price implies a discount below the price of average sugar beets because of the lower sucrose percentage. Finally, a quality price equal to the average price meant the producers in that county had average beets that year. On average, over the sample, the price of quality sugar beets was \$2.10 per ton higher than the price of average sugar beets (see table 1). These differences in prices are likely attributed to better sugar beet varieties which yield greater sucrose, improved management practices (e.g., less nitrogen application before or during the growing season), and greater awareness by producers of the advantage to producing higher cost sugar beets that would improve extraction rates and sugar content percentages. In turn, this would increase their profits.

Estimation

The previous section described the data used in this research. Other marketing inputs are used as the input price on which to normalize cost and the prices for labor, capital, energy, average sugar beets, and quality sugar beets. The total cost function incorporating quality [equation (2)] was estimated jointly with the input share functions [equation (3)] for labor, capital, energy, sugar beets, and quality sugar beets. Symmetry restrictions were imposed. The five-equation system was estimated with SAS, using iterated seemingly unrelated regression.[5]

To measure the significance of elasticities, bootstrapped confidence intervals were constructed. Bootstrap procedures are convenient for intractable inference problems and are often equivalent or superior to first-order asymptotic results (Mittelhammer, Judge, and Miller, 2000). Bootstrap estimates were obtained by: (*a*) resampling the residuals of the model, (*b*) predicting cost and quantities of inputs, (*c*) reestimating the three-equation system with predicted values, and (*d*) recalculating the elasticities. This process was repeated 1,000 times to generate distributions of price and substitution elasticities. A 90% confidence interval was then constructed based on the percentile method, which requires ordering estimated elasticities and then selecting outcome 50 (0.05 * 1,000) for the lower critical value and outcome 950 (0.95 * 1,000) for the upper critical value.

Parameter Estimates

As reported in table 2, 25 of the 27 parameter estimates for the cost function are significantly different from zero at the 0.10 level.[6] The system-weighted R^2 value for this equation is 0.8983, indicating that 89.83% of the variability in the cost of processing sugar beets is explained by the variability in the dependent variables. The weighted mean squared error is 0.9741. This statistic measures the variance in the actual annual costs compared to the costs predicted by the model. For this cost function, the error between the actual annual total costs and the predicted annual total costs is $974.10. The R^2 values for the labor, capital, energy, average sugar beet, and quality sugar beet share equations are 0.91, 0.88, 0.96, 0.87, and 0.90, respectively.

Elasticities

Parameter estimates and mean input quantities were used to calculate input price elasticities of demand and Morishima elasticities of substitution for the cost function at the mean (tables 3 and 4). For the model, the own-price elasticities for labor, capital, energy, average sugar beets, and quality sugar beets are negative—i.e., as the price for these inputs increases, the corresponding quantities demanded decrease (table 3). The own-price elasticities for labor, energy, average sugar beets, and quality sugar beets are inelastic (-0.4207, -0.3362, -0.9115, and -0.8756, respectively). In contrast, the own-

[5] Monotonicity was checked for each of the demand equations as advised by Barnett and Pasupathy (2003). All quantities were positive, indicating there were no violations of monotonicity. Moreover, the eigenevalues of the Hessian matrix were all negative, indicating curvature conditions were satisfied.

[6] We conducted a likelihood ratio test comparing cost models where sugar beets were aggregated as one input as well as the two inputs. That hypothesis was rejected.

Table 2. Parameter Estimates and Standard Errors for the Cost Functions for Seven Sugar Beet Processing Plants

Variable	Parameter Estimate	Standard Error	Variable	Parameter Estimate	Standard Error
Intercept	-2.792950	3.049037	P_kP_b	-0.000010	0.000020
P_l	0.056108*	0.008862	P_kP_e	0.000016*	0.000003
P_k	0.004076*	0.000650	P_kP_u	-0.000080*	0.000018
P_b	0.814173*	0.098039	P_kQ	0.002529*	0.000093
P_e	0.010826*	0.004764	P_b^2	-0.026790*	0.002495
P_u	0.739005*	0.065334	P_bP_e	0.000669*	0.000232
Q	4.826479*	1.212940	P_bP_u	-0.002540*	0.000482
P_l^2	-0.000430*	0.000069	P_bQ	0.524195*	0.015872
P_lP_k	8.07E-06	0.000005	P_e^2	-0.000200*	0.000003
P_lP_b	0.002037*	0.000507	P_eP_u	-0.000530*	0.000213
P_lP_e	-1.80E-04*	0.000054	P_eQ	0.032521*	0.000556
P_lP_u	0.003004*	0.000549	P_u^2	-0.021220*	0.001699
P_lQ	0.056693*	0.001212	P_uQ	0.449857*	0.011610
P_k^2	-3.08E-06*	0.000000	Q^2	0.318287*	0.162416

Note: An asterisk (*) denotes parameter estimate is significantly different from zero at the 10% level of significance.

price elasticity for capital is elastic, with a value of -1.0724. The difference between average sugar beets and quality sugar beets suggests plants are using systems that enable them to provide incentives for quality sugar beets.

As observed from table 3, the Allen-Uzawa cross-price elasticities of demand indicate that labor is a substitute for capital, average sugar beets, and quality sugar beets; capital is a substitute for labor and energy; energy is a substitute for capital and average sugar beets; average sugar beets are a substitute for labor and energy; and quality sugar beets are a substitute for labor. The remaining pairs of inputs are complements for each other. However, the Allen-Uzawa elasticity does not allow for optimal adjustment of all inputs to a change in a price ratio.

The Morishima elasticities of substitution are a measure of ease of substitution. For example, from the first numeric column in table 4, a 1% increase in the price of labor causes a 1.1859 increase in the quantity ratio of capital to labor, a 0.1459 increase in the quantity ratio of energy to labor, a 1.6671 increase in the quantity ratio of average sugar beets to labor, and a 2.0213 increase in the quantity ratio of quality sugar beets to labor. Similar comparisons are shown in table 4 for a 1% increase in the respective price of capital, energy, and average and quality sugar beets. With the exception of the ratio of energy to labor with regard to an increase in the price of labor, elasticities are higher, suggesting substitution between inputs i and j occurs when the price of input j increases.

Of particular interest are the substitution elasticities between average and quality sugar beets and the other inputs. Regardless of whether the price of average or quality sugar beets is changed, there remains relevant substitutability between them. For instance, a 1% decrease in the price of average sugar beets results in a decrease in the ratio of quality sugar beets to average sugar beets (i.e., the elasticity is 0.7867).

Table 3. Allen-Uzawa Elasticities Corresponding to the Cost Function Shown in Table 2

	Price Change				
Equation	α_L	α_K	α_E	α_B	α_U
Labor, α_L	-0.4207	0.1138	-0.1903	0.7556	1.1458
Capital, α_K	0.1949	-1.0724	0.4176	-0.0916	-0.7533
Energy, α_E	-0.2800	0.3588	-0.3362	0.3946	-0.3214
Average Sugar Beets, α_B	0.1828	-0.0129[a]	0.0649	-0.9115	-0.0889
Quality Sugar Beets, α_U	0.3179	-0.1221	-0.0606	-0.1019	-0.8756

[a] Denotes that the elasticity was not significant at the 10% level.

Table 4. Morishima Elasticities Corresponding to the Cost Function Shown in Table 2

	Price Change				
Quantity Ratio (numerator)	α_L	α_K	α_E	α_B	α_U
Labor, α_L	—	0.6156	0.1407	0.6035	0.7386
Capital, α_K	1.1859	—	1.4256	1.0542	0.9557
Energy, α_E	0.1459	0.7476	—	0.4011	0.2756
Average Sugar Beets, α_B	1.6671	0.7851	1.3061	—	0.8095
Quality Sugar Beets, α_U	2.0213	0.1571	0.5541	0.7867	—

The important question for consideration by a manager is: What impact do price changes have on sugar beet procurement costs? For example, consider percentage changes in price for the last two years of the data (1999–2000) during which the average price of average (quality) sugar beets decreased by 2.54% (2.72%). Based on the estimated own-price elasticities, a 1% decrease in the price of average (quality) sugar beets would result in a 0.9115 (0.8756) increase, ceteris paribus, in the quantity demanded of average sugar beets. A 2.54% decrease in the price of average sugar beets would result in a 2.3152% (i.e., $0.9115 * 2.54 = 2.3152$) increase in the quantity of average sugar beets. Similarly, a 2.72% decrease in the price of quality sugar beets would result in a 2.3816% (i.e., $0.8756 * 2.72 = 2.3816$) increase in the quantity of quality sugar beets.

This information can be used to measure the effect on total costs. With the decrease in prices of average sugar beets from 1999–2000, the costs of procuring average sugar beets decreased by 10.14%, from $81.341 to $73.09 million. The total tons of average sugar beets fell from 2,126 to 2,025, or 7.78%. The costs of quality sugar beets fell from $71.761 to $65.047 million (9.35%), and tons fell from 1,931 to 1,799 (6.82%). Continuing with the example for average sugar beets, there was a 2.54% decrease in the price of average sugar beets from 1999–2000. These price decreases resulted in a net reduction in total costs of 10.53%.

Economies of Scale

The economies-of-scale (EOS) statistic was calculated using equation (5). When the EOS statistic is less than one, there are diseconomies of scale, and when it is greater than one, it exhibits economies of scale. The economies-of-scale statistic for the cost function is 0.99023, which is not significantly different from one, suggesting the plants examined in this study are operating at optimal scale.

Comparison to LMC International Estimates

Using a traditional cost-of-production budget approach, LMC International (2000) determined cost estimates of producing and processing sugar beets around the world for 1994. As documented in LMC's *Worldwide Survey of Sugar and HFCS Production Costs* 2000 report, these estimates were comprised of all costs of production and processing through the delivery of refined white sugar into storage at the factory. The Eastern U.S. sugar beet producing regions (Great Lakes and Red River Valley) had average low and high costs of 15.27¢ per pound and 25.13¢ per pound, respectively. The range was due to the various plants that were surveyed in the different geographic regions.

In commenting on the LMC figures, U.S. Department of Agriculture economist Stephen Haley (2001) stated, "Economists generally argue that marginal costs are more relevant in predicting supply response changes due to changes in output prices, government support, input prices, and the like." These costs were converted into dollars per ton so that the results from our research could be compared with the LMC figures. Within the United States, the costs reported by LMC range from $305.40 per ton to $502.60 per ton in the Eastern producing regions, and $385.00 per ton to $681.20 per ton in the Western producing regions. Using the mean quantities for each parameter, the average cost for producing beet sugar from the estimated cost function is $441.24 per ton, which is within the range reported by the LMC survey for the Eastern producing regions. Accounting methods were used to determine the costs of producing beet sugar reported by LMC, while the costs in our research are marginal costs and were determined by economic theory incorporating quality differences in inputs.

Implications

An important implication of the results of this study is that higher quality sugar beets lower a plant's costs, as seen in the application of the elasticities. These cost savings can be significant in some years. Other studies of processing costs using a differentiated input, such as lean pork carcasses, have found similar results (Boland, Foster, and Akridge, 1995). Although our results were found for long-standing vertically integrated sugar beet processing firms with multiple plants, we would expect the results would also apply for plants that have recently vertically integrated—such as those in Colorado, Idaho, Michigan, Montana, Nebraska, and Wyoming. Specifically, we would anticipate that these newly vertically integrated sugar beet processing plants would have lower costs over time.

One issue requiring future research is the link between governance and ownership structure and quality sugar beets. Property rights theory appears to provide a reasonable explanation as to why vertical integration may be occurring. However, it does not imply that such ownership structures are being formed because of the opportunity to procure higher quality sugar beets. For example, Taylor and Brester (2005) show that land available for sugar beet production has greater value in Montana than alternative crops. Furthermore, they demonstrate that soil quality is a land endowment that matters with regard to land value.

Cooperatives are governed by a board for directors who are producers and members of the cooperative. Sugar content in sugar beets is positively correlated with improved soil quality. Growers with lower soil quality endowments may argue against the imposition of economic incentives for increased sugar because their land endowments prohibit them from attaining this quality. Furthermore, because any such increased incentives to quality sugar beet producers may have to come at the expense of average sugar beet producers, it is likely that the dynamics of group action would tend to limit increased use of incentives to produce sugar beets with more sugar.[7]

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[7] In fact, the CEOs of two different sugar beet companies indicated to one of the authors that, although things had improved in recent years, they still did not pay enough for high quality sugar beets. It should be noted that while the payment systems used for quality are linear (i.e., a percentage increase in quality is linearly linked to increased revenue), sugar deteriorates at a nonlinear rate (Cole, 1975).

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