Journal of Agricultural and Applied Economics, 35,1(April 2003):15–28

Designing U.S. Corn Grades to Reflect End Use Value

Jeffrey J. Reimer and Lowell D. Hill

The 1986 U.S. Grain Quality Improvement Act introduced an explicit, economic purpose for grades—that they transmit information about end use value—but provided little guidance about what factors to include in grades. We determine which quality characteristics best reflect the processed value of U.S. corn in the case of a Japanese wet miller. Foreign material is the only grade factor closely related to processed value, but a large number of nongrade attributes, many of which reflect the intrinsic properties of corn, are found to vary substantially across shipments and to provide extensive information about value. Recommendations for U.S. grades are made.

Key Words: commodity marketing, corn, grades, maize, quality information

JEL Classifications: L15, Q13

An important purpose for grades in commodity markets is to provide buyers with information they can use to estimate value, without the necessity of physically examining each lot (Shepherd). Meeting this objective requires that grades transmit information about the quantity and quality of end products derived from a commodity. Prior to the 1986 amendment to the U.S. Grain Standards Act, the economic concept of "end use" value was not a criterion for the structure of grades (U.S. Congress). The purpose of grades in the preamble of the 1916 Grain Standards Act was "that trading in grain may be facilitated." Although industry, producers, and government were supportive of uniform grades and the terminology of the 1916 legislation, it provided little guidance for selecting the factors to include in grades or the limits associated with each factor. Any easily measured attribute accepted by the trade could meet this criterion.

The factors selected for U.S. grades in the early 1900s were based on trade practices, not research, and have remained virtually unchanged despite major changes in production, marketing, processing, and measurement technology. The U.S. Department of Agriculture (USDA) has, however, made numerous minor changes in definitions and factor limits in response to pressure from farmers and importers (USDA, Federal Grain Inspection Service [FGIS]). Some limits were changed several times only to be returned to their original level a few years later. A review of the more than 300 changes between 1916 and 1986 gives the impression of a certain degree of arbitrariness and a response indicative of "greasing the squeaky wheel" rather than providing more or better economic information. Some grade-de-

Jeffrey J. Reimer is post-doctoral research associate, Department of Agricultural and Applied Economics, University of Wisconsin, Madison, WI. Lowell D. Hill is professor emeritus, Department of Agricultural and Consumer Economics, University of Illinois, Urbana-Champaign, IL.

This research was carried out when Reimer was with the Department of Agricultural Economics, Purdue University, and he is grateful to this department for financial support.

The authors thank two anonymous reviewers, as well as Paul Farris and Phil Paarlberg, for useful comments and insights. The authors are grateful to the firm providing data.

termining attributes have little relationship to the yield of products, and several attributes important to end users are not part of grades (Hill). The end use criterion in the 1986 amendment to the Grain Standards Act provided general guidelines but failed to resolve the primary issue of which measurable factors best reflect the quantity and quality of products derived from grain.

The study at hand addresses this issue in the case of corn. The goal is to help reshape the debate over U.S. grades in general and U.S. corn grades in particular such that quality attributes will increasingly be evaluated in terms of their ability to transmit useful information about end use value. Toward this objective, we use detailed data from a Japanese firm to (i) determine the relationships between quality attributes and the output of processed products, (ii) estimate the implicit values of these same attributes, and (iii) identify factors that could be incorporated into current grades to increase efficiency in transmitting information about value. A key requirement for these tasks are indicators of corn quality beyond those tested by the FGIS and included on the official certificate of every exported shipment.

The firm from which data were collected accounts for one-sixth of all imports by Japanese wet millers, and we view it as representative of that sector. Although this sector is not representative of corn importers in general, in that their definition of "high quality" corn might differ from that of other types of importers, the Japanese wet-milling market has several features that make it appropriate for this analysis. First, Japanese wet millers account for approximately one-third of that country's corn imports, and Japan itself is the single largest purchaser of U.S. corn, typically importing about one-third of U.S. exports. Furthermore, the wet-milling sector's share of Japan's corn use has been increasing over time (Caplan). Wet millers produce starch, gluten feed, gluten meal, and germ, which are used as intermediate inputs in a vast and ever-expanding array of food, pharmaceutical, and industrial products. Starch, for example, can theoretically be converted into an enormous assortment of chemicals now produced from petroleum sources (Jackson). Because new uses for wet-milling products are the subject of intense research and are continually being developed, the demand for wet-milling products has grown more rapidly than for most other corn derivatives over the past two decades and is set to continue this trend (Earley; Ohio Corn Marketing Program). As such, wet millers are a prominent and expanding market for U.S. corn. Another feature of this sector is that the firms are quite conscious of quality, ranking corn quality (including intrinsic properties and cleanliness) as well as end product quality as important criteria in sourcing decisions (Caplan). This is reflective of a general trend toward greater sensitivity to quality that is being demonstrated by all types of corn users (USDA, Foreign Agricultural Service [FAS]).

The remainder of the paper is organized as follows. In the following two sections we briefly describe previous research on corn quality and lay out the conceptual and empirical framework for our analysis. In the subsequent two sections, we describe the sources of our data and present empirical procedures and results. The final section summarizes and concludes.

Previous Studies

Few studies have considered the relationships between quality, grades, and price for corn, despite being an important export commodity for the United States, with sales abroad projected to rise from 2.1 billion bushels in 2001 to 2.8 billion bushels in 2011 (Food and Agricultural Policy Research Institute). A study by Mercier, Lyford, and Oliveira examined the role of FGIS-tested quality characteristics in the price determination process for U.S. corn exports. The authors found that moisture content is the only FGIS-tested factor that significantly affects the price paid across all importers, although test weight and damaged kernels are significant in the context of certain types of end users.

Another study by Mercier examined USDA surveys of corn-importing countries concerning how importers rank quality among factors that influence supplier choice, and considered the benefits to U.S. producers and exporters in providing cleaner, higher quality corn to the world market. Industrial users in Asia identified starch, broken corn, foreign material, moisture, stress-cracked kernels, and kernel size as the most important attributes (Mercier, p. 13). Regression analysis with factors tested by the FGIS at origin suggested that numerical grade was not a useful predictor of price and that test weight was not statistically significant in the decision-making process of importers.

These results are comparable to those of Hill et al. (1990), in which survey respondents identified levels of starch, protein, oil, and foreign material as the most important attributes for wet millers, followed by mold damage and broken kernels. Test weight, a measure of density, was the least important of factors. A one-vessel case study by Hill et al. (1993) demonstrated that percent levels of starch, oil, stress cracks, and germination as measured at destination were important determinants of the yield of wet miller products.

The study at hand builds on those mentioned by providing statistical evidence as to which characteristics transmit important information about end use value. This is a necessary step in determining what factors might be usefully incorporated into U.S. grades, as well as which ones provide information of little importance, in a manner consistent with the economic purpose of grades outlined in the 1986 Grain Quality Improvement Act.

Theoretical and Empirical Models

Our approach to the objectives laid out above is based on the neoclassical input characteristics model of Ladd and Martin. We hypothesize that the processor purchases the raw input, corn, for quality characteristics (including intrinsic properties and cleanliness) and that it is these characteristics, not the corn itself, that give rise to value in the wet-milling process. Wet milling yields four products sold as intermediate products: starch, gluten meal, gluten feed, and germ, with starch being the most plentiful and valuable of these. Accordingly, we model the processor as a multiproduct firm, and assume further that the production function for each product is independent of the production functions of all other products.

Attributes That Determine Processed Product Output

We hypothesize that the output for each product i, which we denote q_i, is a function of quality attributes automatically tested at the U.S. port of origin, most of which are grade-determining $(a_1, \ldots, a_m)$, and a range of other quality attributes $a_{m+1}, \ldots, a_n$ that are not currently part of USDA grades. This can be formally stated as

$$q_i = q_i(a_1, \ldots, a_m, a_{m+1}, \ldots, a_n).$$

Because we have 253 observations on the firm's predicted yields of processed products, as well as the results of its quality tests for individual shipments (described later in the data section), we are able to estimate this production function for each product i. This allows us to determine the extent to which the firm uses information about grade-determining versus nongrade attributes in predicting the yield of processed products. Our regression specification is

$$(1) \qquad q_i = \beta_0 + \sum_j \beta_{ij} a_j + \epsilon_i,$$

where β_0 is an intercept coefficient, and β_{ij} are coefficients associated with product i and quality attribute j. We assume that the error terms are distributed normally, identically, and independently. Should a quality coefficient be significantly different from zero, this would suggest that the given attribute is used by the processor to predict the yield for that product. We hypothesize that the processor uses more than just the FGIS-tested factors to determine the yield of processed products, that is, the processor pays close attention to attributes $(a_{m+1}, \ldots, a_n)$.

Attributes That Provide Information About End Use Value

In estimating Equation (1) for the different products, it will often be the case that a characteristic such as protein, for example, contributes to the yield of one product but lowers the yield of another. Because it should ultimately be the total value of processed products as opposed to individual yields that is important to a firm, the implicit demand for protein in this case will depend on the relative market prices of the two products. As such, protein could theoretically have a positive implicit value, despite it decreasing the output of some products. With this in mind, we need to work in terms of the values of the processed products.

Multiplying the hypothesized production function q_i for each product by its price p_i and summing over products gives the total processed value of wet milling.

$$\sum_i p_i q_i = \sum_i p_i q_i(a_1, \ldots, a_n).$$

Letting c denote corn comprising n attributes, differentiating the above expression gives the marginal processed value. This derivative is $\partial \Sigma_i p_i q_i/\partial c = \Sigma_i p_i \Sigma_j (\partial q_i/\partial a_j)(\partial a_j/\partial c)$. A more informative way to write this derivative is

$$PV = \sum_j (\partial a_j/\partial c) \sum_i p_i(\partial q_i/\partial a_j),$$

where PV is the processed value and $\Sigma_i p_i(\partial q_i/\partial a_j)$ is the marginal revenue product for characteristic j. This is also sometimes called the implicit value of an attribute.

Because we have 253 observations on the firm's predicted product yields and the prices at which its sells the four products (described later), we can calculate the processed value in yen (¥) per kilogram of individual shipments. This allows us to provide an estimate of the marginal revenue product for individual characteristics. To do so, we specify the following regression model based on our expression for PV above.

$$(2) \qquad PV = \gamma_0 + \sum_j \gamma_j a_j + \epsilon,$$

where γ_j is the coefficient associated with the level of attribute j in a unit of corn ($\partial a_j/\partial c$), which is defined for simplicity as a_j. This coefficient provides an estimate of the marginal revenue product of an attribute, $\Sigma_i p_i(\partial q_i/\partial a_j)$, and will enable us to establish which characteristics—be they tested or not tested by the FGIS—provide useful information to the processor.[1]

In general, the size of coefficients and their statistical significance will determine whether a characteristic provides important information. Two cases in which statistical significance plays a particularly important role warrant consideration. One scenario is that the marginal revenue product for an attribute is high (i.e., the attribute creates substantial value in the wet-milling process), but the presence of this attribute varies little across shipments. Information about the presence of this characteristic on a shipment-to-shipment basis would therefore be of limited value to the firm, despite the characteristic itself being quite important. In a regression context, this scenario would give rise to a γ_j coefficient that is substantially different from zero, but not so statistically, since the standard error of an estimator is inversely related to regressor variance.

In another important scenario, several measured characteristics are highly correlated with each other, in which case the processor might only need information on one of them. Inclusion of the others in a regression model would result in statistically insignificant individual coefficients, although a joint hypothesis that the coefficients are simultaneously equal to zero would be rejected. Use of pairwise correlation analysis for selection of variables to include on the right side of Equations (1) and (2) will help in avoiding this type of problem.

Data

A firm having a one-sixth share of the Japanese wet-milling market and wanting to re-

[1] Although the intercept coefficient γ_0 is not part of the theoretical model, its inclusion here is based on standard econometric practice.

Table 1. Comparison of Quality Information Collected at Origin and Destination

Characteristics Routinely Tested by FGIS at U.S. Port of Origin	Characteristics Routinely Tested By Processor at Destination
Broken corn and foreign material* (%)	Broken kernels (%)
Moisture (%)	Foreign material (%)
Total damaged kernels* (%)	Moisture (%)
Test weight* (lbs./bu.)	Spoiled (%)
Insects (no. of sublots infected and no. per sublot)	Test weight (lbs./bu.)
Heat-damaged kernels* (%)	Insects (%)
	Stress cracks (%)
	Starch (%)
	Protein (%)
	Oil (%)
	Ash (%)
	Coarse fiber (%)
	Germination (%)
	4.76-mm-pass (%)
	Kernel weight (g/1,000 kernels)
	Other grain (%)
	Dust (%)
	Whole kernels (%)
	Pentosan (%)
	Viscosity torque (kg/m)

Note: Characteristics with an asterisk are U.S. grade determining.

main anonymous provided records on 253 individual corn cargoes received at its plant between July 1990 and August 1996. The cooperating firm provided shipment-specific information on its own yield predictions for four processed products (starch, gluten feed, gluten meal, and germ), as well as the results of 20 different quality tests it conducted and used as a basis for making those predictions.[2] In addition, the firm provided information on the monthly price at which it sold its four products to other firms within Japan. These data are used to estimate Models 1 and 2 [Equations (1) and (2)] of the previous section.

[2] The process of making the predictions was not shared with us, hence the need for Equation (1). Although it might seem preferable to work with actual yields, the firm does not calculate this for individual shipments. Instead, it predicts product yields for individual shipments that arrive and then combines several shipments in a way to reduce variation in the quality and quantity of output. Actual yields are calculated for this blend only. Because we are trying to model the firm's behavior (in particular, derive a willingness to pay for certain characteristics), and the firm itself knows only the predicted yield of a given shipment, it follows that we in turn should use the predictions.

Measurements on Quality, Yield, and Value

Table 1 compares the degree and type of quality information collected on a given shipment of corn at different points in the marketing channel. The left column shows that the FGIS carries out a limited number of quality tests at the origin port, some of which are used to determine grade. These include the composite category broken corn and foreign material (BCFM), test weight (TW), total damaged kernels (DKT), and heat-damaged kernels (HD). The right column of Table 1 lists 20 quality tests carried out by the processor for each of 253 shipments imported over the sample period. This information is based on samples taken from the vessel on arrival, prior to unloading, and is used by the firm to predict yields of the four products derived from the wet-milling process. At this point, the firm would likely have no legal recourse if the quality of corn is unexpectedly low in some dimension, since most contracts identify the FGIS origin grade as final in any dispute. However, these measurements are useful for

Table 2. Descriptive Statistics

Variable	Mean	Median	SD	Minimum	Maximum
End use value (¥/kg)	40.80	40.86	1.20	36.83	44.51
Starch yield (%)	69.06	69.11	2.35	61.55	75.02
Gluten meal yield (%)	4.83	4.84	0.66	2.77	7.40
Gluten feed yield (%)	15.02	14.99	2.03	10.08	21.55
Corn germ yield (%)	6.86	6.78	0.57	5.30	9.66
Broken kernels (%)	11.53	11.40	2.46	0.60	22.50
Foreign material (%)	0.13	0.10	0.25	0.00	3.70
Moisture (%)	14.44	14.60	0.91	11.10	16.50
Spoiled (%)	1.97	1.70	1.24	0.20	7.50
Test weight (lbs./bu.)	55.05	55.20	1.91	38.20	59.50
Insects (%)	0.44	0.00	0.80	0.00	3.60
Stress cracks (%)	39.70	41.00	16.13	3.30	75.00
Starch (%)	73.72	73.68	2.09	65.94	80.11
Protein (%)	8.38	8.43	0.60	7.27	10.62
Oil (%)	4.38	4.33	0.31	3.67	6.34
Ash (%)	1.13	1.15	0.19	0.68	1.53
Fiber (%)	1.74	1.78	0.19	0.97	2.13
Germination (%)	53.05	53.00	22.63	3.00	98.00
4.76-mm-pass (%)	3.98	3.80	1.73	0.40	10.60
Kernel weight (g/1,000 kernels)	314.01	311.30	26.90	245.00	375.30
Other grain (%)	0.15	0.10	0.18	0.00	1.40

Note: End use value is calculated using the average price of each product over the sample period.

blending the shipments to minimize quality variation in the wet-milling process.

For the 253 observations, Table 2 presents the mean, median, standard deviation, and extreme values associated with end use value, product yields, and quality. Pairwise correlations are presented in Table 3. In Table 2, many of the quality attributes vary substantially across the shipments. Foreign material, for example, has a mean of 0.13%, but a standard deviation of 0.25 and takes on values as high as 3.70%. Other variables have broader ranges. Starch content takes on values from 65.94% to 80.11%, whereas stress cracks range from 3.30% to 75.00%. The greatest variation is exhibited by germination, with a low of 3.00% and a high of 98.00%.

These differences in quality across shipments matter a great deal for the processor, as end use value ranges from ¥36.83 to ¥44.51/kg for the 253 shipments (Table 1).[3] In terms of a 50,000-metric-ton vessel, total end use value ranges from U.S.$16.01 to U.S.$19.35 million, based solely on differences in quality.[4] The high variation in quality across shipments and consequent large variation in end use value suggests that transmission of information concerning quality has a critical role to play in the export market for U.S. corn.

Interpretation of Quality Variables

In this section we provide a brief description of each of the 20 factors measured by the processor and indicate the expected effect on end use value. This information is derived from

[3] End use value is the sum of processed values of the four products, in which price (¥/kg) is multiplied by yield (%, corresponding to kg product/kg corn). Average prices over the sample period are used to avoid any biases related to time. These were 52.52, 41.40, 5.42, and 25.06, respectively, for output of starch, gluten meal, gluten feed, and germ (¥/kg, f.o.b. the processor's plant). In this analysis, quality differences are the sole reason that shipments have different processed values.

[4] This is calculated using the average 1990–1996 exchange rate of ¥115.04/U.S.$ and because 1 metric ton is 1,000 kg.

Table 3. Pairwise Correlations

	End Use Value	Starch Yield	Meal Yield	Feed Yield	Germ Yield	Broken Kernels	Foreign Material	Mois- ture	Spoiled
Starch yield	0.97	1							
Meal yield	0.17	−0.04	1						
Feed yield	−0.68	−0.74	−0.01	1					
Germ yield	0.22	0.12	−0.08	−0.07	1				
Broken kernels	−0.25	−0.25	0.11	0.00	−0.15	1			
Foreign material	−0.10	−0.06	−0.08	−0.14	−0.08	0.09	1		
Moisture	0.04	0.12	−0.32	−0.13	0.04	−0.07	−0.12	1	
Spoiled	0.13	0.17	−0.07	−0.24	−0.07	0.05	0.10	0.03	1
Test weight	−0.05	−0.08	−0.04	0.17	0.22	−0.02	−0.13	−0.05	−0.22
Insects	0.03	−0.04	0.21	0.10	0.17	0.07	−0.06	−0.21	0.22
Stress cracks	−0.17	−0.09	−0.19	−0.06	−0.31	0.03	0.10	0.16	−0.04
Starch	0.61	0.75	−0.29	−0.84	−0.18	−0.07	0.12	0.27	0.28
Protein	0.02	−0.14	0.56	0.19	0.19	0.23	−0.07	−0.37	−0.05
Oil	0.13	0.06	−0.14	−0.09	0.92	−0.11	−0.02	0.07	−0.13
Ash	−0.01	−0.06	−0.05	0.19	0.40	0.15	−0.04	−0.26	0.00
Fiber	0.07	0.19	−0.41	−0.11	−0.15	−0.12	−0.03	0.43	0.00
Germination	0.04	−0.03	0.15	0.13	0.21	0.17	−0.04	0.03	−0.22
4.76-mm-pass	−0.58	−0.46	−0.20	−0.12	−0.39	0.36	0.25	0.07	0.08
Kernel weight	−0.08	−0.06	−0.19	0.17	0.11	−0.24	−0.05	0.23	−0.28
Other grain	0.13	0.14	−0.03	−0.09	0.00	−0.01	0.08	−0.10	0.05

pends on what comprises the other grains. Soybeans (the most common) can be valuable for its higher overall oil content, but wheat can be beneficial for its higher yield of starch.

The last four characteristics listed in the right column of Table 1 are not used in our analysis, because they either have a very high correlation with another, similarly defined variable, or because they are not normally used for predicting wet-milling yields. Dust and whole kernels are not included in further analysis because they have correlations of 0.98 and −0.79 with 4.76-mm-pass and broken kernels, respectively. Pentosan (a type of carbohydrate) and viscosity torque (a measure of starch quality) do not normally affect processed product recovery and end use value, and are also excluded from further analysis.

Empirical Procedures and Results

In this section, we describe the procedures and results of estimating the models of Equations (1) and (2) developed earlier. Recall that Equation (1) is essentially a production function, relating the firm's predicted output of each product to the quality attributes embodied by a shipment of corn. Equation (2) provides a means of estimating the marginal revenue products, or implicit values, associated with the attributes, using the total processed value of that shipment.

The Production Function

A version of Equation (1) was estimated for each of the four products arising from the wet-milling process: starch, gluten meal, gluten feed, and germ. Using ordinary least squares, the adjusted R^2 was quite strong for all four regressions, at .860, .733, .847, and .925, respectively (Table 4). The small amount of variation left unexplained by each regression appeared to have no systematic pattern in plots of residuals, and Durbin-Watson tests rejected a hypothesis of autocorrelation.

We first examine the regression concerning starch yield (Table 4). Starting with the upper left-hand entry of the table, we see that a one percentage point increase in broken kernels is predicted to lower starch yield by 0.018 percentage points. Because the associated stan-

Eckhoff (personal communication); Hill et al. (1990, 1993); and Weller, Paulsen, and Steinberg. The first characteristic in Table 1 is broken kernels. These reduce the yield of starch because they leak starch into the steep water and can clog the screens in the steep tanks (necessitating cleaning and reducing milling capacity). The second factor, foreign material, defined as all material other than corn, usually must be cleaned out and disposed of or sold at a reduced price before steeping (the first part of the wet-milling process). Foreign material reduces the quantity of starch per ton of purchased grain, and in the case of weed seeds can be deleterious to livestock when used for animal feed (the products gluten feed and meal are used for this purpose).[5] The effect of moisture on product yields works both ways, and its sign is indeterminate a priori. Higher moisture decreases the yield of products per ton of corn purchased, but lower moisture can increase broken kernels and dust as a result of greater breakage during handling. Spoiled kernels are generally related to mold damage and unambiguously reduce the quantity and quality of end products. Test weight is a measure of bulk density but in actuality is influenced by many factors other than the true density of corn. Test weight does not affect the intrinsic properties of kernels, unless caused by other measurable attributes such as high drying temperatures, mold damage, and high moisture. As a result, nearly all surveys have shown that foreign buyers rank test weight at the bottom of the list of important attributes affecting end use value (Hill et al. 1990). It is expected to insignificantly affect the yield of processed products but, if significant, should be positive. Insects, whether living or dead, reduce the yield of processed products. Fumigation of cargo at origin eliminates most live insects, but others can emerge during extended voyages.

In contrast to the quality factors described above, the ones below are not part of U.S. grades, not automatically tested by the FGIS at the export port, or both (Table 1). Stress cracks are internal splits within kernels, and indicate that the corn underwent severe drying conditions. High temperatures gelatinize the starch within the kernel, which inhibits separation and recovery. Stress cracks also can result in more broken kernels during handling. They have a negative effect on value. Starch content has a strong positive correlation with the yield of starch, and can be efficiently measured by properly calibrated near-infrared transmittance (NIRT) technology available in FGIS laboratories in all export facilities. Likewise, protein content is also measurable by NIRT technology and increases the value of animal feed by-products, including gluten meal and feed. It is negatively correlated with starch, however (Table 3). Oil content can also be measured by NIRT technology; it has a higher value than starch and could have a positive coefficient, even though it too is negatively correlated with starch content. Ash content is not readily measurable by NIRT, and has little value for starch, although it might be a good predictor of other products. Fiber is sometimes calculated as a residual after measuring starch, oil, and protein and would likely have a net negative relationship with value. It has little direct value in feed by-products and could result in the feed exceeding the maximum limit on fiber allowed in poultry feed, for example. Germination rate is not readily measured during loading of the vessel but is an indicator of good starch yield since corn with high germination has not been damaged by high drying temperatures. The characteristic 4.76-mm-pass refers to the percentage of material that passes through a sieve of this size. This material generally has a detrimental effect on value because it leaches starch into the steep water and can clog the screens in steeping tanks. Kernel weight is measured as the weight of 1,000 kernels and is an indication of kernel size. The coefficient signs are unknown a priori since it could require longer steeping times and be harder to process, but on the other hand, larger kernels tend to give more starch and less pericarp (fiber) per kernel. Finally, the net effect of other grain de-

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[5] The firm does not aggregate broken corn and foreign material into the aggregate category used by the USDA, instead preferring to maintain a distinction between those factors (Table 1).

Table 3. Extended

Test Weight	Insects	Stress Cracks	Starch	Protein	Oil	Ash	Fiber	Germination	4.76-mm-pass	Kernel Weight
1										
−0.04	1									
−0.24	−0.60	1								
−0.22	−0.16	0.17	1							
0.12	0.43	−0.37	−0.38	1						
0.24	0.04	−0.26	−0.15	0.15	1					
0.18	0.38	−0.36	−0.28	0.74	0.33	1				
0.08	−0.26	0.16	0.37	−0.32	0.04	−0.27	1			
0.32	0.31	−0.46	−0.22	0.38	0.26	0.33	0.05	1		
−0.13	−0.21	0.34	0.09	−0.25	−0.24	−0.23	0.01	−0.21	1	
0.37	−0.40	0.16	−0.11	−0.39	0.17	−0.34	0.32	−0.04	−0.10	1
−0.05	0.13	−0.08	0.06	0.04	0.04	0.06	−0.02	0.05	−0.02	−0.10

dard error estimate for this factor is relatively large (0.026), the coefficient does not statistically differ from zero, and we conclude that it transmits little information about starch yield.

Those characteristics which do have statistical significance are highlighted by one, two, or three asterisks, which indicate significance at the .10, .05, and .01 levels, respectively (Table 4). In the starch regression, we see that the coefficients for insects, starch, fiber, 4.76-mm-pass, and other grain are all statistically different from zero at a .01 level of significance; thus, they can be considered as the most robust indicators of starch yield. Other significant indicators of yield include foreign material and stress cracks (at the .05 level) and germination (at the .10 level). The signs and size of nearly every coefficient is consistent with our a priori expectation described in the previous section. We see, for instance, that a one percentage point increase in starch content allows for greater starch yield by 0.952 percentage points, a nearly one-to-one relationship. Foreign material, however, lowers starch yield by 0.554 percentage points for every one percentage point increase since it is normally removed prior to the wet-milling process. Only in the case of ash, which is negatively correlated with starch content and yield, does the sign of the coefficient conflict with prior expectations. We do not consider this to be a problem, however, because this coefficient is not statistically significant—the standard error is four times larger than the coefficient.

The regressions for the three other products are similarly strong, with high adjusted R^2 values and coefficient signs and significance nearly always consistent with our earlier discussion. Because these products are not as important as starch, however, the results are discussed only briefly here.[6] For gluten meal, the most critical attributes in terms of statistical significance and coefficient size are protein, ash, fiber, and 4.76-mm-pass (Table 4). The level of starch content, for example, makes little difference once protein content has been accounted for, and the presence of ash is quite

[6] Gluten meal, gluten feed, and germ contribute 5%, 2%, and 4% to end use value, compared to a starch contribution of 89%. This is based on average prices and product yields.

Table 4. Regression Results

	Equation (1)				Equation (2)
Dependent Variable	Starch Yield	Gluten Meal Yield	Gluten Feed Yield	Corn Germ Yield	Total End Use Value
Broken kernels	−0.018	0.008	0.003	0.001	−0.555
	(0.026)	(0.011)	(0.024)	(0.005)	(1.447)
Foreign material	−0.554**	0.009	0.267	−0.012	−27.566**
	(0.241)	(0.101)	(0.221)	(0.043)	(13.390)
Moisture	−0.048	−0.014	0.060	0.052***	−1.479
	(0.074)	(0.031)	(0.068)	(0.013)	(4.113)
Spoiled	0.057	0.011	−0.043	0.013	3.525
	(0.052)	(0.022)	(0.047)	(0.009)	(2.865)
Test weight	0.023	0.014	−0.022	0.010	1.925
	(0.035)	(0.015)	(0.032)	(0.006)	(1.946)
Insects	−0.481***	−0.035	0.190**	0.073***	−23.864***
	(0.100)	(0.042)	(0.092)	(0.018)	(5.560)
Stress cracks	−0.011**	−0.001	0.002	0.002*	−0.551**
	(0.005)	(0.002)	(0.005)	(0.001)	(0.278)
Starch	0.952***	0.004	−1.002***	0.004	44.837***
	(0.034)	(0.014)	(0.031)	(0.006)	(1.899)
Protein	0.109	1.225***	−0.998***	−0.113***	48.208***
	(0.163)	(0.068)	(0.149)	(0.029)	(9.047)
Oil	0.260	0.023	−2.004***	1.590***	43.603***
	(0.208)	(0.087)	(0.191)	(0.037)	(11.540)
Ash	0.124	−3.720***	2.870***	0.338***	−123.470***
	(0.477)	(0.199)	(0.437)	(0.085)	(26.490)
Fiber	−1.472***	−1.200***	2.831***	−0.637***	−127.590***
	(0.361)	(0.151)	(0.331)	(0.064)	(20.050)
Germination	0.006*	0.001	−0.004	−0.001**	0.293
	(0.003)	(0.001)	(0.003)	(0.001)	(0.183)
4.76-mm-pass	−0.672***	−0.074***	−0.175***	−0.063***	−40.892***
	(0.40)	(0.017)	(0.037)	(0.007)	(2.243)
Kernel weight	−0.001	−0.002*	−0.001	0.000	−0.140
	(0.003)	(0.001)	(0.003)	(0.001)	(0.168)
Other grain	1.122***	−0.054	−0.285	−0.126**	52.024***
	(0.310)	(0.129)	(0.284)	(0.055)	(17.210)
Intercept	1.934	0.770	99.193***	0.199	676.060***
	(3.885)	(1.623)	(3.562)	(0.691)	(215.800)
Adjusted R^2	0.860	0.733	0.847	0.925	0.836

Notes: Entries with one, two, and three asterisks are statistically different from zero in a two-sided test at the 0.10, 0.05, and 0.01 level, respectively. Standard errors are in parentheses.

detrimental with respect to yield in this case. For the product gluten feed, levels of insects, starch, protein, oil, ash, fiber, and 4.76-mm-pass are all critical, with starch having a strongly negative effect on output. In the case of corn germ, 10 out of the 16 quality attributes substantially affect yield, with oil content appearing to play the biggest role in this case. Because oil content is negatively correlated with starch (Table 3), this result was expected.

Significantly, nearly every characteristic found to be of importance is not a criterion for U.S. grades. The only exception is foreign material (part of the composite U.S. grade factor BCFM), which plays an important role for estimating starch yield. A question that arises is: can the other two factors that directly underlie

U.S. grades (broken kernels and test weight) provide critical information, but simply not vary from shipment to shipment, or be correlated with another variable? Neither possibility appears to be viable given the statistics in Tables 2 and 3. The former table indicates that broken kernels and test weight range from 0.6 to 22.5% and 38.2 to 59.5%, respectively, suggesting substantial variation. Table 3 indicates that the insignificance is likely not caused by multicollinearity either because the highest pairwise correlation is 0.36 and 0.37, respectively.

Note that several of the characteristics have conflicting effects on the yields of different products. Fiber, for example, has a clearly negative effect on starch, gluten meal, and germ yields, but it has a strong positive association with gluten feed. That this and other characteristics have mixed effects—that is, they increase the yield of some products while decreasing the yield of others—underscores the need to examine total processed value in identifying those characteristics that transmit critical information. Equation (2), which is estimated below, evaluates the joint product nature of the relationships.

Marginal Revenue Products of Quality Attributes

Equation (2) involves regression on the same grade and nongrade characteristics used for Equation (1). In this case, the dependent variable is processed value, constructed as the sum of the yield of the four processed products weighted by their average selling price. In a perfectly competitive environment, the estimates of marginal revenue product generated here can be interpreted as the amount that the firm should be willing to pay to get either more or less of a characteristic. To the authors' knowledge, this is the first statistical evidence as to which dimensions of quality beyond those tested at the U.S. port are economically important.

On regressing Equation (2) by ordinary least squares and the 253 observations, inspection of residuals and diagnostic tests revealed no evidence of heteroscedasticity or autocorrelation, the latter of which was verified statistically through a Durbin-Watson test. The results suggest that end use value is closely linked to quality attributes because the adjusted R^2 for the regression was .836, and 10 of the 16 estimated quality coefficients are statistically different from zero at the .05 level or better (Table 4). The basic results were found to be invariant across different functional forms, including linear, log-log, and log-linear specifications.

The sign of every quality coefficient is as anticipated in our earlier discussion, with the exception of spoiled kernels, although this is not troublesome because, statistically, this coefficient is not different from zero. Among the characteristics that communicate much information about the processed value of corn (i.e., are statistically different from zero), foreign material, insects, stress cracks, ash, fiber, and 4.76-mm-pass have negative marginal revenue products. The other particularly important attributes—starch, protein, oil, and other grain—all have a positive relationship with end use value. Foreign material is the only characteristic among these to underlie USDA grades. However, its ability to transmit information is limited because it is combined into the composite category BCFM along with the insignificant attribute broken corn. Insects is the only important nongrade factor explicitly tested by the FGIS in all exported shipments.

A slight change in level of one of the quality characteristics can make a very big difference with respect to value. For instance, a one percentage point reduction in foreign material increases overall revenue by ¥27.566/kg (Table 4). A one percentage point increase in starch raises the processed value by ¥44.837/kg. On a 50,000–metric ton shipment, these results suggest very large revenue differences of U.S.$11.98 million and U.S.$19.49 million, respectively.[7]

Most of the informationally valuable characteristics for the processor, including starch, protein, oil, ash, and fiber, are related to the intrinsic properties of corn, which is consistent

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[7] Calculated using average 1990–1996 exchange rate of ¥115.04/U.S.$.

with Eckhoff (personal communication) and Mercier, as well as Hill et al. (1990). The finding that stress cracks (caused for the most part by hot air drying) and foreign material (normally cleaned out before steeping) provide important information about value is also highly consistent with earlier survey results. That the coefficient for other grain is positive and significant suggests that outside grains such as soybeans (with their added oil) or wheat (with added starch) actually improve the ultimate value of the corn.

In comparing the results for Equations (1) and (2), total processed value is clearly influenced mostly by the results for the starch regression because starch has both the highest yield and price. However, a number of the coefficients in the end use value regression are also influenced by the other products in an important way. Hence, the results of Equation (2) should be of ultimate interest to the firm, and consequently to this analysis.

Implications

We have demonstrated that if levels of foreign material, insects, stress cracks, starch, protein, oil, ash, fiber, 4.76-mm-pass, and other grain are known, a processor can make a strong assessment of end use (i.e., final processed) value. However, only one of these factors, foreign material, can be specified at the time of negotiation through U.S. grade. Even control over this is limited because it is combined into a composite category along with broken kernels.

Can foreign buyers control for characteristics not included in U.S. grades? The ability to do this without use of an identity-preserved market channel is quite limited. In Japan, processor purchases are nearly always made through one or more trading companies, who in turn purchase from international grain companies (Caplan, p. 9). The U.S. export elevators of these firms receive corn from many origins. The grade of corn received is usually No. 1 or 2, and the export grade is usually No. 2 or 3. At the time of loading, the cargo is blended to meet or exceed the minimum quality specified by the grade. Nongrade factors can vary widely, depending on the origin, crop year, handling, and storage history. As such, it is difficult for a processor to purchase U.S. corn on the basis of attributes that are directly correlated with end use value.

Although the level of insects is automatically tested at the origin port without charge and levels of stress cracks, starch, protein, and oil can be tested by the FGIS on request, measurement at this stage does not allow for selection on the basis of a particular attribute, since buyers find out its level only after a vessel is loaded.[8] Furthermore, as long as they are not part of U.S. grades (and identity preservation is not used), derived demand for these attributes will not be transmitted back to the originating elevator and farm. Local elevators that receive grain directly from producers typically only measure those characteristics that are grade-determining. The incentive for farmers, therefore, is to only be concerned about the attributes that underlie grades, even if they are not of importance to the end user.

One way that some importers have circumvented these problems is through use of identity-preserved market channels, which can entail direct contact between producer and processor. In this case, the grain can be segregated at the originating farm by way of containerization and never enter into standard U.S. market channels. Vachal and Reichert report that about 1% of U.S. grain is currently marketed by this method and that container use and other forms of identity preservation is likely to increase.

At the same time, it seems unlikely that all but a small share of the market will ultimately be able to justify this method. Given the current U.S. grain-handling system—rather efficient by world standards—the relatively much higher cost of contracting and identity preservation makes it impractical for a vast majority of corn importers. The fact that 1% of the grain market has so far opted for containerization does not imply that most importers

[8] The FGIS introduced optional testing of starch, protein, and oil content since the first version of this paper was completed, in part because of an earlier presentation of findings from this research.

are not concerned about quality and would not like more information and control over factors not in current U.S. grades. The costs of identity preservation might simply be too large. There are likely many below this extreme (such as the processor supplying data for this paper) who would benefit from being able to send clearer signals about which attributes are desired, and being able to select on the basis of those attributes. Furthermore, most of the characteristics found important in this study can be included in grades without adding undue burden to the system. For example, measurement of three particularly important characteristics—starch, oil, and protein—has become quick and inexpensive because NIRT technology is used by the FGIS at U.S. export ports.

Summary and Conclusions

This study has sought to determine what quality attributes best transmit information about the end use value of corn, using detailed data from a Japanese wet miller. Although the Japanese wet-milling market is not representative of all corn importers, it is a prominent and growing market for U.S. corn. Moreover, the sensitivity to quality exhibited by wet millers is suggestive of where the international corn market appears to be headed in general. The use of shipment-specific processed value and quality characteristics—including and in addition to those normally tested by the FGIS—allows for statistical analysis of which characteristics might be usefully incorporated into U.S. grades, as well as which provide little information about value.

The significant factors in determining end use value are foreign material, insects, stress cracks, starch, protein, oil, ash, fiber, 4.76-mm-pass, and other grain. The current U.S. practice of combining broken corn and foreign material into one composite category (BCFM) is not supported by the results of this study because broken corn does not provide valuable information about yield for any of the four processed products and was not found to be a good indicator of value. This is consistent with earlier findings by Hill et al. (1990) and mirrors the frequent suggestion that BCFM be separated into subcategories.[9] Because test weight is a grade-determining characteristic but not significant in the models related to yield and value, it would seem that a less important measure has been substituted for more important ones in the historical organization of grades for the U.S. grain-handling system.

Of the characteristics found to be important, only foreign material is represented in U.S. grades but (as indicated above) is combined with an insignificant attribute. The level of insects is measured and reported at no extra charge on the origin certificate but is not grade-determining. Information on stress cracks, starch, protein, and oil is available on request for a fee since they have been classified as "official criteria." However, measurement after a vessel has been loaded precludes selection on the basis of a particular attribute. Moreover, as long as an attribute is not included in grades, the derived demand for it is not transmitted back to the originating elevator and farm because local elevators typically only test those attributes that are grade determining.

The increased use of identity-preserved market channels has partly been in response to the inadequacies of current U.S. grades for transmitting adequate information about the evolving quality needs of foreign buyers. Identity preservation, however, is a particularly expensive option given the structure of the U.S. grain-handling system. As a result, grades will remain the primary means of transmitting information about quality and end use value between the vast majority of foreign buyers and domestic handlers and producers. The findings of this study strengthen the position of industry observers who recommend that easily measured intrinsic characteristics such as starch, protein, and oil be incorporated into U.S. corn grades.

[Received April 2002; Accepted August 2002.]

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[9] Separation of BCFM into two or more subcategories has been partially adopted for grain sorghum and has long been in place for wheat and barley grades.

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