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# Comparing End-Use Values for North Dakota Hard Red Spring Wheat Varieties

David K. Lambert
William W. Wilson

Department of Agribusiness and Applied Economics
Agricultural Experiment Station
North Dakota State University
Fargo, ND 58105-5636

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# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# Abstract

Markets for agricultural products may be inefficient when signals do not adequately reflect product characteristics important to market participants. Although preferences can be explicitly stated through price premiums or characteristic values can be determined via hedonic methods, the problem is compounded when product quality information is costly to obtain. Bundling of quality traits by variety can serve to signal product quality. A procedure is developed in this paper to derive the value of different varieties in meeting buyer demands. An application to the hard red spring market wheat both validates the ability of the procedure to distinguish among varieties, as well as provides empirical support to the existence of Akerlof's lemon market in the release of wheat varieties.

***JEL Codes:*** L66, Q13

***Keywords:*** Agricultural markets, product quality, distance functions, wheat

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**David K. Lambert and William W. Wilson***

## INTRODUCTION

As markets mature there is a strong tendency for fragmentation and the emergence of market segments defined by specific quality characteristics. With increased segmentation buyers may increasingly demand products meeting specific quality standards. In order for successful transmission of buyer demands to upstream suppliers, appropriate signals must be present to both relay buyer demands as well as reward sellers providing products that satisfy these demands.

For some agricultural products, quality characteristics are measurable and efficiently priced (Buccola and Iizuka; Schroeder et al.). However, the traits demanded by end-users are often not discernable at the point of sale. Barkema and Cook have suggested that traditional market-pricing mechanisms have become too “fuzzy” to transmit buyer demands to agricultural suppliers when product quality is uncertain. Examples of these “fuzzy” markets include registered bulls (Chvosta et al.), hard red spring wheat (Wilson and Gallagher), and markets for fruit quality based on grade (Chalfant et al.). Some product characteristics may be observable and thus potentially serve to distinguish product by quality. However, these observable traits may only imperfectly indicate the set of quality characteristics important to the buyer. For example, wheat protein level and test weight are two characteristics of hard red spring wheat that are observable at the point of sale. Markets distinguish wheat based on these two characteristics. However, protein and test weight are not perfect indicators of the wheat properties affecting the quality of the resulting flour in producing baked products for final demand. End-use characteristics such as absorption and mixing tolerance are of primary interest to the miller and baker purchasing the wheat. Due to the high measurement costs of determining these end-use traits, markets do not exist for the traits of primary importance to the processor.

Forces driving market segmentation will only intensify the development of specific quality based markets. Consumers are increasingly demanding processed foods due to high opportunity costs associated with home food preparation. Industry has adapted by providing retail products embodying more processing. In addition, income effects and demographic changes lead to further food market segmentation through demands for specific food products, such as low calorie and ethnic foods. Hennessy notes both of these consumer trends lead to market segmentation, and derives conditions under which vertical integration is adopted in industries such as pork and poultry to reduce input quality uncertainty.

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* Authors are Professor and Chair, and Professor, respectively, in the Department of Agribusiness and Applied Economics at North Dakota State University, Fargo, North Dakota.

When quality is variable, testing costs are high, and segmented markets exist, vertical integration may itself be costly for the agricultural buyer facing thousands of potential suppliers. Contracting for quality may meet buyer needs, but high testing costs and quality variability may still bear high transaction costs. Costs may be reduced if additional quality signals can be identified. For example, quality variability may be reduced if contract specifications include not only quality standards, but suggest specific plant varieties or animal breeds known to produce quality distributions consistent with processor requirements. Specific varieties or breeds may bundle quality characteristics in packages more consistent with buyer needs. The problem remains of determining the value of these alternative varieties to the processor to determine if contracting for variety improves upon open market purchases based on traditional market signals.

Producer adoption of varieties with improved production characteristics is rational when markets for end-user traits are imperfect. The high cost of obtaining product quality information parallels the asymmetrical information problem discussed in Akerlof. Markets price protein and test weight, among other observable wheat characteristics, instead of the end-use traits important to processors. Suppliers (i.e., farmers) will therefore adopt varieties and production practices that maximize net returns to the traits that command a price premium. To the extent that per acre yield positively contributes to protein and test weight, farmers will select varieties having high yields, test weights, and protein instead of varieties of higher utility to processors. In contrast to farmer incentives based on yields, test weights, and protein, end-users desire wheat having desirable processing characteristics. If grain markets do not provide incentives based on end-user needs to upstream suppliers, wheat markets may follow Akerlof's market for lemons. Imperfect information markets underlie Barkley and Porter's findings of farmers adopting varieties having less desirable characteristics for downstream processors.

The objective of this research is to address the value of different varieties of hard red spring wheat for meeting end-user demands. Field and lab data strongly support the existence of quality differences among wheat varieties. Our research measures the economic value of wheat varieties in terms of meeting processor, rather than producer, needs. We find statistically significant differences among commercially grown HRS wheat grown in North Dakota in meeting several characteristics identified by end-users to be important quality indicators in food processing. A final application of the model suggests that designing a wheat variety to specifically meet processor needs can increase the attractiveness of the variety for processors and potentially lead to gains for both producers and processors entering into contracts specifying delivery of such varieties.

## Elements of the Wheat Problem

In the wheat sector, demand for new or existing products is growing for items such as tortillas, wraps, frozen-dough and par-baked products, variety breads, hamburger buns, and bagels. Further segmentation is creating markets for non-food uses and animal feed. With advances in breeding technology it has become increasingly possible to breed for specific end-use requirements for the different market segments. Future breeding objectives may differ from traditional varietal development strategies that have generally sought to meet the end-use requirements of the broader market. There is precedence for breeding for specific end-uses, led by the corn and oilseed sectors. Recent attention is being focused on similar strategies in the wheat foods sector. Wheat breeding programs are evolving to meet specific end-use requirements. These efforts include initiatives in Kansas and other states to develop white wheat, marketing strategies in Canada are focusing on specific varieties for specific end-uses, and several significant alliances are forming to focus wheat breeding initiatives to meet specific markets.

Interestingly, recent research has suggested that farmers may be adopting varieties with less desirable end-user characteristics. Barkley and Porter motivated their study in Kansas by concerns that growers were not responding to end-use quality in variety adoption decisions. A more recent study compared variety adoption in the United States. and Canada (Dahl et al.). The variety adoption research found average variety life cycles of 5-7 years in the United States, versus longer life cycles of 15 years in Canada. Growers in the United States responded to economic incentives (primarily deficiency payments encouraging higher yielding varieties), agronomic traits (e.g., yields, leaf rust susceptibility, and maturity), quality characteristics (e.g. protein and test weight), and exhibited a greater tendency to adopt publicly released varieties. However, the distribution of variety characteristics important to downstream users may either be unaffected or negatively affected by a new release. Production characteristics may improve, but the economic value of the product for food processing may fall.

Variety development and farmer variety choices may adversely impact U.S. competitiveness in international wheat markets. Over the past decade there has been heightened interest in the role of grain quality in international competition (U.S. Congress OTA, 1989a, 1989b). End-use performance is becoming increasingly important in quality rating of wheat in international markets. Foreign and domestic buyers have raised concerns about the inconsistent quality and the apparent deterioration over time in end-use performance of U.S. grain shipments compared to competitor countries. These problems are particularly acute in U.S. hard wheat (which normally commands a price premium) because of the intensity of international competition in these classes.

Studies in other countries have highlighted the quality problem. The Grain Research and Development Corporation of Australia (Booz and Allen) concluded that Canada and Australia were recognized as "quality" suppliers, and the United States as a "price" supplier. The significance of the problem is also recognized in the United States domestic industry. A study conducted for the Minnesota Association of Wheat Growers and Minnesota Wheat Research and Promotion Council indicated that domestic end-users have reduced their use of HRS wheat over the years, in part because of changes in end-use performance. Domestic millers of HRS indicated a noticeable reduction in gluten strength. A survey conducted by U.S. Wheat Associates indicated there has been a drop in protein quality over the last five years and that CWRS has better quality than DNS. The Canadian marketing system has always been highly regulated on issues related to quality, in contrast to that in the United States. Kraft et al. suggested that Canadian wheat earns quality premiums relative to U.S. wheat. In a related study, Stevens and Rowan interviewed importers and cited that “Buyers rated consistency of quality from shipment to shipment as the most important factor in their decision to import grains (p. iv).”

There is no doubt that the intensity of international competition has an impact on variety development strategies. During the past decade each of the major wheat exporting countries has confronted this problem. Australia has been struggling with declining protein levels (Frazier, Peterson). France has induced a radical shift from soft to medium hard wheat. Canada has increased segregation. The strategy in the United States[1] has generally increased the number of varieties being released within existing classes with some shift toward hard white wheats. In all cases, quality problems have been dealt with through variety development strategies. One of the fundamental differences between competitor countries, notably Canada, France and Australia, and the United States are, in the former, regulations govern varietal development and release. In the United States, market signals determine the success of newly released varieties.

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[1] Between 1974 and 1996, 70 varieties of HRS were adopted in the U.S. versus 30 varieties being adopted in Canada (Dahl and Wilson). Far more varieties are grown within each production region in the U.S. than in comparable producing regions in Canada.

Variety development and release decisions are made in an environment with many uncertainties and lengthy time lags, making it difficult to respond to short-term changes in market conditions. The process of varietal release is complicated, time consuming, and involves tradeoffs between conflicting objectives in terms of the attributes of the released varieties. Brennan (1988, 1993) and Brennan and Murray provide summaries of the issues with particular emphasis on the role that markets should play in variety development. Brennan highlights the importance of market incentives for growers in inducing breeders to bring about quality improvement. He identified the need for and conditions under which breeders must respond to meet the needs of "niche" markets. Since breeding varieties to serve niche markets is a long-run process, breeding is unlikely to be appropriate if the market provides only a short-term opportunity.

An important dimension of variety development is that differences in end-use performance can be attributed to intrinsic quality differences among varieties. Unlike several other countries, the United States does not have formal regulations covering variety release at the national level. Decisions involve individual breeders and their institutions and are subject to market pressures. In addition, unlike other countries, variety is not a criterion in determining wheat class within the United States.[2] Varieties are instead marketed by class, grade and specification of measurable characteristics (e.g., test weight and protein) which are imperfectly correlated with end-use characteristics (e.g., farinograph measures, loaf volume, etc.). Despite the heterogeneity in variety quality, marketing of wheat by varieties in the United States has been very limited. There is, however, a growing recognition of the importance of variety as a signal of end-use quality.[3]

Evolving industry concerns about variety development and marketing will escalate in importance with the advent of second stage benefits from transgenic breeding strategies. The ability to target end-use attributes in the case of wheat variety development through genetic modification provides numerous potential advantages (Cook et al.). However, many of these attributes may not have been heretofore measured within the marketing system. Enhanced yields of traits important to traditional end-users, such as absorption, would not be valued under the current marketing system. The addition of new product characteristics, such as those arising from nutraceutical development, pose more complex valuation problems under the existing market system based on grades and observable wheat characteristics. One solution would be to exploit bundling of traits by variety. Such a system demands the development of methodologies that can be used to determine the relative value of new and existing varieties.

The worth of a better animal or crop has traditionally been determined through application of the hedonic pricing model developed by Rosen. Application of the hedonic model to agricultural markets include Ladd and Gibson, Buccolla and Iizuka, and Melton et al. The hedonic model is premised upon a

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[2] In most other major wheat producing countries, varieties are used extensively within the marketing system. In Canada, varieties are visually distinguishable and determine classification. In Australia, farmers declare variety at first point of delivery and this information is used for binning and marketing. In France, contracts call for explicit varieties, and/or excluded varieties.

[3] For example, representatives from General Mills told audiences in the Dakotas and Montana that within 5 years "50 percent of our grain-based products will be from identity-preserved varieties." This was a company goal, suggesting IP proportions may in fact be greater. The focus is on desirable varieties and to reduce the number of varieties in purchasing (Ron Olson, VP for Procurement). The policy is designed to enhance processing efficiency with targeted varieties.

utility maximizing consumer constrained by budget who chooses her purchases based on contributions of product characteristics to utility. First-order conditions equate the marginal contributions of a vector of product attributes to market price. Empirical application allows specific marginal values for product attributes to be derived from a sample of market transactions.

Hedonic models have been used extensively for valuing individual (measurable) characteristics in wheat markets. Academic and government researchers have made extensive use of hedonic analysis for evaluating wheat quality problems. Those estimating hedonic values using regression models include Wilson (1989), Veeman (1987), Larue (1991), and Uri et al. Characteristic valuation through hedonic analysis can also be solved using optimization models.[4] In addition to hedonic models, some studies have modeled demand for wheat differentiated by quality and country of origin (e.g., Hill, Wilson (1995), Wilson and Gallagher, Wilson and Preszler).

Traditional application of the hedonic method estimates the implicit value of measurable characteristics. However, it is inappropriate when traits desired by purchasers are not observed at purchase and, therefore, not reflected in price. Incomplete information about product quality increases the transaction costs associated with market activity (Phlips, Barzel). Efforts to reduce or shift among market participants the burden of these transaction costs has led to a variety of market alternatives, such as contracting, standards, and the use of quality indices based on observable information (Chvosta et al.). For example, wheat quality depends upon flour absorption, mixing tolerance, loaf volume, and other traits associated with product quality. These end-use traits are not observed when wheat is purchased from farmers. Instead, protein and other physical traits are observed, which have traditionally served as imperfect indicators of the end-use traits. Market participants measure and do seek to differentiate among these traits. Since the relationship between traits observed and priced in the market and end-use traits is imperfect, prices themselves are imperfect indicators of the baking characteristics actually valued by downstream users.

Multiple end-use characteristics are important to the processor. Consequently, valuation procedures must be able to distinguish contributions of a set of observable inputs to a set of unobservable end-use traits. Buccola and Iizuka recently developed an econometric technique to determine the marginal cost of alternative output characteristics in milk. However, their approach focused on a market in which end-use qualities are observable, explicitly priced, and production is separable. The approach adopted here follows more closely the work of Rolf Färe and others in using distance functions to determine values in a multiple input, multiple output market. Dual approaches to derive shadow prices have been utilized by Färe and others for both market and nonmarket goods based on distance functions characteristics (Färe et al.). A similar approach is developed in this paper to derive relative costs for attaining outputs from different wheat varieties. Duality results arising from the distance function approach allow direct cost comparisons of different varieties.

## Empirical Methods

The objective of this research is to estimate the value of different varieties of HRS wheat for meeting end-user demands. The model developed to determine variety value assumes that a functional relationship exists among variety attributes observable at the time of purchase and end-use traits that are revealed during processing. Sufficient observations are presumed available from either field and

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[4] Ladd and Martin made this point and applied their analysis to corn. Ireland also strongly urged using math programming techniques for applying hedonic analysis.

laboratory analysis or from processing firm records to estimate this relationship. The estimated relationship contains information about the distribution of end-use traits conditional upon a set of traits observable at time of purchase. Since the relationship between the observable traits and the end-use traits is not perfect, field observations form the database for estimation of a distance function. Noise in the observations and differences in the relative efficiencies of different wheat varieties in yielding the set of end-use traits support the use of a stochastic frontier estimation procedure for determining the coefficients of the distance function.

The processor wants to achieve specific levels of inputs traits, $\mathbf{y} \in \Re_+^m$, based on her processing requirements. Yields of these traits are conditional upon a set of traits observable at the time of input purchase, $\mathbf{x} \in \Re_+^n$. The processor desires to obtain sufficient levels of **x** to assure that **y** is attained. Varieties can be blended if necessary to achieve **y**. The situation can be specified as the input requirement set necessary to obtain **y**, or $\mathbf{x} \in L(\mathbf{y})$. Technology is completely characterized by defining the distance function over the input requirement set:

$$D(\mathbf{x},\mathbf{y}) = \sup\{\theta : (\mathbf{x}/\theta) \in L(\mathbf{y})\} \quad [1]$$

The vector of input traits **x** can produce **y** if and only if D(**x**, **y**) $\geq$ 1. The scalar $\theta$ represents the maximal radial contraction in **x** possible to remain within the input requirement set. Additional properties of the distance function assume free disposability of the elements of **x**, the distance function is homogeneous of degree 1 in **x**, is non-increasing in **y**, and is concave in **x** (Färe and Primont). The distance function does not represent an economic problem, but rather characterizes the technological relationship between **x** and **y**. The function envelopes the set of all $\mathbf{x} \in L(\mathbf{y})$. Vectors that use "too much" **x** are included in the set, but are not considered efficient. Efficient sets are defined according to Färe and Primont as the subset of L(**y**) corresponding to :

$$\mathit{eff}\ L(\mathbf{y}) = \{\mathbf{x} : \mathbf{x} \in L(\mathbf{y}),\ \mathbf{x}' \leq \mathbf{x} \Rightarrow \mathbf{x}' \notin L(\mathbf{y})\ \} \quad [2]$$

Optimal vectors of **x** are conditional upon the imposition of behavioral assumptions regarding the decision maker.

When the processor's objective is to minimize the costs of attaining a specified level of end-use characteristics, $\bar{\mathbf{y}}$, she faces the following cost function:

$$C(\mathbf{w},\bar{\mathbf{y}}) = \inf_x \{\mathbf{w}'\mathbf{x} : D(\mathbf{x},\bar{\mathbf{y}}) \geq 1\} \quad [3]$$

where **w** is a vector of market price differentials paid for input characteristics. The Lagrangian associated with [3] is

$$\min_x \ \Gamma = \mathbf{w}'\mathbf{x} + \lambda\,(1 - D(\mathbf{x},\bar{\mathbf{y}}))\ . \quad [4]$$

Necessary first-order conditions are:

$$\begin{aligned} &\mathbf{w} - \lambda\, \nabla_x D(\mathbf{x},\bar{\mathbf{y}}) = 0 \\ &1 - D(\mathbf{x},\bar{\mathbf{y}}) = 0\ . \end{aligned} \quad [5]$$

Under regularity conditions of the distance function, cost minimizing demands for traits **x** can be solved employing the implicit function theorem, resulting in:

[6] $\mathbf{x} = \mathbf{x}^*(\mathbf{w}, \bar{\mathbf{y}})$.

substitution into the distance function yields

[7] $D(\mathbf{x}^*(\mathbf{w}, \bar{\mathbf{y}}), \bar{\mathbf{y}}) \equiv D(\mathbf{w}, \bar{\mathbf{y}}) \equiv 1$.

The distance function expressed in terms of **w** and **y** is, when the set **x** is convex, the cost function from the following duality relationship between cost and distance functions (Färe, 1988):

[8] $$C(\mathbf{w},\bar{\mathbf{y}}) = \inf_x \{\mathbf{w}'\mathbf{x} : D(\mathbf{x},\bar{\mathbf{y}}) \geq 1\}$$

$$D(\mathbf{x},\bar{\mathbf{y}}) = \inf_w \{\mathbf{w}'\mathbf{x} : C(\mathbf{x},\bar{\mathbf{y}}) \geq 1\}$$

The cost function can be derived from the distance function via minimization with respect to input characteristics and the distance function can be derived from the cost function via minimization with respect to input prices (as noted in Färe et al. 1993). From the first-order conditions for cost minimization, cost minimizing demands are on the efficient frontier, so that $\theta^* = 1$.[5]

Consider how the processor's costs might change if choice were constrained to selection of **x** from a subset of the choice set, variety *k*. Recall that input and output characteristics are stratified by observations from K varieties. Thus, $(\mathbf{x},\mathbf{y}) = \bigcup_{k=1}^{K} (\mathbf{x},\mathbf{y})^k$ . Empirical estimation of the distance function over sample observations will then yield estimates of $\theta^k = (\theta_i^k, i = 1,\ldots S^k)$, where $S^k$ is the number of observations of variety k:

[9] $$D^k(\mathbf{x},\mathbf{y}) = \sup_{x\in k} \{\theta^k : (\mathbf{x}/\theta^k) \in L(\mathbf{y})\}$$

Parameter $\theta^k$ is a random variable censored from below at 1. $\theta^k$ represents the relative efficiency with which variety *k* converts **x** to **y**.

The cost minimization problem is constrained if the processor must limit her selection of wheat to a specific variety of wheat *k*. Given sample information or processor expectations of the distribution of $\theta^k$, the expected value of $\theta^k$ might serve as the lower bound in the constrained optimization problem. Because of available information about the expected efficiency of variety *k* in converting **x** to **y**, the processor's problem might be expressed:

[10] $$\min_{x\in k} \{\mathbf{w}'\mathbf{x} : D(\mathbf{x},\bar{\mathbf{y}}) \geq E(\theta^k)\},$$

leading to the restricted Lagrangian:

[11] $$\min_{x\in k} \Gamma^k = \mathbf{w}'\mathbf{x} + \lambda\left(E(\theta^k) - D(\mathbf{x},\bar{\mathbf{y}})\right).$$

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[5] If this were not true, an alternative choice set $\mathbf{x}' < \mathbf{x}^*$ could be found, with $\mathbf{x}' \in L(\bar{\mathbf{y}})$ . In this case, $\mathbf{w}'\mathbf{x}' < \mathbf{w}'\mathbf{x}^*$ , thus violating optimality of **x*(w, y)**.

Using procedures similar to those developed in Färe et al. (1993) and relying upon the linear homogeneity of the distance function with respect to **x**,

$$\begin{aligned}
\mathbf{w}'\mathbf{x} + \lambda\left(E(\theta^k) - D(\mathbf{x},\bar{\mathbf{y}})\right) &= \mathbf{w}'\mathbf{x} + E(\theta^k)\lambda\left(1 - D\left(\left(\mathbf{x}/E(\theta^k)\right),\bar{\mathbf{y}}\right)\right) \\
\text{[12]} \qquad &= E(\theta^k)\left[\mathbf{w}'\left(\mathbf{x}/E(\theta^k)\right) + \lambda\left(1 - D\left(\left(\mathbf{x}/E(\theta^k)\right),\bar{\mathbf{y}}\right)\right)\right] \\
&= E(\theta^k)\left[\mathbf{w}'\mathbf{z} + \lambda\left(1 - D(\mathbf{z},\bar{\mathbf{y}})\right)\right] \\
&= E(\theta^k)\Gamma
\end{aligned}$$

where $\Gamma$ is the objective function value from [4]. The expected cost difference between achieving $\bar{\mathbf{y}}$ when choice is restricted to variety *k* to the unrestricted minimization problem is thus:

$$[13] \qquad C^k = \frac{E(\theta^k)\Gamma}{\Gamma} = E[\theta^k].$$

The random variable $\theta^k$ can be used to characterize the expected difference in cost among a number of alternative processes (e.g., varieties) to generate a set of desirable characteristics **y**.

## Data and Empirical Estimation

The North Dakota State University Department of Cereal Science collects milling and baking characteristics for both commercially available and experimental varieties of HRS wheat. Samples are collected from six field stations distributed around the state. Varieties are tested on a number of different characteristics, including wheat and flour protein content, test weight, falling number, flour extraction rates, farinogram test results, and mixing and loaf characteristics. The sample period covered 1989-2000. Given the continuous development and release of new varieties, not all varieties are represented in each year. For example, test results for Alsen, a new scab-resistant variety, were first available in 1999.

The empirical application uses two field characteristics as traits influencing end-use quality, **x** = [wheat protein, test weight], which are routinely measured in the market system. The end-use traits considered important for processing success are **y** = [peak time, mixing tolerance, absorption]. These end-use traits have been identified in previous studies to be important to millers and bakers (Janzen et al).

The initial choice set includes eight wheat varieties grown in North Dakota: 2375, Amidon, Butte 86, Grandin, Gunner, Keene, Oxen, and Russ. These eight varieties comprised approximately 73% of HRS wheat plantings in North Dakota in 2000. Sample statistics for these varieties are listed in Table 1. The sample contained 447 observations for these eight varieties. In order to test the ability of the distance function approach to determine the relative costs of new variety releases to generate end-use traits, three new varieties are compared to the original eight varieties. Alsen, a much-touted new release with significant scab-resistance, was released commercially in 2000. Parshall and Reeder were both released in 1999.

**Table 1. Sample characteristics of eight initial wheat varieties (means and standard deviations in parentheses).**

| Variety | Share of 2000 Plantings | Wheat Protein | Test Wt | Absorption | Peak Time | Mix Tol |
|---|---|---|---|---|---|---|
| 2375 | 13.7 | 14.773 | 60.560 | 64.835 | 10.738 | 5.019 |
| n=80 | | (1.138) | (1.771) | (2.939) | (7.317) | (5.019 |
| Amidon | 4.9 | 14.913 | 60.200 | 64.716 | 9.357 | 3.968 |
| n=63 | | (1.218) | (1.754) | (2.614) | (4.246) | (5.049) |
| Butte 86 | 2.2 | 15.219 | 60.123 | 66.651 | 9.731 | 4.559 |
| n=80 | | (1.004) | (2.105) | (2.583) | (5.590) | (5.509) |
| Grandin | 5.9 | 15.229 | 60.154 | 66.085 | 13.272 | 5.916 |
| n=79 | | (1.119) | (2.245) | (3.138) | (9.625) | (7.137) |
| Gunner | 14.4 | 15.877 | 61.606 | 65.197 | 8.661 | 9.952 |
| N=31 | | (1.104) | (1.559) | (2.026) | (4.138) | (6.990) |
| Keene | 2.9 | 14.987 | 61.440 | 65.487 | 9.250 | 10.292 |
| N=30 | | (0.924) | (1.510) | (1.861) | (4.747) | (8.449) |
| Oxen | 9.3 | 14.697 | 59.728 | 63.510 | 10.154 | 9.756 |
| N=39 | | (0.898) | (2.191) | (2.447) | (5.220) | (8.296) |
| Russ | 19.4 | 14.564 | 60.053 | 65.120 | 10.444 | 8.306 |
| N=45 | | (0.886) | (2.011) | (2.240) | (5.065) | (7.386) |

Estimation of the cost differences reflected in expression [13] requires representation of the distance function and a method to characterize the random variable $\theta^k$ for each variety. The estimated distance function will envelope observations based on the definition in expression [1]. Distance functions can be represented using either nonparametric envelopment techniques (Chambers et al.) or parametric representation of the distance function (Atkinson et al.). Among the parametric approaches, estimation has resulted from mathematical programming procedures (Färe et al, 1993) in which the distribution of parameter estimates and the model error structure is unimportant. Alternatively, statistical estimation (Atkinson et al.) of the distance function permits hypothesis testing of parameters and explicit consideration of the distance function error structure.

Because the underlying biological processes are inherently noisy (Chambers et al), due partially to omitted variables such as weather and cultural practice differences, we estimated the distance function using stochastic frontier methods. The stochastic frontier assumes a composed error term consisting of a deterministic, half-normal distribution relating to the relative efficiency of the individual observations, and a normally distributed stochastic error capturing the effects of data noise.

We parameterize the input distance function using the translog functional form:

$$
\begin{aligned}
\ln\left(D(\mathbf{x},\mathbf{y})\right) = {} & \alpha_0 + \sum\nolimits_{k-1} \delta_k d_k + \sum\nolimits_n \alpha_n \ln x_n + \sum\nolimits_m \gamma_m \ln y_m \\
& + \frac{1}{2}\sum\nolimits_n \sum\nolimits_{n'} \alpha_{nn'} \ln x_n \ln x_{n'} \\
& + \frac{1}{2}\sum\nolimits_m \sum\nolimits_{m'} \gamma_{mm'} \ln y_m \ln y_{m'} \\
& + \sum\nolimits_n \sum\nolimits_m \beta_{nm} \ln x_n \ln y_m
\end{aligned}
\tag{14}
$$

The input distance function presumes linear homogeneity of inputs. Linear homogeneity is imposed via parameter restrictions:

$$
\sum\nolimits_n \alpha_n = 1, \; \sum\nolimits_{n'} \alpha_{nn'} = \sum\nolimits_n \alpha_{nn'} = 0, \text{ and } \sum\nolimits_m \beta_{nm} = 0 \text{ for all } n. \tag{15}
$$

Symmetry is further imposed on the matrix of coefficients for the cross-product terms for both inputs and outputs ($\alpha_{nn'} = \alpha_{n'n}$ and $\gamma_{mm'} = \gamma_{m'm}$). Calculation of the expected value of the cost differences among the eight varieties derives from estimation of $\delta_k$, the parameters associated with variety dummies $d_k$. The coefficient $\delta_k$ thus measures $E\left(\theta^k\right)$. Equation [14] was estimated using maximum likelihood methods in TSP v. 4.4 (Hall and Cummins).

## Results

Parameter estimates are presented in Table 2. Ignoring the variety intercept shifts, 17 of the 21 model coefficients are significantly different than zero. Most of the insignificant coefficients are associated with the multiplicative terms in the end-use traits. Curvature of the distance function relative to end-use traits appears to be small.

**Table 2. Parameter estimates with standard errors in parentheses**

| | Estimate | | Estimate |
|---|---|---|---|
| $\alpha_0$ | 0.02538** | $\alpha_{tw}$ | 0.70680** |
| | (0.00459) | | (0.01436) |
| $\delta_1$ | -0.01034** | $\alpha_{pr,pr}$ | 0.82181** |
| | (0.00365) | | (0.20830) |
| $\delta_2$ | -0.00979** | $\alpha_{pr,tw}$ | -0.82181** |
| | (0.00374) | | (0.20830) |
| $\delta_3$ | -0.00901** | $\alpha_{tw,tw}$ | 0.82181** |
| | (0.00369) | | (0.20830) |
| $\delta_4$ | -0.00776** | $\gamma_{ab}$ | -0.23111** |
| | (0.00348) | | (0.02708) |
| $\delta_5$ | -0.04156** | $\gamma_{pt}$ | -0.00094 |
| | (0.00437) | | (0.00386) |
| $\delta_6$ | -0.02314** | $\gamma_{mt}$ | 0.00665** |
| | (0.00426) | | (0.00154) |
| $\delta_7$ | 0.00071 | $\gamma_{ab,ab}$ | 1.15400 |
| | (0.00420) | | (0.97135) |
| $\beta_{pr,ab}$ | -0.12437** | $\gamma_{ab,pt}$ | -0.05675 |
| | (0.04221) | | (0.06062) |
| $\beta_{pr,pt}$ | -0.03026 | $\gamma_{ab,mt}$ | -0.11434** |
| | (0.03818) | | (0.03172) |
| $\beta_{pr,mt}$ | 0.15462** | $\gamma_{pt,pt}$ | 0.01000 |
| | (0.01673) | | (0.00847) |
| $\beta_{tw,ab}$ | -0.59887** | $\gamma_{pt,tw}$ | 0.01252** |
| | (0.06446) | | (0.00369) |
| $\beta_{tw,pt}$ | 0.24549** | $\gamma_{tw,tw}$ | -0.00002 |
| | (0.06259) | | (0.00445) |
| $\beta_{tw,mt}$ | 0.35338** | $\lambda$ | 1.48510** |
| | (0.02933) | | (0.36997) |
| $\alpha_{pr}$ | 0.29320** | $1/\sigma$ | 41.1237** |
| | (0.01436) | | (3.15950) |

1. * (**)- significant at the 95% (99%) level

The distance function appears not to be separable in the input (**x**) and output (**y**) traits. Following Denny and Pinto, the translog function can be represented in separable form if, for each input $x_i$ and output $y_j$, $\beta_{ij}/\beta_{ij'} = \alpha_j/\alpha_{j'}$. In the present application, with two input and three output traits, separability implies six restrictions. A Wald test for testing the hypothesis that all restrictions are jointly met is strongly rejected ($\chi^2$=711.11). Rejection of separability precludes the use of aggregate input and output measures in estimating the functional relationships among the elements of **x** and **y**.

Statistically significant differences exist in the intercept shift terms for six of the wheat varieties. Defining the intercept in terms of deviations from Russ, varieties 2375, Amidon, Butte 86, Grandin, Gunner, and Keene lie below the stochastic frontier. Expected cost differences, $E(\theta^k)$, among the varieties relative to Russ range from +0.78% (Grandin) to +4.24% (Gunner) (Table 3). The distance function model presumes a radial contraction in all inputs to achieve the frontier. Consequently, costs reflect a proportionate increase in both wheat protein and test weight necessary to achieve a given level of end-use traits relative to Russ. For example, if a given level of **y** can be achieved using variety Russ containing 15% protein and a 60 pound test weight, achieving the same level of **y** using Gunner would require a protein level of 15.64% and a 62.54 pound test weight.

The variety comparison model is based upon the behavioral assumption that processors wish to minimize costs subject to meeting target levels of end-use attributes. Levels of these end-use traits depend upon processing requirements of the individual products being produced. As an illustration of the differences among the varieties in achieving given levels of end-use traits, wheat protein levels were simulated to achieve a given vector of end-use traits, subject to the sample mean test weight of 60.4 pounds.[6] The final column of Table 3 shows the necessary protein levels. An expected protein level of 15.3% of Russ would meet the target end-use trait levels. In contrast, protein level for Gunner must be 17.1%, an increase of 11%. This value differs from the 4.24% expected cost difference, $E(\theta^k)$, in Table 3 due to holding test weight constant. Predictably, costs are higher when substitution is not permitted between protein and test weight levels.

Substitutability between test weight and protein can be calculated from taking the total differential of the distance function, holding output traits fixed. The resulting slope of the function relating protein to test weight is 0.40 at the means of all the data series. This value is derived from dividing the partial derivative of the distance function with respect to protein ($x_1$) by the partial with respect to test weight ($x_2$), or $D_1/D_2 = dx_2/dx_1$. From the first-order conditions [5], cost minimization would require a relative cost of protein to test weight of $w_1/w_2 =$ 0.40 for mean values of **x** and **y** to be optimal.

Comparison of historical market price premiums with the price ratio derived from the first-order conditions is difficult given variable transformations used in estimation and discontinuous premium pricing for protein. Historical protein premiums for HRS wheat is 14 cents/bu. for 13 to 14 percent (standard deviation is 19 cents) and is 40 cents/bu. for protein levels between 14 and 15 percent (standard deviation is 34 cents). The premium for test weight is generally linear over the ranges observed, with price historically increasing 4 cents per pound per bushel (standard deviation is 5 cents).

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[6] For the example, the target end-use traits were the sample means of 65.3% for absorption, peak time of 10.5, and a mixing tolerance of 6.4 minutes. Additional simulations can give levels of the observable traits (wheat protein and test weight) necessary to achieve any feasible combination of end-use traits.

**Table 3. Displacement from frontier and associated cost savings of individual varieties (normalized to variety Russ).**

| Variety | Displacement | Cost Difference $E(\theta^k)$ | Protein Required to produce y |
|---|---|---|---|
| 2375 | 0.9897 | 1.0104** | 15.78 |
| Amidon | 0.9903 | 1.0098** | 15.74 |
| Butte 86 | 0.9910 | 1.0091** | 15.69 |
| Grandin | 0.9923 | 1.0078** | 15.66 |
| Gunner | 0.9593 | 1.0424** | 17.11 |
| Keene | 0.9771 | 1.0234** | 16.28 |
| Oxen | 1.0007 | 0.9993 | 15.41 |
| Russ | 1.0000 | 1.0000 | 15.32 |

Notes:
1. * (**)- significant at the 95% (99%) level
2. Expected protein percentage was calculated to correspond to an absorption rate of 63.0, peak time of 11.0, mix tolerance of 2.0, and a test weight of 58.0

Maintaining the optimal price ratio of $w_1/w_2 =$ 0.40 and using the average price premium of 4 cents per pound per bushel for test weight, protein premiums for increasing from the range 12-13 percent to 13-14 percent should be approximately 8 cents and for increasing from the range 13-14 to 14-15 percent should be 15 cents. The results of the model thus indicate that, under the cost minimization assumptions of the model, historical protein premiums are too high by a factor of approximately two for achieving given levels of the end-use characteristics.

### *Comparative Analysis of New Varieties*

Variety development has traditionally concentrated on either improving agronomic properties or increasing levels of observed traits such as wheat protein. As niche markets develop, greater value potentially accrues to segregation, and consequently increased value can be captured from variety development leading to improved end-use characteristics. To illustrate this we, compare three newly released varieties to currently grown varieties of HRS wheat grown in North Dakota. In addition, an illustration of the model's ability to identify cost savings derived from variety development intended to increase the biological efficiency of producing desirable end-use traits is presented.

Recent breeding trials have resulted in the release of three varieties having desirable production characteristics. Parshall and Reeder were both released commercially in 1999. Alsen, a new variety with increased resistance to fusarium head blight, was released amid great fanfare in 2000. Summary statistics for the three varieties are reported in Table 4. Comparison of these new varieties with the original eight varieties involves re-estimating the translog distance function; including a dummy term to determine if a statistically significant intercept shift (relative again to Russ) results from these new varieties.[7]

**Table 4. Sample characteristics of three additional wheat varieties (means and standard deviations in parentheses).**

| Variety | Wheat Protein | Test Wt | Absorption | Peak Time | Mix Tol |
|---|---|---|---|---|---|
| Alsen | 15.042 | 61.442 | 65.958 | 10.050 | 15.833 |
| n=12 | (0.613) | (1.753) | (1.819) | (5.074) | (7.218) |
| Parshall | 15.068 | 61.895 | 64.795 | 17.263 | 17.263 |
| n=19 | (0.827) | (1.561) | (2.749) | (7.830) | (7.830) |
| Reeder | 14.976 | 60.592 | 63.760 | 9.340 | 14.540 |
| n=25 | (0.964) | (1.935) | (2.363) | (4.033) | (5.138) |

The three new varieties typically perform worse in the generation of the end-use traits than all but two of the eight varieties currently popular in North Dakota. Alsen and Reeder are both displaced in the interior of the stochastic frontier, with expected cost differences of 2.36% higher than Russ in achieving the frontier. The expected cost increase for Parshall is 4.23% to achieve the frontier of the distance function. All three displacements from the frontier are significantly different than zero. Required protein levels are listed in the last column of Table 5, and are consistent with the noted cost differences in terms of higher protein levels to achieve the mean levels of absorption, mixing tolerance, and peak time, subject to holding test weight fixed at its mean, used in the simulation.

**Table 5. Cost differences of "new" varieties.**

| Variety | Displacement | Cost Difference $E(\theta^k)$ | Protein Required to produce **y** |
|---|---|---|---|
| Alsen | 0.9770 | 1.0236 | 16.38 |
| Parshall | 0.9594 | 1.0423 | 17.12 |
| Reeder | 0.9770 | 1.0236 | 16.38 |

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[7] In addition to possible differences in the intercept, the functional relationship between the inputs and outputs represented by the remaining coefficients of the distance function might change. However, insufficient observations are available for the newer varieties to test for differences in these remaining 16 unrestricted parameters.

*Cost Reductions Associated with a New Variety Designed to Increase End-use Traits*

The final empirical test of the model evaluates the comparative cost of a prospective new variety that increases the input requirement set for a given vector of **y**. Since Russ was found to be the most efficient variety in terms of producing desirable end-use traits among the eight varieties considered in the initial choice set, the "new" variety was based on the relationships among the inputs (protein and test weight) and the outputs (absorption, peak time, and mixing tolerance) for Russ. The 45 observations for Russ were adjusted to reflect a hypothetical new variety bred to improve yields of the end-use traits. Specifically, test weight and protein levels for each Russ observation were decreased by a fixed contraction rate, yields of **y** were not adjusted, and the stochastic frontier was recalculated with the original eight varieties plus the new version of Russ. Using the same panel approach, the dummy variable on the new variety measures $E\left(\theta^{new}\right)$, or the displacement from the frontier of this new variety.

Results are in Figure 1. The results show that expanding the input requirement set **x** for given levels of **y** reduce expected costs to the processor. In other words, breeding varieties specifically to enhance end-use traits would increase value to the cost minimizing processor. This result is not surprising. However, the potential cost savings, as well as product improvement for processors arising from breeding research to improve end-use traits, suggest a potential role for processing firms in breeding efforts. In addition to active participation in breeding projects, processor strategies might also entail vertical coordination with both farmers and distribution firms to fully capitalize on the values of new, end-user friendly, wheat varieties.

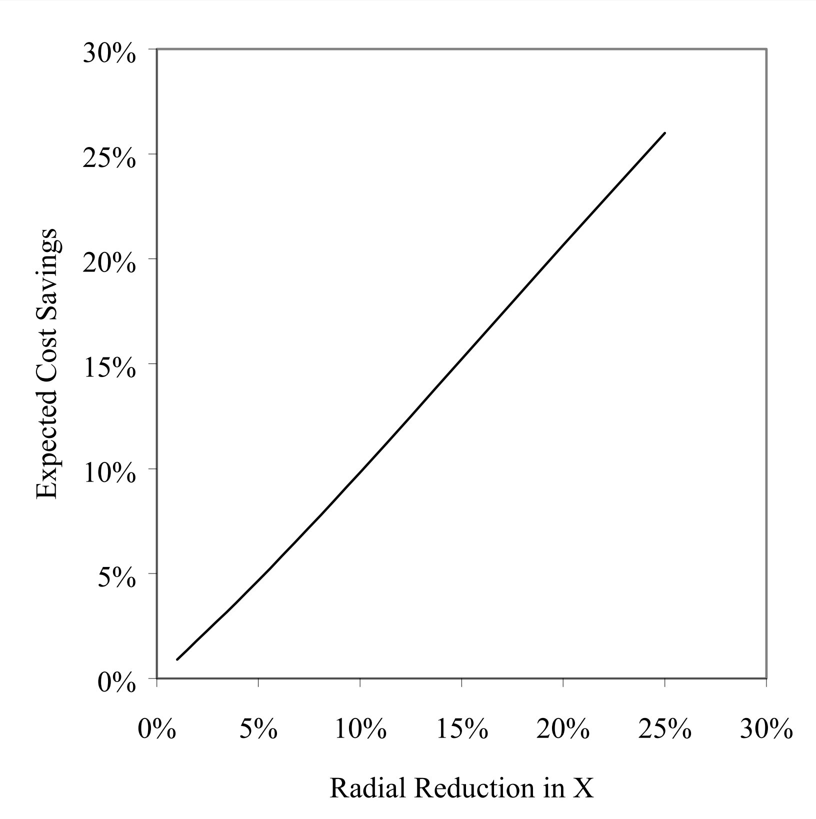

**Figure 1.** Cost savings associated with new variety with proportional decreases in test weight and protein required to produce desirable levels of end-use traits.

## Conclusions

Variety development has provided an important source of productivity gain, can potentially improve the ability to meet end-user requirements, and may foster development of new products. Breeding innovations have been particularly prominent in recent years in cases of corn and oilseeds for meeting end-use demands. In the case of wheat in the United States, numerous varieties have been released, generally with the idea of expanding grower choice sets to include varieties having improved agronomic properties or enhanced yields for characteristics for which premiums do exist in the current market system. However, characteristics desired by end-users are often not reflected in market transactions, making variety valuation more complex and detracting from the efficacy of market solutions.

The procedure developed in this paper distinguishes different varieties of HRS in terms of meeting end-use levels desired by a cost minimizing processor. Results indicate statistically significant cost differences among six of eight varieties commonly grown in North Dakota, suggesting that varieties are heterogeneous in their end-use performance and, consequently, value. Increases in costs ranged between 0.78% and 4.24% for the six varieties, indicating the extent that costs would change to achieve a set of desired characteristics relative to the efficient frontier. This is an important conclusion and supports industry concerns about lack of consistency in end-use performance that can be attributable to variety heterogeneity.

First-order conditions resulting from the processor's cost minimization problem allow estimates of allocative efficiency to be derived. Results suggest that mean values of market premiums overprice protein relative to test weight. Unless processors place a premium on protein for a specific niche market requirement, the varieties included in the research reported here can meet processor needs with lower levels of protein than would be warranted by incurring the mean premiums observed for protein levels relative to mean test weight premiums.

Finally, the procedure distinguished values to end-users of new relative to incumbent varieties. Three varieties recently released in North Dakota (Alsen, Parshall, and Reeder) were compared to the eight varieties accounting for 72.7% of the HRS wheat plantings in 2000. All three performed worse in the generation of end-use traits compared to the varieties currently adopted. All three required significantly greater protein levels and test weight relative to incumbent varieties to achieve mean levels of absorption, mixing tolerance, and peak time. However, attractiveness of the three varieties for production characteristics as well as yield of traits priced in the market led to farmer adoption of all three varieties from negligible levels in 2000 to 17.7% of planted acres in year 2001 (North Dakota Agricultural Statistic Service).

It is debatable whether markets for specific end-use traits will ever fully develop to provide adequate signals to agricultural suppliers. Continued market segmentation and the existence of possibly ephemeral markets due to rapid food product development and changing consumer demands provide interesting conceptual fodder for identifying the conditions necessary and sufficient for the evolution of efficient markets for end-use traits. In the absence of efficient markets, food processors might instead identify crop and animal varieties that bundle desired traits in a package ideally suited to their specific applications. One condition necessary for expenditure of the resources to develop specific varieties and to design contractual arrangements to guarantee delivery would be the existence of added economic value of the new variety over incumbent varieties.

The food processing industry is very aware of the advantages of procuring grain varieties developed to meet specific food manufacturing needs. General Mills has its own seed-breeding program, supporting research in 15 U.S. states. Advances in identity preservation of grain varieties through the distribution system is enabling farmers to grow specific wheat varieties for specific buyers. General Mills estimates that use of a precise variety of grain can add from 10 to 20 percent in manufacturing efficiency. These savings are substantial for a firm where grains account for over 80% of their $7.08 billion revenues in 2000 (Egerstrom). The research indicates the economic rationale underlying decisions such as General Mills to identity preserve grain procurement, as well as serving as a procedure to guide future breeding efforts to improve end-use quality.

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