Hedonic Price Estimation for Kansas Wheat Characteristics

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A hedonic price model is applied to a cross-sectional time-series data set of Kansas wheat characteristics. Results indicate that prices received by wheat producers reflect the presence of conventional quality characteristics of wheat and also milling and dough characteristics. Furthermore, the results indicate that the alternative sets of characteristics exhibit quality information that is, to some degree, independent of one another. Important conclusions regarding the efficiency of current grading and pricing practices for wheat are drawn from this analysis.

Key words: hedonic prices, wheat characteristics, panel data.

A fundamental concern of agricultural market participants involves understanding the factors which influence a particular commodity's price in the marketplace. Agricultural commodities are often of a heterogeneous nature, exhibiting differences in quality, variety, and physical attributes. Fundamental forces operate in the competitive marketplace to efficiently assign a price to a particular commodity which reflects the presence and quality of such attributes. Such differential prices reflect the relative utility provided by a differentiated commodity's attributes. In this light a commodity's market price is often viewed as being determined by some combination of implicit (or hedonic) prices which are assigned to individual attributes of the commodity.

In the case of the U.S. grain system formal quality grades are assigned as a means for facilitating the transmission of quality information to buyers and thus efficiently determining a prevailing price which reflects quality information. An efficient grading system will operate to ensure that market prices accurately reflect the end-use quality of a commodity. However, considerable disagreement exists over the economic efficiency of the U.S. grading system for grains. Hill (p. 26) argues that the current grading system is inefficient because it fails to convey accurate information about end-use grain qualities and that it provides little incentive for improving grain quality.

A thorough understanding of the market forces which determine a differentiated product's price takes on even greater importance when one considers the resources and efforts which are directed toward the development of alternative varieties and characteristics of certain agricultural commodities. In recent years a major component of basic applied agricultural research has involved the development of alternative crop varieties whose qualities are attractive to consumers and producers. An effective economic evaluation of such efforts necessarily requires a careful consideration of the market's willingness to pay for alternative product characteristics. Likewise, recognition of the relative values assigned to individual commodity characteristics provides insights into the appropriate directions for further product development.

The theoretical development of models for understanding the markets for differentiated products builds heavily on work by Lancaster; Griliches; and Rosen. The empirical estimation of such hedonic prices has received a great deal of attention in recent years. Applications of hedonic modeling techniques to agricultural commodity markets include work by Ladd and Martin; Ladd and Suvannunt; Perrin; Ethridge

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and Davis; Carl, Kilmer, and Kenny; Veeman; Wilson (1984, 1989); Estes; and Schroeder et al.

Wheat is a prominent example of an agricultural commodity exhibiting wide differences in variety and quality which may influence its selling price. In Kansas alone over 25 different varieties of wheat were grown in 1988. The quality of wheat is traditionally characterized by such variables as protein content, weight per bushel, dockage and defects, and water content. In addition, less obvious characteristics such as milling traits and physical dough properties may have an important impact on the price a wheat producer receives for his or her product.

The general objective of this article is to develop and estimate hedonic price models which provide estimates of the marginal implicit prices of several important wheat characteristics. The general model is applied in two specific areas. First, the hedonic price functions are applied to wheat characteristics which are commonly used to gauge wheat quality in the marketplace. Secondly, a set of variables which measure the performance of wheat in its end-product uses is incorporated into the hedonic price function. These variables include milling characteristics such as the milling rating and theoretical flour yield as well as data obtained from physical dough tests. Of course, the applications are not independent in that one would anticipate that wheat quality characteristics such as protein content and physical defects are important indicators of the potential performance of the wheat in use. The empirical applications of the alternative models are to a cross-sectional time-series panel of Kansas wheat quality data. Implications for the efficiency of current grading and pricing practices in Kansas wheat markets are drawn from estimates of the alternative hedonic price models.

Theoretical Model

The general theory of hedonic prices has developed along two closely related lines. The first follows a consumers' goods approach and considers individual characteristics to be utility-providing attributes in a consumer's maximization problem. The second approach views each individual characteristic as an input into a productive process. Under this approach a differentiated agricultural product such as wheat is demanded by processors because of the particular characteristics it possesses. These characteristics are input arguments in a production function. In either case, utility or profit maximization will yield a hedonic price function which expresses the commodity's market price as a function of the quality and quantity of physical attributes associated with the commodity.[1]

Ladd and Martin assume a perfectly competitive market situation where a firm maximizes a profit function subject to an input characteristics production function, $f_y(z)$. The quantity of each characteristic is an argument in the production function. The first-order conditions of the profit maximization problem yield a hedonic price function:

$$(1) \qquad P_x = R_y \sum_{k=1}^{m} (\partial f_y/\partial z_{ky})(\partial z_{ky}/\partial x_y),$$

where P_x is the price of input x, R_y is the price of output y, $\partial z_{ky}/\partial x_y$ is the marginal yield of the kth characteristic in the production of y from input x, and $R_y\ \partial f_y/\partial z_{ky}$ is the value of the marginal product of characteristic k used in the production of y. The $R_y\ \partial f_y/\partial z_{ky}$ term represents the marginal implicit price of the kth characteristic or hedonic price. Equation (1) states that the price paid for each input is equal to the sum of the marginal implicit prices of the characteristics possessed by the input multiplied by the marginal yield of those characteristics.

Equation (1) may be simplified by assuming that $R_y\ \partial f_y/\partial z_{ky} = B_k$ and $\partial z_{ky}/\partial x_y = z_{kxy}$ are both constant.[2] Rewriting equation (1), a simplified linear hedonic price function can be obtained:

$$(2) \qquad P_x = \sum_{k=1}^{m} B_k z_{kxy},$$

where B_k is the marginal implicit value of the characteristic k and z_{kxy} is the quantity of char-

[1] It should be noted that additional assumptions are necessary to consistently aggregate maximization conditions for individual consumers and producers to the market level. In addition, the definition of a particular functional form for the hedonic price equation may require additional conditions.

[2] This simplification means that each additional unit of input x contributes the same amount of the kth characteristic to the production function, y, and that the marginal implicit price for characteristic k is constant, which is consistent with the reality of many inputs (Ladd and Martin).

acteristic k contained in each unit of input x that goes into the production function, y.[3] By regressing input prices on input characteristics, as measured by the z_{kxy}, one can determine the effect that physical characteristics have on the prices paid for inputs and thus measure the marginal implicit values of the characteristics.[4]

Buyers consider several factors when purchasing a particular lot of wheat. We define the following variables which represent characteristics relevant to the determination of the purchase price for Kansas wheat:

PROT = percent protein of wheat,
TWGT = test weight per bushel of wheat (pounds per bushel),
H2O = percent moisture content of wheat, and
DEF = percent total defects contained in wheat.

Protein is an important factor used to gauge end-use performance of wheat. Protein content is used to predict the quantity of a given wheat's gluten, which is a protein essential in the bread-making process. Protein is thus a desirable component of hard wheat and is expected to exhibit a positive influence on wheat price. Test weight also is one of the most widely used indicators of wheat quality. Test weight measures the density of wheat kernels and thus is an important indicator of flour yield. Test weight is expected to have a positive influence on wheat price. Moisture content is an important characteristic in that a higher moisture content indicates a lower content of dry matter and is conducive to moisture damage in storing and handling the wheat. Moisture content thus is expected to lower the prices received for wheat. Moisture content and test weight are strongly related in that test weight tends to decrease as moisture content increases and kernels swell. Finally, total defects are comprised of foreign material, damaged kernels, and shrunken and broken kernels and are expected to have a negative effect on wheat prices.[5]

As an alternative to those characteristics which are conventional measures of the quality of a given lot of wheat at the time of purchase, we also consider a set of variables which directly measure the milling and dough properties of the wheat lot. These characteristics certainly are not independent from those traditionally considered to reflect a wheat's quality (i.e., those variables listed previously). However, it is possible that the eventual performance of a given lot of wheat in its end uses may be inaccurately or not fully measured by those variables usually considered by the market at the time of purchase. To this end, we consider an alternative model of implicit prices which incorporates the following milling and dough characteristic variables:

MIL = milling rating (a combined rating of flour extraction and flour ash),
FN = falling number (a measure of sprout damage in wheat),
TFY = theoretical flour yield of wheat,
WG = wet-gluten content of the wheat flour,
ABS = dough water absorption,
MIX = mixing time (the time required for dough to reach maximum consistency),
STAB = a measure of the stability of dough, and
VAL = the valorimeter measure (a numerical measure of the breakdown properties of dough).

The milling rating, falling number, theoretical flour yield, and wet-gluten content are measures of the milling properties of a wheat lot. The milling rating is an ordinal ranking which increases as flour extraction increases and as flour ash decreases. Ratings range between 1 and 5, where 1 is poor and 5 is excellent. A higher milling rating should result in a higher wheat price. The falling number is a measure of sprout-induced starch damage in the wheat. Higher falling numbers indicate a lower degree of starch damage and thus should exhibit a positive relationship with market price. The theoretical flour yield is determined through a formal evaluation of kernel sizes in wheat. A greater theoretical flour yield should increase price. The wet-gluten content of wheat

[3] The development of the linear hedonic pricing equation assumes that all buyers utilize the input in the same manner for the same purpose, such that they all possess identical production functions. An alternative situation would exist if different buyers preferred different characteristics (e.g., protein versus moisture content) for different uses (e.g., baking versus noodle manufacture). In this case the hedonic pricing schedule would no longer be linear. The homogeneous nature of Kansas wheat production (Hard Red Winter wheats) and its overwhelmingly predominant use in the baking sector temper concerns that the hedonic pricing equation is nonlinear.

[4] Refer to Ladd and Martin for a more detailed explanation of this derivation.

[5] Shrunken and broken kernels accounted for over 82% of total defects in the data utilized in this analysis.

flour is a more precise measure of the gluten protein content of a particular wheat and should have a positive effect on wheat price.

The absorption, mixing time, stability, and valorimeter readings are all laboratory measures of the physical properties of dough. These measures are obtained from the farinograph, an instrument manufactured for the express purpose of measuring the physical factors which determine flour quality. Absorption refers to the amount of water which a flour can absorb at a given consistency of the dough. A higher level of absorption implies a greater yield of dough and thus should exhibit a positive influence on wheat prices. Mixing time refers to the time required for dough to reach its maximum consistency in mixing. Higher mixing times are associated with stronger[6] wheats and thus should have a positive effect on wheat prices. The stability measure of dough measures the abuse and fermentation that the flour is able to withstand. High measures of stability indicate a dough that is tolerant to mixing. However, a very high measure of stability indicates an exceptionally tough dough and thus implies poor machining properties. In this light a qualitative measure of stability (equal to one) was defined for deviations greater than one standard deviation from the mean stability value. This measure was utilized in the empirical applications which follow and is expected to have a negative effect on wheat prices. Finally, the valorimeter value refers to the amount of dough breakdown which has occurred 12 minutes after the dough has reached its maximum consistency. A higher value indicates a stronger flour and thus should positively influence wheat prices.

Discussion of Data

The Kansas State Board of Agriculture, in cooperation with the Kansas Wheat Commission, annually publishes a comprehensive review of the quality of the season's wheat crop in *Kansas Wheat Quality*. The series reports various measures of wheat quality characteristics and physical attributes. The characteristics are reported as district averages for nine different wheat-producing districts in Kansas. The nine districts are shown in figure 1. This series served as the source for the quality data utilized in this analysis. A comprehensive cross-sectional time-series panel of observations of average wheat attributes for each of the nine wheat-producing districts was collected for the period covering 1970 through 1987. Annual averages of prices received by producers in each of the nine districts were collected from unpublished data obtained from the Division of Statistics of the Kansas State Board of Agriculture.

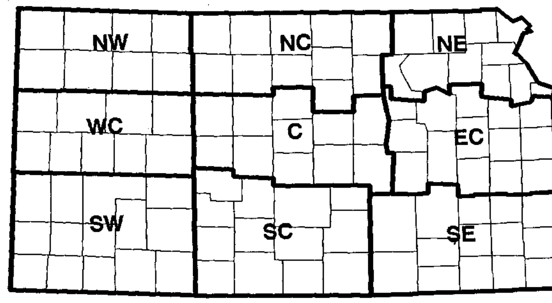

Figure 1. Kansas statistical crop-reporting districts

The basic quality information was generated from inspection certificates for samples of Kansas wheat arriving at terminal markets. For example, in 1987, 9,748 carlots arriving at terminals in 80 Kansas counties were sampled. Determinations of protein percentage, test weight, and other grade factors were made by trained evaluators of the Kansas and Missouri Grain Inspection Departments. The quality characteristics were recorded along with information regarding the wheat lot's county of origin. The basic quality characteristics were available for the entire period 1970–87, thus yielding 162 cross-sectional time-series observations.

The specific quality information regarding milling and dough properties was generated through laboratory analyses of wheat samples taken from each of the nine regions. The threshed wheat samples were collected as a part of the Objective Wheat Yield Survey program of the Kansas Agricultural Statistics Department. In 1987 the survey involved 295 samples taken from growing areas throughout the state. The subsequent analyses were conducted by personnel of the Department of Grain Science and Industry at Kansas State

[6] The "strength" of dough refers to its visco-elastic properties. Stronger wheats produce dough which has a stronger visco-elastic mass and thus are more suitable for use in the bread-making industry.

Table 1. Summary Statistics for Variables Utilized in the Analysis of Kansas Wheat Prices

Variable	n	Mean	Standard Deviation
Price ($/bu.)	162	2.912	.854
Test Weight (lb./bu.)	162	60.760	1.316
Protein Content (%)	162	11.740	.626
Water Content (%)	162	12.083	.781
Total Defects (%)	162	2.748	.602
Milling Rating	63	2.870	.682
Falling Number (sec.)	63	371.430	23.248
Theoretical Flour Yield (%)	63	75.703	.650
Wet Gluten 14% M.B. (%)	63	25.973	2.819
Absorption (%)	63	54.989	2.259
Stability (min.)	63	22.044	5.761
Mixing Time (min.)	63	8.548	2.991
Valorimeter	63	72.152	7.791
U.S. Price ($/bu.)	162	3.003	.853

University. Because several of the analytical techniques are relatively new, the sample of milling and dough characteristics was available only from 1980 through 1987. This portion of the analysis utilized 63 cross-sectional time-series observations. Summary statistics of the data are provided in table 1.

Empirical Model and Econometric Procedures

As noted above, we assume that the marginal implicit values of individual wheat characteristics are constant. The implication is that the yields of the characteristics are constant and that the price of the input is linearly related to the quantity and/or quality of the characteristic (Ladd and Martin). Additionally, since this analysis deals with only one input, wheat, and one production function, the milling process, the subscripts x and y can be eliminated from equation (2). Thus, the market level price for a particular bushel of wheat is determined by the linear sum of the marginal implicit values multiplied by the quantity or quality level of each characteristic. Inclusion of an additive intercept allows the coefficients to be interpreted as premiums and discounts over a base price, which is defined by the intercept. This approach has been applied to the malting barley market by Wilson (1984) and to the aggregate world wheat market by Veeman and by Wilson (1989). Thus, we assume that the empirical relationship between wheat market prices and marginal implicit prices can be represented by the following linear sum:

$$P_{it} = \alpha_0 + \sum_{k=1}^{m} \beta_k z_{itk}, \tag{3}$$

where P_{it} is the average price of wheat (dollars per bushel) from the ith region in the year t and the β_ks represent marginal implicit prices for the $k = 1, \ldots, m$ wheat characteristics, as measured by the z_{itk}s.

Although many of the quality measures utilized in this analysis are of a continuous nature, for some characteristics actual buyer behavior may be more accurately reflected by discrete quality measures. In particular, buyers typically apply discounts for test weight under a given level and for moisture content which exceeds a certain level. Conversely, premiums are not usually paid for higher-than-average test weights or lower-than-usual moisture content measures. A consideration of actual wheat marketing behavior in Kansas suggested the use of a truncated variable equal to one for test weights under 60 pounds per bushel, and equal to zero otherwise. Likewise, a discrete variable was defined to be equal to one for moisture content measures greater than one standard deviation over the mean value (i.e., for moisture content measures over 12.86%). These discrete variables are expected to have a negative effect on wheat price.

In that the empirical application uses pooled data covering the period from 1970 through 1987, some method of converting annual prices to an equivalent basis is necessary. The prices were converted to 1987 equivalent dollars by deflating by an index of average U.S. wheat prices normalized to be equal to one in 1987. This allows the individual coefficients, which represent marginal implicit values of the characteristics, to be interpreted in 1987 dollar terms.[7] Such an approach also adjusts the prices for market level supply and demand shocks.

[7] The national average wheat price series was collected from selected issues of the *Grain Market Situation and Outlook* series [U.S. Department of Agriculture (USDA)]. Three alternative deflators were considered: the producer's price index (PPI), an index of prices received by farmers, and an index of prices received for grain commodities (all collected from the USDA's *Agricultural Prices* series). In each case the results were found to be nearly identical to those presented.

Estimation of empirical relationships which combine cross-sectional and time-series data can present special problems in econometric analyses. In particular, it is often necessary to account for differences which might exist among cross-sectional units. The usual problems associated with serial correlation also may be present in the time-series structure of the data. In this application because of the panel nature of the price and characteristics data, it is necessary to make special allowances for possible unobserved effects common to each individual region represented in the cross section as well as any dynamic time-series effects which operate across years.

We will assume that a varying intercept term captures any differences among the cross-sectional units (regions) in our analysis and thus that each unit shares common slope parameters. To this end, we amend equation (3) to include a variable intercept term:

$$(4) \qquad P_{it} = \alpha_0 + \mu_i + \sum_{k=1}^{m} \beta_k z_{itk},$$

where P_{it} is the deflated price in region i in time t, $\alpha_{0i} = \alpha_0 + \mu_i$ is the intercept for the ith region, α_0 is the mean intercept, and μ_i represents the difference from this mean for the ith region. The appropriate econometric procedure for estimation of equation (4) depends on whether the cross-sectional effects, μ_i, are of a random or fixed nature. Consideration of a standard Hausman test revealed that the cross-sectional effects are of a fixed nature.[8] Thus, in the applications which follow, we utilize a series of regional dummy variables to account for fixed cross-sectional effects.

In addition to cross-sectional effects, efficient estimation also may require that one recognize any time-series correlation or heteroskedasticity[9] which may be present in a panel of data. Parks and Kmenta (pp. 512–14) discuss an alternative model which can be applied in analyses of panel data.[10] The Parks estimation procedure assumes that the residual errors for each cross-sectional unit are correlated over time. The procedure also allows for heteroskedasticity among the error terms among cross-sectional units. The Parks model is given by:

$$(5) \qquad P_{it} = \alpha_0 + \sum_{k=1}^{m} \beta_k z_{itk} + \sum_{i=1}^{n} \mu_i d_i + u_{it},$$

where P_{it} is the deflated price, the d_is are regional dummy variables and u_{it} is allowed to follow a heteroskedastic first-order autoregressive process:[11]

$$(6) \qquad E(u_{it}u_{jt}) = \sigma_{ij} \quad \text{for } i = j \text{ and 0 otherwise},$$

and

$$u_{it} = \rho u_{it-1} + e_{it},$$

where the e_{it}s are white noise residuals.

The applications of the hedonic price model, represented by equation (5), are pursued in two distinct directions. First, the full set of conventional grade and quality factors, covering 1970–87, are evaluated for their effect on price received by Kansas wheat farmers. Second, the alternative set of milling and dough characteristics are considered in conjunction with the standard grade and quality factors for the shorter period covering 1980 through 1987. In each case standard F-tests are utilized to consider a series of maintained hypotheses regarding the importance of certain characteristic groups. This approach allows a distinct evaluation of the marginal valuations of individual characteristics while also allowing us to consider which characteristic groups are most relevant to the determination of Kansas wheat prices.

Table 2 presents three regressions for the full set of conventional wheat quality measures, obtained through an application of the Parks procedures. The first regression contains only the regional dummies. The second regression includes the regional dummies plus the standard grading factors utilized at local and terminal elevators to assign a price to a lot of wheat. The third regression contains the regional dummies and the grade factors plus protein and water content measures. Protein and water content are not explicitly represented by

[8] Details regarding the application of the Hausman test are available from the authors upon request.

[9] Heteroskedasticity is suspected because of the grouped nature of the annual, regional average price dependent variables (Johnston, p. 293). Application of the Parks procedure restricts this heteroskedasticity to be of a form where error variances differ across regions. Thus, we implicitly assume that the sampling of prices varies across regions but has remained relatively constant over time. This assumption is supported by the very stable structure of Kansas wheat production over this period.

[10] The Parks estimation procedure has been applied to a consideration of hedonic prices in the world wheat market by Wilson (1989) and by Veeman.

[11] Estimated values of the autoregressive parameters for the cross-sectional units, ρ_i, were between .2 and .5 in the applications which follow. Detailed estimates of the autoregressive parameters are available from the authors upon request.

Table 2. Parameter Estimates: Hedonic Price Equations for Kansas Wheat Quality Characteristics, 1970–87

Variable	Regression 1	Regression 2	Regression 3
Intercept	2.5381 (.0292)***	2.6206 (.0413)***	2.0490 (.1233)***
d_{NC}	−.0192 (.0398)	−.0119 (.0395)	−.0305 (.0347)
d_{EC}	.0392 (.0442)	.0377 (.0424)	.0532 (.0385)
d_{NE}	.0891 (.0450)**	.0902 (.0435)**	.0830 (.0374)**
d_{NW}	−.1193 (.0371)***	−.1168 (.0375)***	−.1063 (.0324)***
d_{SC}	.0165 (.0390)	.0132 (.0374)	.0187 (.0300)
d_{SE}	.0165 (.0403)	.0012 (.0396)	.0361 (.0364)
d_{SW}	−.0575 (.0364)	−.0593 (.0380)	−.0653 (.0325)**
d_{WC}	−.0890 (.0353)**	−.0897 (.0369)**	−.0906 (.0298)***
Test Weight		.0143 (.0173)	.0071 (.0152)
Total Defects		−.0311 (.0109)***	−.0313 (.0099)***
Percent Protein			.0492 (.0098)***
Percent Water			−.0545 (.0161)***
F-test for grade factors		4.1526**	
F-test for water and protein			20.6096***
F-test for grade factors, water and protein			13.1404***
Buse R^2	.2431	.2685	.4184
S.S.E.	81.000	63.000	44.957

Note: Numbers in parentheses are asymptotic standard errors. Single, double, and triple asterisks indicate significance at the 10%, 5%, and 1% levels, respectively. The eight d_is ($i = NC, \ldots, WC$) represent regional dummy variables. For explanation of Buse R^2, see text footnote 12.

U.S. wheat grading standards but are hypothesized to influence wheat prices. Table 2 also presents the results of nested F-tests for each of the alternative models.

The first regression in table 2, containing only regional dummies, explains only 24% of the weighted variation in wheat prices, as indicated by Buse's R^2.[12] In order to overcome perfect collinearity the variable representing the central region is omitted, and the intercept thus represents the mean price in the central region. In general, the regional dummy values seem to suggest lower prices in the western regions and higher prices in the eastern regions. However, only the northeast, northwest, and west central regional dummies have relatively large t-ratios. These effects likely reflect the significant differences in handling and processing facilities which exist among regions as well as differences in distances from principal central markets. In particular, the trend of higher producer prices with eastern movement across Kansas may reflect the higher transportation costs associated with moving grain from western-producing regions into Kansas City-area markets. These price differences also may reflect region-specific residual quality differences.

[12] Buse's R^2 is a goodness-of-fit measure which takes into account the GLS nature of Parks' procedures. It represents the proportion of the GLS weighted variation of the dependent variable explained by the regression.

The second regression in table 2 contains the regional dummies plus conventional grading characteristics, test weight and total defects. An F-test for significance of these two grade factors has a value of 4.15, which is significant at the 5% level. However, only the total defects variable appears to be significant at the 5% level. This indicates that the grade characteristics do have a significant impact on price received by Kansas wheat producers but that total defects appears to be the more important of the two grading factors.

The third regression in table 2 contains the regional dummies, the grading factors, plus protein and moisture contents. F-tests for the addition of protein and moisture strongly verify their importance as factors which influence wheat prices. Buse's R^2 rises to almost .42, reflecting a reasonable degree of explanatory power for a set of pooled data. This indicates that regression 3 explains 42% of the weighted variation in wheat prices. With the exception of test weight, each quality coefficient is of the correct sign and is significant at the 1% level. Recall that coefficients on continuous variables represent the marginal implicit values assigned to one-unit increases in the content of those characteristics. Coefficients on the qualitative variables represent the premiums and discounts associated with moving from one classification level to another. Thus, the results correspond to a 3.13 cents-per-bushel discount for an additional percentage point of total defects, a 4.92 cents-per-bushel premium for an additional percentage point of protein, and a 5.45 cents-per-bushel discount for wheats with moisture contents over 12.86%. In all, the results indicate that Kansas wheat prices are significantly influenced by the quality measures often considered at country and terminal elevators.

An alternative application of the hedonic price model including the milling and dough characteristics was pursued for the period covering 1980–87 for the nine wheat-producing regions of Kansas. This application consisted of five nested regression models. The first three repeat the preceding analyses using an abbreviated set of conventional grading characteristics data. A fourth regression considers the alternative milling and dough characteristics along with the regional dummy variables. A fifth regression contains both sets of quality measures. Nested F-tests are applied to each of the models to evaluate the influence of alternative groups of characteristics on the prices received for Kansas wheat.

Table 3 presents the regressions for the alternative applications of the wheat hedonic price models.[13] Regressions 1 through 3 are somewhat similar to those contained in table 2. A significant discount of 11¢ per bushel for test weights under 60 pounds is suggested in regression 3. A significant premium of 4.8¢ per bushel for an additional percentage point of protein is implied by regression 3. However, the total defects and percent water coefficients are no longer of the right sign and are no longer significant at the 5% level. In light of the shorter time-series span of the data, the R^2s rise significantly. Again, standard F-tests confirm the importance of the grading factors and protein and moisture content.

Regression 4 contains the regional dummies and the milling and dough characteristics. Note that, in light of its ordinal nature, the milling rating is expressed as a series of qualitative variables where the average value for each annual, regional unit is rounded to its nearest categorical value. Milling rating 2 is chosen as the default category. The falling number, wet gluten content, theoretical flour yield, stability, and milling rating 4 variables all appear to be significant determinants of the price of wheat. With the exception of the falling number and stability, each significant coefficient is of the correct sign. The coefficients indicate respective premiums of 4.5¢ per bushel for an additional theoretical flour yield percentage point, 1.6¢ per bushel for an additional percentage point of wet gluten, and 6.77¢ per bushel when moving from a milling rating of 2 to 4. A discount of .1¢ per bushel is implied for a one-unit increase in the falling number. Regression 4 explains over 89% of the weighted variation in wheat prices. An F-test of the null hypothesis that all of the milling and dough characteristic coefficients are zero is strongly rejected.

Regression 5 contains both the standard grading characteristics and the milling and dough characteristics, in addition to the regional dummies. Inferences regarding individ-

[13] Some difficulty was encountered in obtaining estimates of the autocorrelation parameters in the applications using the shorter panel of data. The correlation coefficients had very small values. This suggests that autocorrelation likely is not present in the shorter data set. The resulting error covariance matrix was not positive definite and thus could not be used in the GLS estimation. Thus, the Parks procedures were restricted to provide only a correction for cross-sectional heteroskedasticity.

Table 3. Parameter Estimates: Hedonic Price Equations for Kansas Wheat Quality Characteristics, 1980-87

Variable	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5
Intercept	2.5864 (.0375)***	2.7155 (.0717)***	2.0947 (.2184)***	−.9584 (1.4483)	−2.2567 (2.4502)
d_{NC}	−.0317 (.0541)	−.0439 (.0496)	−.0493 (.0441)	−.0176 (.0445)	−.0309 (.0416)
d_{EC}	.0338 (.0528)	.0356 (.0534)	.0211 (.0420)	.0115 (.0543)	.0418 (.0526)
d_{NE}	.0835 (.0548)	.0695 (.0512)	.0800 (.0443)*	.0707 (.0391)*	.0862 (.0392)**
d_{NW}	−.1235 (.0493)**	−.2055 (.0548)***	−.1804 (.0505)***	−.1411 (.0354)***	−.1400 (.0456)***
d_{SC}	−.0127 (.0530)	−.0770 (.0509)	−.0731 (.0449)	.0297 (.0500)	.0103 (.0529)
d_{SE}	−.0163 (.0538)	−.0209 (.0497)	−.0370 (.0525)	−.0334 (.0456)	.0004 (.0554)
d_{SW}	−.1173 (.0504)**	−.2147 (.0580)***	−.2043 (.0511)***	−.1323 (.0390)***	−.1459 (.0517)***
d_{WC}	−.1274 (.0503)**	−.2262 (.0577)***	−.2078 (.0506)***	−.1615 (.0319)***	−.1568 (.0488)***
Test Weight		−.1104 (.0332)***	−.1085 (.0297)***		.0393 (.0330)
Total Defects		−.0129 (.0246)	.0025 (.0213)		.0248 (.0274)
Percent Protein			.0484 (.0169)***		.0735 (.0309)**
Percent Water			.0795 (.0445)*		.0385 (.0503)
Falling Number				−.0011 (.0005)**	−.0005 (.0007)
Wet Gluten				.0160 (.0028)***	.0021 (.0067)
Theoretical Flour Yield				.0450 (.0207)**	.0508 (.0330)
Milling Rating 1				.0520 (.1192)	.0840 (.0970)
Milling Rating 3				.0212 (.0252)	.0480 (.0292)
Milling Rating 4				.0677 (.0329)**	.0848 (.0425)**
Absorption				.0037 (.0086)	.0017 (.0118)
Mixing Time				−.0131 (.0093)	−.0160 (.0123)
Valorimeter				−.0000 (.0041)	.0028 (.0054)
Stability				.0444 (.0214)**	.0190 (.0249)
F-test for grade factors		7.4567***			
F-test for water and protein			8.6553***		
F-test for grade factors, water and protein			8.2757***		
F-test for milling characteristics				23.8016***	3.0492**
F-test for grading characteristics					3.2070**
F-test for structural change					2.2723***

Table 3. Continued

	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5
Buse R^2	.3886	.5036	.6208	.8904	.7891
S.S.E.	63.000	62.961	62.505	57.170	60.718

Note: Numbers in parentheses are asymptotic standard errors. Single, double, and triple asterisks indicate significance at the 10%, 5% and 1% levels, respectively. For an explanation of Buse R^2, see text footnote 12.

ual parameters are difficult to draw from this regression given the likely high degree of collinearity between the alternative quality measures. However, regression 5 does allow one to pursue nested hypothesis testing of each of the alternative sets of quality characteristics to determine which set, if either, provides a more complete explanation of the determinants of wheat prices. An F-test for the null hypothesis that all of the coefficients for the conventional grading characteristics are zero is rejected at the 5% level. Likewise, an F-test for the null hypothesis that all of the coefficients for the milling and dough characteristics are zero is rejected at the 5% level. This suggests that both sets of quality characteristics exercise an influence on the determination of wheat prices and that the information provided by each set of quality measures is independent of the other to some degree. It would appear that Kansas wheat prices are responsive both to conventional grading characteristics and to alternative milling and dough characteristics which reflect the value of wheat in its end uses. The two sets of characteristics also convey quality information that is different, to some degree, in that neither of the alternative characteristic sets is found to be unimportant in the presence of the other. This would seem to suggest that wheat buyers do consider alternative quality measures other than those which are commonly used in grading wheat at the elevator when purchases are made.

Throughout the alternative regression models, the regional dummies indicate significant fixed cross-sectional effects. This significance is maintained even as additional quality variables are used to adjust the prices for quality differences. In particular, western markets appear to receive lower average prices than central markets while the eastern markets appear to receive higher average prices than the central markets. These effects likely reflect the significant differences in handling and processing facilities which exist among regions as well as differences in distances from principal markets. In particular, the trend of higher producer prices with eastern movement across Kansas may reflect the higher transportation costs associated with moving grain from western-producing regions into Kansas City-area markets. These price differences also may reflect unobservable region-specific residual quality differences which are not represented in the quality characteristics included in the hedonic models. Finally, the variability of wheat quality across alternative regions might contribute to regional price differences. However, an examination of the variability of the alternative quality measures across alternative regions failed to reveal higher quality variances in western regions.

In light of the fact that the second set of regressions utilizes a much shorter period for estimation, it is of interest to consider whether the discounts and premiums revealed for the conventional grading characteristics are significantly different in the later period. Such a difference would suggest the occurrence of a structural change in the hedonic relationships for the grading characteristics as alternative quality measures became available. A test for structural change between regression 3 in table 2 and regression 3 in table 3 was carried out by including a dummy variable for the earlier period and interacting this dummy variable with each of the grading characteristics and regional dummies. An F-test of the significance of these slope and intercept shifting variables was carried out and is presented in table 3.[14] The F-statistic has a value of 2.27 which

[14] A more straightforward means of considering structural change might involve the application of a standard Chow test of equality of the coefficients between the alternative periods. However, the application of such a test is precluded by the GLS nature of the Parks procedures. In particular, the covariance matrix structure varies with respect to the number of observations included in a regression. The F-test utilized to consider structural change provides an equivalent type of evaluation of parameter stability between the alternative regimes.

rejects the null hypothesis of parameter stability between the two periods. Thus, the implied premiums and discounts differ in the two alternative periods.[15] The finding that quality premiums and discounts differ over time is not unexpected and does not necessarily imply inefficiencies in the pricing system. Kansas wheat prices certainly respond to aggregate quality levels. For example, a national shortage of protein in a particular year likely would raise the premium attached to additional protein in that year. In this light, the implied premiums and discounts obtained from the first set of regressions should be interpreted as average values for the entire period, 1970–87. Alternatively, the finding that total defects and moisture content are not significant determinants of wheat prices but that test weight does exert a more significant influence on wheat prices in the more recent period may imply that recent grading and pricing practices have suffered efficiency losses in identifying and discounting for defects and moisture but are more efficient in assessing test weight effects on wheat quality.

The preceding models indicate that wheat prices are influenced by a variety of quality characteristics. Considerations of conventional grading characteristics as well as alternative measures of end-use quality indicate that many, though not all, available measures of quality influence price. In order to consolidate the information contained in these models, three restricted versions of the alternative models were considered. Table 4 presents three regression models representing restricted versions of the conventional grading characteristics and alternative milling characteristics models. On the basis of Hausman tests, the preceding hedonic price equations were estimated using a standard fixed-effects representation by including a separate indicator variable for each cross-sectional unit. Regressions 1 and 2 consolidate the fixed effects into west, central, and east regions for the conventional grading characteristics (using the entire sample) and the alternative milling characteristics models, respectively. The coefficient estimates are nearly identical to the unrestricted versions and thus indicate that aggregation of the fixed effects has little influence on the results for the remaining characteristics. Results from nested F-tests of the alternative sets of quality characteristics are identical to those obtained from the full fixed-effects models. Regression 3 consolidates the cross-sectional effects and omits falling number and the laboratory tests from the milling characteristics. This restriction is imposed to evaluate whether the falling number and the laboratory tests contain independent quality information that influences wheat prices. Coefficients for the remaining characteristics are nearly unchanged, indicating premiums of 1.7¢ and 4.9¢ per bushel for wet gluten and theoretical flour yield, respectively, and an 11.8 cents-per-bushel premium when going from a milling rating of 2 to 4. However, an F-test of the exclusion of the laboratory characteristics has a value of 4.8438, indicating rejection of this restriction at the 1% level. Likewise, an F-test for the exclusion of falling number and the laboratory tests has a value of 4.0725, indicating rejection of this restriction at the 1% level. Thus, the falling number and the laboratory tests appear to include significant quality information that is not reflected in the milling ratings or in wet gluten or theoretical flour yields.

In all, each set of alternative quality characteristics was shown to exert a significant influence on the prices received by Kansas wheat farmers. The fact that milling and dough characteristics appear to be significant determinants of wheat prices suggests that buyers do have some ability to gauge end-use quality characteristics at the time of purchase. Although some independence between the alternative measures is suggested by the preceding F-tests, the degree of this independence is likely limited given that the F-values in regression 5 of table 3 are quite small. Thus, it is of interest to consider the power of standard grading characteristics in explaining end-use milling and dough characteristics.

The five conventional grading characteristics were regressed against each of the end-use milling and dough characteristics. The results of these regressions are presented in table 5. In general, the conventional grading characteristics appear to be significant indicators of the end-use milling and dough characteristics. This is especially true for protein content, which appears to be a significant determinant of seven of the eight milling and dough quality in-

[15] Parameter estimates and details regarding the test utilized for structural change are available from the authors upon request. The individual parameter estimates indicated that significant differences between the alternative regimes exist for test weight and water content. However, the revealed premium for protein and discount for total defects were not found to be significantly different between the alternative regimes.

Table 4. Parameter Estimates: Restricted Hedonic Price Equations for Kansas Wheat Quality Characteristics

Variable	Regression 1	Regression 2	Regression 3
Intercept	2.0379 (.1192)***	−1.0926 (1.5343)	−1.6295 (1.5195)
d_E	.0569 (.0234)***	.0247 (.0296)	.0696 (.0288)***
d_W	−.0883 (.0195)***	−.1596 (.0241)***	−.1592 (.0236)***
Test Weight	.0073 (.0150)		
Total Defects	−.0318 (.0095)***		
Percent Protein	.0502 (.0095)***		
Percent Water	−.0560 (.0156)***		
Falling Number		−.0007 (.0006)	
Wet Gluten		.0149 (.0038)***	.0171 (.0038)***
Theoretical Flour Yield		.0440 (.0022)**	.0492 (.0207)***
Milling Rating 1		.0236 (.1143)	−.0007 (.1151)
Milling Rating 3		.0322 (.0258)	.0307 (.0258)
Milling Rating 4		.0878 (.0348)***	.1180 (.0320)***
Absorption		.0029 (.0090)	
Mixing Time		−.0186 (.0112)*	
Valorimeter		.0025 (.0048)	
Stability		.0575 (.0226)***	
F-test for milling characteristics		3.6903***	
F-test for grading characteristics		4.6762***	
F-test for laboratory characteristics			4.8438***
F-test omitted milling characteristics			4.0725***
Buse R^2	.3956	.7866	.6496
S.S.E.	98.891	57.966	61.283

Note: Numbers in parentheses are asymptotic standard errors. Single, double, and triple asterisks indicate significance at the 10%, 5%, and 1% levels, respectively. d_E and d_W are dummy variables for east and west regions, respectively. For an explanation of Buse R^2, see text footnote 12.

dicators. The test weight indicator variable displays a significant negative influence on the theoretical flour yield and the milling rating. Total defects exhibits a significant negative influence on the theoretical flour yield and the absorption quality measures. Moisture content exhibits significant negative influences on the falling number, the absorption rate, and the mixing time. The absorption rate seems to be most influenced by the conventional grading characteristics of the eight milling and dough characteristics. Buse's R^2 ranges from a low of .11 for the valorimeter to a high of .76 for wet gluten. This suggests that the conventional grading characteristics appear to explain some of the variation in end-use quality character-

Table 5. Parameter Estimates: Milling and Dough Characteristics as Determined by Physical Characteristics

Independent Variable	Dependent Variable							
	Theoretical Flour Yield	Falling Number	Wet Gluten	Milling Rating	Absorption	Stability	Valorimeter	Mixing Time
Protein Content	.0151 (.18)	16.8440 (4.83)*	3.3745 (12.84)*	−.5775 (−5.67)*	1.7512 (6.87)*	.3553 (4.42)*	3.1296 (2.22)*	1.2331 (2.27)*
Water Content	−.2309 (−1.07)	−29.0340 (−3.13)*	−.7572 (−.97)	.0001 (.00)	−1.7853 (−2.18)*	−.1535 (−.62)	−5.5993 (−1.55)	−2.5482 (−2.27)*
Test Weight	−.3105 (−2.53)*	−.1474 (−.03)	−.3683 (−.97)	−.4581 (−3.05)*	.3992 (1.03)	.0788 (.64)	.3381 (.17)	.2352 (.31)
Total Defects	−.6354 (−5.11)*	−5.68 (−1.17)	−.6274 (−1.70)	.1424 (1.01)	−1.9653 (−5.53)*	−.0421 (−.35)	−1.9810 (−.97)	−1.0224 (−1.33)
Intercept	77.3950 (74.23)*	189.0700 (4.32)*	−11.9200 (−3.68)*	9.5418 (7.51)*	39.4630 (12.52)*	−3.7590 (−3.80)*	40.8880 (2.34)*	−3.2802 (−.49)
Buse R^2	.48	.35	.76	.42	.59	.26	.11	.14

Note: Numbers in parentheses are t-ratios. An asterisk indicates significant at the 5% level. For an explanation of Buse R^2, see text footnote 12.

istics but that a considerable degree of the variation in these quality measures is independent of the standard grading characteristics.

Concluding Remarks

This analysis has considered hedonic price models for alternative quality characteristics of Kansas wheat. In particular, two alternative models which explore conventional measures of wheat quality as well as detailed milling and dough properties were developed and estimated. The results indicate that standard grading characteristics as well as alternative end-use quality characteristics influence the prices Kansas farmers receive for their wheat at local and terminal elevators. Hedonic price models for both sets of characteristics demonstrate that prices are responsive to quality variables. Furthermore, the results indicate that the alternative sets of characteristics exhibit quality information that is, to some degree, independent of one another.

These results may be useful in addressing the efficiency of current grading and pricing practices for wheat. If the hedonic price models had indicated that neither set of quality characteristics influenced prices, one could conclude that the pricing system was indeed inefficient because prices failed to reflect relevant quality information. At the other extreme, if both sets of quality characteristics were revealed to influence prices and if hypothesis testing had shown that neither set of characteristics exercised significant influence on prices in the presence of the other, a fully efficient pricing and grading system would be implied. Such a result would suggest that the variables currently utilized at local and terminal elevators to determine wheat prices paid to farmers perfectly reflect the end-use quality of wheat, as measured by the milling and dough characteristics. In reality, the conclusions implied by the empirical results fall between these two extremes. The results suggest that wheat prices are responsive to differences in the quality of wheat, as measured both at the farm gate and in milling and baking uses, thus lending support to an efficiently operating grading system. However, the degree of this efficiency is called into question by the fact that the quality information conveyed by standard grading characteristics displays a degree of independence from the quality information implied by end-use characteristics. In addition, several measures of wheat quality at the mill and bakery are not shown to be reflected in wheat prices. Regressions of conventional grading characteristics on end-use quality variables confirm a relationship between the standard grading characteristics and end-use quality but also reveal this relationship to be quite limited. In this light, end-use quality might be better reflected in the prices received by farmers if alternative grading characteristics were used in the grading process. However, any such changes would necessarily need to be weighed against the added costs associated with revising the grading system so as to more accurately reflect end-use quality at the farm gate before definite conclusions regarding efficiency can be reached.

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