# DERIVED DEMAND FOR WHEAT BY CLASS

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**Derived Demand for US Wheat by Class**

**Abstract:** To quantify price responsiveness and economic substitutability among wheat classes, derived demand functions were specified from a normalized quadratic profit function. Own-price and cross-price elasticities were estimated for hard red winter, hard red spring, soft wheat (combined red and white), and durum wheat. In general, soft wheat varieties were less responsive to their own price than were hard wheat varieties. Cross-price elasticities indicate that hard red winter wheat, hard red spring wheat, and soft wheat varieties are economic substitutes. Cross-price elasticities are different from those previously reported, which can have important policy implications.

**Keywords:** elasticities, normalized quadratic, substitution

## Introduction

In the United States the use of wheat as input into food production has been increasing in recent years. USDA-ERS estimates that per-capita flour consumption, including semolina, has increased from 110 pounds in 1972 to 148 pounds in 1997 (Barnes and Shields 1998). Per-capita durum flour and semolina consumption alone are up 52% from 1970 to 1990. To date, there has been little research on the U.S. domestic demand for wheat by class. Chai (1972) and Barnes and Shields (1998) estimated ad hoc or reduced-form demand models for wheat by class. Alternatively, we consider wheat as an input into food production and estimate a derived demand system for wheat by class. Here the objective is to determine substitutability across U.S. wheat classes, as well as the responsiveness of quantity demanded to price changes. While physical substitutability among wheat classes has been extensively studied (Faridi and Faubion 1995), *economic* substitutability among wheat classes has not and is in need of further investigation.

There are six major classes of wheat grown in the U.S., including hard red winter (*HRW*), hard red spring (*HRS*), soft red winter (*SRW*), soft white (*SWW*), hard white, and durum (*DUR*). Hard white wheat will be excluded from this analysis due to its recent emergence, resulting in a lack of sufficient market information. The remaining classes are used to produce a wide variety of products. The protein content in hard red winter and hard red spring is utilized in the production of bread and rolls. Soft red winter is used to produce flat breads, cakes, crackers, and pastries. Soft white wheat is used to produce crackers, cookies, pastries, muffins, and flour for cakes. Durum is used in the production of semolina flour and a variety of pasta products.

To analyze domestic demand for wheat, a factor demand system representing wheat by class was derived from a restricted profit function. The factor demand equations are a function of their own-price, prices of the remaining classes of wheat, and prices of wheat flour. The equations are estimated with a feasible generalized least squares (GLS) estimator using a seemingly unrelated regression (SUR) framework. By estimating the equations simultaneously with SUR, more efficient parameter estimates are obtained (Judge et al. 1988).

The paper proceeds in the following manner. First, a brief literature review is provided. Second, the conceptual model is introduced and defined. Third, the data and empirical model are discussed. Fourth, the results are presented, policy implications are discussed, and conclusions are drawn.

**Literature Review**

Chai (1972) estimated domestic demand for wheat by class over the period from 1929 to 1963. Linear equation-by-equation OLS estimation included *HRW*, *HRS*, *SRW*, *SWW*, and *DUR.* Models were estimated from 1929 to 1941, then from 1946 to 1963, excluding the years influenced by World War II. Demand for each wheat class was specified as a function of its own-price, price of competing classes, and per-capita disposable income. Chai concluded that price elasticities were more elastic for hard classes than soft classes of wheat.

Blakeslee (1980), as part of a structural model, estimated domestic U.S. demand at the farm level for wheat as food from 1954 to 1974. In this specification, per-capita food use was defined as a function of wheat price, deflated average hourly earnings of workers in the bakery products industry, and average per-capita disposable income. The estimated own-price elasticity was negative and inelastic at -0.012, while the estimated income elasticity was positive and inelastic at 0.074. Over the period of this analysis, per-capita use of wheat as food was in a downward trend.

Barnes and Shields (1998) estimated the total U.S. demand for wheat by class as food use. The wheat classes include used were *HRW*, *HRS*, *SRW*, *SWW*, and *DUR* . The double-log demand equations are defined as the quantity demanded of wheat by class for food use as a function of own-price, price of substitute goods, income, and population. The authors found negative and inelastic own-price elasticities for each of the five wheat classes, with *SWW* being the most elastic at -0.77 and *DUR* being the least elastic at –0.16. In relation to substitutability, the authors report that HRW is considerably more substitutable for *HRS* than *HRS* is for *HRW*. Further *HRS* is more substitutable for *DUR* than *DUR* is for *HRS*. They also found that *HRW* is substantially more substitutable for *SWW* than *SWW* is for *HRW*. The *DUR* income elasticity was the most elastic in terms of per-capita income.

**Conceptual Model**

In contrast to Chai, and Barnes and Shields, the demand for wheat by class is examined from a conceptually different perspective. The approach taken here is to follow Goodwin and Brester (1995), and others, considering wheat as an input into food production. Hence, derived demand equations are specified for the flour milling industry. This is done for several reasons. First, only 15% of flour processed is directly sold to consumers. The other 85% is used in baked goods (Harwood et al. 1989). Second, which is directly related to the first, prices used in Barnes and Shields demand model (in conjunction with an income variable) are farm level prices and not retail level prices.

Third, a demand model specified as a function of farm level prices and consumer income is an ad hoc or a reduced-form model. Neither are theoretically suitable for estimating own-price and cross-price elasticities.

Neoclassical theory of the firm implies profit maximization can be represented by a multiple output profit function consisting of both input and output prices (Chambers 1988; Varian 1992). The indirect profit function can be written as:

$$\pi = \pi(p, w; z)$$

where $p=(p_1,\ldots,p_q)'$ is a $(q \times 1)$ vector of output prices and $w=(w_1,\ldots,w_k)'$ is a $(k \times 1)$ vector of input prices. Here $z$ represents a vector of restricted input prices, indicating a restricted profit function.

The indirect profit function is the maximum profit associated with given product and factor prices (Beattie and Taylor 1985). The advantage of the indirect profit function is the ability to obtain the unconditional factor demand and product supply functions. In this framework, factor demand and output supply equations may be obtained by use of Hotelling's Lemma, that is by differentiating the profit function with respect to the corresponding input and output prices. The system of factor demand and output supply equations are given by:

$$\frac{\partial \Pi}{\partial w} = -x(p, w; z)$$
$$\frac{\partial \Pi}{\partial p} = y(p, w; z)$$

where $y=(y_1,\ldots,y_q)'$ is a $(q \times 1)$ vector of output quantities and $x=(x_1,\ldots,x_k)'$ is a $(k \times 1)$ vector of input quantities.

Output and input prices are taken to be exogenous, assuming firms are price takers in the output markets and the factor input markets. Following the above notation (for wheat by class) output prices are defined as $p_q$, for $q$=*KCB*, *MNS*, *CHC*, *SEM*, and factor input prices as $w_k$, for $k$=*HRW*, *HRS*, *SRW*, *SWW*, *DUR*. This yields a system of five factor demand equations and four output supply equations. For this paper the focus is on the system of derived demand equations to determine substitutability across U.S. wheat classes, as well as the responsiveness of quantity demanded to price changes. To satisfy general demand restrictions symmetry and homogeneity are imposed by appropriately restricting coefficient estimates in the empirical models below.

Harwood et al. (1989), and others, have indicated that the flour milling industry has gone through a period of extensive technical change. To model the effects of technical progress on the factor demands, we focus on the concept of disembodied technical change. That is, technical change that is not embodied in any particular input or groups of inputs (Chambers 1988). The normalized quadratic model of the indirect profit function, can be altered to test for disembodied technical change over time. Linear terms of a time trend $t$ are included in the derived demand equations from the normalized quadratic model. The variable should capture aspects of technical change and any other trending factor not included in the model.

**Data**

Annual prices, quantities, and producer price indices for the empirical analysis for each of the five wheat classes are based on June to May production years, from 1977/78 to 1997/98 (*DUR* prices are not available until 1981/82). The price and quantity data were obtained from the USDA-ERS and the producer price indices are from the Bureau of Labor Statistics. Real input and output prices were defined by deflating with the Producer Price Index.

Wheat prices are calculated by the ERS for the leading classes by geographic region in the U.S. In particular, the *HRW* price is calculated as the average price received by producers in Kansas, Nebraska, Texas, Oklahoma, and Arkansas. *SRW* price is an average from the geographic region containing Ohio, Indiana, Illinois, and Missouri. The *SWW* price is an average of all wheat produced in Washington, Oregon, and Idaho. *DUR* is the average price received by farmers for all durum wheat produced in the US. The *HRS* price is the average price received by producers in the US for other spring wheat. Output prices for the milling industry were compiled from the *Milling and Baking News* (Sosland). The series include flour prices of Kansas City bakers standard (*KCB*) for *HRW*, Minneapolis spring standard (*MNS*) for *HRS*, Chicago cracker (*CHC*) for *SRW* and *SWW*, and semolina (*SEM*) flour for *DUR*.

The quantity data is wheat used for domestic food use by class. The ERS calculated food use by adding the wheat ground for flour, food imports (including all wheat flour, semolina, all pastas, and couscous), and a constant (estimated by ERS), less food exports (including wheat flour, semolina, and all pastas). Total food use has increased 56% from 587 million bushels in 1977 to 915 million bushels in 1998. However, by-class food use has remained fairly constant relative to total food use in this time period. *HRW* accounted for 44% of total food use in 1977 and 43% in 1998, with an average of 41% from 1977 to 1998. *HRS* food use was 23% of the total in the beginning and ending years, averaging 25%. *SRW* accounted for 19% of total food use in 1977 and 17% in 1998, averaging 19%. *SWW* was 7% in the beginning and ending years and as an average it represented 8% of total food use. *DUR* food use was 6% of total in 1977 and 8% in 1998, averaging 7%.

**Empirical Methods**

The factor demand equations are derived from a normalized quadratic profit function. The normalized quadratic allows estimation of price elasticities, as well as the explicit investigation of the interactions between input prices and output quantity and the impact of technical change. The normalized quadratic function is given by (Shumway, Saez, and Gottret 1988)

$$\Pi^*(p,w) = b_0 + \sum_{i=1}^{m-1} b_i w_i^* + \sum_{i=1}^{m-1} b_i p_i^* + .5\left( \sum_{i=1}^{m-1} \sum_{j=1}^{m-1} b_{ij} w_i^* w_j^* + \sum_{i=m+1}^{n} \sum_{j=m+1}^{n} b_{ij} p_i^* p_j^* \right) + \sum_{i=1}^{m-1} \sum_{j=m+1}^{n} b_{ij} w_i^* p_j^*$$

where normalized profit, input prices, and output prices are defined by $\Pi^*=\Pi/w_m$, $w_i^* = w_i / w_m$, and $p_i^* = p_i / w_m$. This formulation assumes *m* inputs and *k*=*n*-*m* outputs.

In the estimation, symmetry is imposed by defining $b_{ij} = b_{ji}$. Homogeneity is imposed by normalizing the input prices, output prices, and profit. Hence, the uncompensated input demand equations are given by

$$-x_i = b_i + b_{1i} w_1^* + b_{2i} w_2^* + b_{3i} w_3^* + b_{4i} w_4^* + b_{5i} p_1^* + b_{6i} p_2^* + b_{7i} p_3^* + b_{8i} p_4^* \quad \text{for i=1, ... ,m}$$

and the output supply equations are given by

$$y_i = b_i + b_{1i} w_1^* + b_{2i} w_2^* + b_{3i} w_3^* + b_{4i} w_4^* + b_{5i} p_1^* + b_{6i} p_2^* + b_{7i} p_3^* + b_{8i} p_4^* \quad \text{for i=m+1, ... ,n}$$

The profit function, the factor demand system, and the output supply equations yield a set of *n*+1 equations to be estimated. The own-price elasticities are given by

$$e_{ii} = \frac{b_{ij} \overline{w_j}}{\overline{x_i}} \quad \text{for i=j}$$

The cross-price elasticities are given by

$$e_{ij} = \frac{b_{ij}\overline{w_j}}{\overline{x_i}} \quad \text{for } i \neq j$$

Before presenting the results, several limitations of the study need to be identified. In the results presented below an incomplete model is estimated. Only the factor demand equations, but not the profit and output supply equations, are estimated from the normalized quadratic model. This is due to limited number of observations in the data set and output quantity information. For example, with only 17 observations the profit function is not estimable using standard econometric techniques. This suggests that the estimates from the incomplete demand system will not be as efficient as those from a complete system.

Furthermore, price and quantity information are not available for other factor inputs (i.e., capital, labor, energy) that cover the same marketing year as the wheat data. To attempt and account for this in the normalized quadratic model, the producer price index is used as a proxy for the price of all other factor inputs into the production process. That is, it is used to normalize the input and output prices, or $w_m = PPI$. Based on the literature review, the important missing factor input is capital, which represents changes in capacity of flour mills over time (Harwood et al. 1989). Given the omitted variables, it is possible that the coefficient estimates are biased.

**Results**

Initially, the factor demand system consisted of the five wheat classes: hard red winter (*HRW*), hard red spring (*HRS*), soft red winter (*SRW*), soft white (*SWW*), and durum (*DUR*). However, the own-price elasticity for *SRW* was predominantly positive across different model types and various econometric estimators (see Terry). To accommodate this problem, *SRW* and *SWW* are combined into soft wheat (*SW*) that reduced the number of demand equations to four. Note that soft red winter wheat and soft white wheat are generally used to produce the similar products. The price of soft wheat was calculated as the simple weighted average of *SRW* and *SWW*.

Tables 1 and 2 contain the parameter estimates and price elasticities for the normalized quadratic factor demand system, respectively. Technical change values are all negative and significant for all classes. The values are expected to be negative in this framework because the dependent variable is defined to be negative. R-square values between observed and predicted values range from 0.70 for *HRS* to 0.97 for *SW*. However, the Durbin-Watson statistics, ranging from 0.82 to 1.5, suggest the presence of autocorrelated errors. Signs of the own-price coefficient estimates were positive (as expected) and the own-price elasticities were negative. The results indicate that the own-prices are inelastic for *HRS*, *SW*, and *DUR*. The most inelastic being *SW*, followed by *DUR* and *HRS*. The own-price elasticity is elastic for *HRW*.

The cross-price elasticities indicate that *HRW* is substitutable for all classes and all classes are substitutable for *HRW*. Moreover, *HRW* is less price responsive to *HRS*, *SW*, and *DUR* than *HRS*, *SW*, and *DUR* are to *HRW*. The cross-price elasticities for *HRS* and *SW* are very similar, but do not indicate substitutability as they are both negative. *DUR* is shown to be more responsive to the price of *SW* than *SW* is to the price of *DUR*.

Following economic theory, the elasticities for output prices were positive for the own end uses. The cross-price results indicate that *HRW* is responsive to the output price of *DUR*, but the opposite is not true. None of the remaining classes are positively responsive to the output price of *HRW*. *SW* is almost twice as sensitive to the *HRS* output price as *HRS* is to the *SW* output price. The *DUR* quantity is more than four times more responsive to the *HRS* output price than *HRS* quantity is to the *DUR* output price.

**Discussion**

For comparison purposes, consider the results of Chai (1972), who examined the food demand for wheat by class from 1929 to 1963, and Barnes and Shields (1998), who examined the consumer demand for wheat by class from 1977 to 1995. In general, Chai found that the soft wheat types were least responsive to own price changes and the hard wheat types the most responsive to own price changes. These estimates were obtained using equation-by-equation OLS. The Barnes and Shields equation-by-equation OLS results were similar. In contrast, Barnes and Shields reported estimates from a double-log consumer demand system using a seemingly unrelated regression estimator, which indicated that soft red winter wheat was the most price responsive. The results of the current study are consistent with equation-by-equation OLS results of Chai and Barnes and Shields, but quite different from the Barnes and Shields double-log consumer demand system.

A predominate difference between the results of the current study's derived demand system and the Barnes and Shields double-log demand system was the estimated own-price elasticity of SRW. Across a host model specifications and econometric estimation techniques, the own-price elasticity for soft red winter wheat was predominately positive (Terry 2000). This conflicts with the finding of Barnes and Shields, who reported a negative own-price for soft red winter wheat. One explanation for the conflicting results is data revisions of the domestic food use series for wheat.

**Policy Implications**

Understanding the economic substitutability and price responsiveness among wheat classes is of interest to various industry agents, researchers, and policymakers. First, in periods of supply shortages, millers may be forced to blend wheat more than typically desired. Second, and of particular importance to Kansas and other states, new varieties of hard white wheat are being introduced that have qualities similar to that of hard red varieties (Boland and Howe). To understand economic substitutability and the potential economic impacts of introducing new varieties of hard white wheat, it is informative to understand the relationships among the existing wheat classes.

In the event that the supply of a specific class of wheat is lower than normal, millers often have to substitute an alternative class to maintain desired production levels. Chai (1972) stated that *HRW* can be substituted for *HRS*, *SRW*, *SWW*, or hard white wheat, and *SRW* can be substituted for *HRW*. Additionally, *HRW* and *HRS* can be substituted for *DUR*. Better understanding of the economic substitutability between wheat classes can help prepare flour millers to respond to changes in supply and demand within the wheat market.

Because of the similarities between *HRW* and new hard white wheat varieties (Boland, Johnson, and Schumaker), it is informative to focus on the relationships between *HRW* and other wheat classes. *HRW*, which has a wide range of protein content, is the most versatile class of wheat and it can be used as a substitute in production processes where a different class of wheat is the predominant input. Specifically, Chai (1972) indicated that *HRW* can be used for bread flour in the place of *HRS* or hard white wheat. Furthermore, it can replace *SRW* or *SWW* in the making of all-purpose and pastry flours.  Similarly, the results of the current study indicate that *HRW* is substitutable for and *HRS*, *SW*, and *DUR*.  For sake of discussion, assume that a new hard white variety is a perfect substitute for *HRW*.  Hence, substitution between the new hard white variety and other wheat classes may be inferred from *HRW*.  Alternatively, if the new hard white variety is more or less versatile as *HRW*, then the results of this study provide baseline estimates of relationships between the new hard white variety and other wheat classes.

**Conclusions**

Economic theory dictates that consumer demand for wheat products is final demand, whereas demand for wheat in raw product form is derived demand.  As a result, a factor demand system is conceptualized and specified for wheat as an input into flour production.  The factor demand system, derived from the normalized quadratic profit function, was estimated and then compared to findings of previous studies.

Empirical results of this study are for the most part encouraging.  As economic theory dictates the expected sign for the own-price elasticity for hard red spring, hard red winter, soft, and durum wheat are all negative.  In most cases the soft wheat varieties are less responsive to their own price than the hard wheat varieties.  This is consistent with Chai, but not the Barnes and Shields demand system results.  The cross-price elasticities are different from those previously reported and have important policy implications.  In contrast to previous reports, substitution elasticities indicate that *HRS* is slightly more price responsive to *HRW*, than *HRW* is to *HRS*.  Additionally, in many cases *SW* is only moderately more price responsive to *HRW*, than *HRW* is to *SW*, unlike the extreme differences reported in previous studies.

Finally, there are several important limitations of this study. First, the empirical results are based on a restricted profit function. Ideally the derived demand system should accommodate all factor input prices. Second, because of limited data, only the factor demand equations were estimated. Third, soft red winter and soft white wheat were combined into soft wheat. Given these limitations, the findings of this study should be considered preliminary in nature. Additional research is needed to investigate the relationship between soft red winter wheat used for food and its own price and prices of substitutes. Even with such limitations, the results of this study are an important step in understanding the economic substitution between wheat classes and suggest directions for future research.

**Table 1. Parameter estimates[a] from the Normalized Quadratic factor demand system. Study period from 1981 to 1997.**

| Variable | Equation $q_{HRW}$ | $q_{HRS}$ | $q_{SW}$ | $q_{DUR}$ |
|---|---|---|---|---|
| **t** | -6.1153 | -6.3869 | -4.5196 | -3.6550 |
| | (-6.0906) | (-7.0980) | (-12.585) | (-16.119) |
| $w_{HRW}$ | **14971.0** | -9063.8 | -2995.7 | -1754.7 |
| | (4.6387) | (-4.7928) | (-1.0907) | (-1.2789) |
| $w_{HRS}$ | -9063.8 | **4574.7** | 2738.6 | 3532.4 |
| | (-4.7928) | (0.7381) | (1.0375) | (3.8617) |
| $w_{SW}$ | -2995.7 | 2738.6 | **1097.7** | -1317.9 |
| | (-1.0907) | (1.0375) | (1.1644) | (-2.0690) |
| $w_{DUR}$ | -1754.7 | 3532.4 | -1317.9 | **630.69** |
| | (-1.2789) | (3.8617) | (-2.0690) | (1.4196) |
| $p_{HRW}$ | **-2276.4** | 1134.0 | 251.66 | 21.9920 |
| | (-0.9657) | (0.8446) | (0.2899) | (0.0370) |
| $p_{HRS}$ | 1697.6 | **-1100.1** | -714.23 | -820.46 |
| | (2.3573) | (-1.0902) | (-1.0939) | (-2.7524) |
| $p_{SW}$ | 663.52 | -355.25 | **-16.4930** | 589.13 |
| | (1.0834) | (-0.4981) | (-0.0776) | (4.8795) |
| $p_{DUR}$ | -225.19 | -386.07 | 499.01 | **-29.6850** |
| | (-0.5810) | (-1.1041) | (2.4888) | (-0.2408) |
| **Constant** | -273.45 | -122.08 | -149.71 | -40.1650 |
| | (-4.2125) | (-2.6319) | (-6.6655) | (-2.6388) |
| **R-Square[b]** | 0.7892 | 0.6950 | 0.9725 | 0.9583 |
| **Durbin-Watson** | 0.8249 | 1.1647 | 1.5002 | 0.9574 |

[a] Coefficients were estimated in an iterative seemingly unrelated regression model and prices are deflated by the producer price index. Symmetry is imposed.
[b] R-square between predicted and actual quantities of wheat.

**Table 2. Elasticity estimates[a] from the Normalized Quadratic factor demand system. Study period from 1981 to 1997.**

| Variable | Equation | | | |
|---|---|---|---|---|
| | $q_{HRW}$ | $q_{HRS}$ | $q_{SW}$ | $q_{DUR}$ |
| $w_{HRW}$ | **-1.5333** | 1.5341 | 0.4851 | 0.9595 |
| $w_{HRS}$ | 0.9572 | **-0.7984** | -0.4572 | -1.9917 |
| $w_{SW}$ | 0.3068 | -0.4635 | **-0.1777** | 0.7205 |
| $w_{DUR}$ | 0.2028 | -0.6747 | 0.2408 | **-0.3892** |
| $p_{HRW}$ | **0.6885** | -0.5668 | -0.1203 | -0.0355 |
| $p_{HRS}$ | -0.5487 | **0.5876** | 0.3650 | 1.4159 |
| $p_{SW}$ | -0.2079 | 0.1840 | **0.0082** | -0.9857 |
| $p_{DUR}$ | 0.0875 | 0.2480 | -0.3067 | **0.0616** |

[a] Elasticity estimates calculated at the means.

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