ECONOMIC SUBSTITUTION FOR U.S. WHEAT FOOD USE BY CLASS

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Abstract: Wheat for food use is conceptualized as an input into flour production and demand is derived from an industry profit function to quantify price responsiveness and economic substitutability across wheat classes. Price and substitution elasticities are estimated for hard red winter, hard red spring, soft red wheat, soft white winter, and durum wheat. In general, hard red winter and spring wheat varieties are much more responsive to their own price than are soft wheat varieties and durum wheat. Substitution elasticities indicate that hard red winter and hard red spring wheat are economic substitutes for milling purposes.

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1. Introduction

Likeness in products or commodities is a principal element in trade and agricultural policy. For instance, like domestic product provisions of the General Agreement on Tariffs and Trade (GATT) play a key role in trade dispute rulings.[1] World Trade Organization (WTO) rulings have covered a range of problems that involve like product determinations, including antidumping and safeguard measures (Bhala and Gantz 2001). Product substitutability is core to the interpretations and rulings of like product determinations. Economic measures of substitutability can assist the recognition of product substitutability in trade law and facilitate settlement of trade disputes (Choi 2003). Estimates of price and substitution elasticities summarize responsiveness of commodities to price changes and are useful measures in formulating agricultural policy (Ahmadi-Esfahani 1989).

Recently, the United States International Trade Commission (USITC) investigated whether the U.S. was materially injured by reason of imports of hard red spring wheat from Canada. Central to the investigation was like product determinations of hard red spring wheat and hard red winter wheat. The USITC reported that while physical substitutability among wheat classes has been studied, there were surprisingly few estimates of substitution elasticities across U.S. wheat classes.[2] A better understanding of substitutability across wheat classes would facilitate future trade disputes, improve food use predictions, enhance other studies of flour milling (Sosland 1998) and assist research programs to develop new varieties of hard white wheat (Boland, Schumacher, and Johnson 2000). Market information is particularly relevant to Australia because it directly competes with the U.S. in wheat export markets.

Given the importance of like product determination in trade and domestic substitution issues, the purpose of the current study is to investigate economic substitution among U.S. wheat classes. This study contributes to the literature in several ways. First, an economic model is specified as a profit function for the flour industry that allows for multiple input prices to account for different classes of wheat. This is consistent with the cost minimization approach applied by Koo, Mao and Sakuarai (2001) for the Japanese flour milling industry in that it does not assume that wheat is a homogenous input. Given that it is motivated by profit maximization, it is conceptually different from the consumer demand approaches examining U.S. wheat by class employed by Chai (1972) and Barnes and Shields (1998). Second, an empirical profit system (profit function and factor demand equations) is specified to estimate price and substitution elasticity measures across wheat classes in the U.S. using aggregate wheat food use data. Previous studies have reported only price elasticities for domestic wheat by class, which are not preferred measures of the ease of substitution (Blackorby and Russell 1989). It is maintained that a demand system framework provides a relevant market setting (1) to posit and test economic hypotheses, (2) to efficiently estimate own- and cross-effect measures of price and substitution elasticities for U.S. wheat food use by class, and (3) to provide insight into like product issues reflective of commercial agreement and market concerns.[3] Indeed, we find that economic restrictions (symmetry and curvature) are not rejected in the demand system and that wheat prices and trend variables account for 0.89 to 0.97 of the variation in domestic demand for wheat by class in the U.S.

The paper proceeds as follows. First, background information is provided on research for wheat by class. Then, approaches to specifying a conceptual profit function for the flour industry and an empirical demand system are presented. This is followed by presentation of data and estimation issues of the empirical demand system, as well as results and discussion. Finally, implications and concluding remarks are provided.

2. Background

There are five major classes of wheat grown in the U.S. for food consumption, including hard red winter (*HRW*), hard red spring (*HRS*), soft red winter (*SRW*), soft white (*SWW*), and durum (*DUR*) wheat.[4] Most *HRW* is grown in the central and southern Great Plains, *HRS* in the northern Great Plains, *SRW* east of the Mississippi River, *SWW* in the Pacific Northwest and *DUR* in North Dakota and Montana. Historically, wheat for food in the U.S. has been used predominately as input into flour production.[5] The hard wheat classes have higher protein content desirable for baking. The higher protein content in hard red spring and hard red winter wheat is suited for the production of bread and rolls. Durum is used in the production of semolina flour and a variety of pasta products. The soft wheat classes have lower protein content. Soft red winter wheat is used in flat breads, cakes, crackers, and pastries. Soft white wheat is processed into crackers, cookies, pastries, muffins, and flour for cakes. *HRW* has the widest range of protein content and is often mixed with *HRS* and *SRW*.

Various studies have examined international wheat markets. Ahmadi-Esfahani (1989) estimated export demand functions for Canada and the U.S., emphasizing the importance of collecting any information that provides insight on the magnitude of elasticities of demand and its role in formulating agricultural policy. Using a log-linear demand relationship between two countries' relative exports and relative prices, he found that relative export prices plus ocean freight rates were important in allocating imports between competing exporting countries. Alston et al. (1990) compared Armington, double-log, and almost ideal demand models for wheat and cotton imports and stressed the need to test whether demand restrictions are appropriate. The Armington model, which can be nested within the more general double-log model by restricting substitution effects, was comprehensively rejected. Wilson and Gallagher (1990) investigated the effects of relative prices on shifts of imported wheat class market shares. They found quality differentials and prices both were competitive factors in international markets. Larue (1991) investigated several issues related to wheat quality for Australia, Canada, and the U.S. Estimating a hedonic price model of FOB prices, he suggested that product differentiation by country of origin and end use was important and that average annual wheat prices were influenced by protein content. Applying hedonic price models to Australia's export markets, Ahmadi-Esfahani and Stanmore (1994) found that the growing Asian markets were conscious of quality, with significant premiums for protein. Mohanty and Peterson (1999) estimated import demand for wheat by class and origin for the U.S. and European Union (EU). They examined several classes of wheat, separating *DUR* from spring wheat and other wheat. Reported price elasticities indicated that *DUR* was more price responsive than spring wheat, which was more price responsive than other wheat. Finally, Dahl and Wilson (2000) examined changes in exports of hard wheat across grades and classes in the U.S. and Canada. They reported change in the distribution among exports by grade and class and predicted that the domestic processing sector (relative to the export market) would have less dominance over higher quality wheat. A common theme in this literature is that of more freely differentiating wheat by end use, geographic region, or origin, as well as the importance of protein content, in the analysis of international wheat markets.

Other studies have examined various aspects of wheat quality on domestic U.S. prices. Bale and Ryan (1977) applied a "Lancaster" production characteristics approach to differentiate classes of wheat by their protein content. Estimates of relative wheat prices were obtained from simple measures of protein supply. This illustrated that relative price movements between two closely related wheat commodities could be predicted by characteristics of those commodities. Espinosa and Goodwin (1991) estimated a hedonic price model for Kansas wheat characteristics. They concluded that wheat prices were responsive to differences in the quality of wheat, as measured both at the farm gate and in milling and baking end uses. Parcell and Stiegert (1998) also estimated the marginal value of hard red spring and red winter wheat-grading characteristics and wheat protein in a spatially competitive framework. The marginal values of protein in Kansas *HRW* and North Dakota *HRS* were affected by the level of protein in other districts within and across regions. These studies further illustrate the role that quality characteristics (in particular protein content) play in determining wheat prices.

Several studies have attempted to differentiate among end uses by estimating domestic U.S. consumer demand by wheat class.[6] Demand for each wheat class was specified as a function of its own-price, prices of competing classes, and income. Chai (1972) estimated domestic demand for wheat by class over the period from 1929 to 1963. Linear equation-by-equation OLS demand models were estimated for *HRW*, *HRS*, *SRW*, *SWW*, and *DUR* using wheat cash prices from major markets. Price elasticities were reported to be more elastic for hard classes than soft classes of wheat. Barnes and Shields (1998) estimated a double-log demand system for wheat by class. The wheat classes examined were *HRW*, *HRS*, *SRW*, *SWW*, and *DUR*. Annual data from 1981 to 1998 were used in the demand system analysis with regional prices at the farm level. Inelastic own-price elasticities were reported for each of the five wheat classes with *SWW* being the most elastic and *DUR* being the least elastic. Barnes and Shields (1998) also estimated linear equation-by-equation OLS models that yielded results qualitatively consistent with Chai (1972). However, Terry (2000) reported inconsistencies with the Barnes and Shields' double-log demand approach further motivating the need to investigate wheat food use by class.

Different from the previous studies, the current study examines wheat by class demand from a U.S. flour milling industry profit function and derives domestic price and substitution elasticity estimates. This approach has advantages. First, consumers in the U.S. typically do not utilize raw grain products for direct consumption. Rather, raw wheat is processed into flour before consumption. Moreover, only 15% of the flour processed is directly sold to consumers, while the other 85% is used in baked goods (Harwood et al. 1989). Second, specification of consumer income in the demand for raw wheat product is not generally consistent with economic theory. Rather, changes in income are signaled through retail prices of flour and baked goods to flour millers and processors. Third, use of farm level prices in a consumer demand model is also problematic. Consumers respond to retail level prices of flour and baked goods. In contrast, in the processing sector, flour millers respond to farm level wheat prices in the input market and flour prices in the output market. Consequently, price elasticities and measures of substitutability across wheat classes derived from an industry profit function of the flour industry are consistent with economic theory and, as will be discussed ahead, are consistent with data available to estimate empirical relationships. Examining demand from a profit function of the flour industry provides insight about U.S. wheat food use different from that provided by previous studies.[7]

3. Deriving demand for wheat food use

Following Wohlgenant (1989), Goodwin and Brester (1995), and Koo, Mao, and Sakuarai (2001), raw product is considered an input into food production. We specify an industry profit function for the flour milling industry and derive factor demand equations. By specifying a profit function, we do not have to assume that wheat is a homogenous input nor that flour is a homogeneous output, but rather can differentiate among types of wheat through input prices and flour produced through output prices.[8] Finally, millfeed output is not considered in the conceptual model specification. This is because millfeed is a by-product of flour milling that is used as feed input in the livestock industry and prices typically follow other feed stuffs such as corn prices (Harwood et al. 1989).

3.1 Conceptual model

Assuming that price-taking firms face the same input and output prices, an indirect profit function for the ℓth firm in the flour industry is defined by

$$\Pi^{\ell}(\mathbf{p},\mathbf{w}) = \Pi^{\ell}\left(\mathbf{y}^{\ell}(\mathbf{p},\mathbf{w}),\mathbf{x}^{\ell}(\mathbf{p},\mathbf{w})\right) = \max_{\mathbf{y}^{\ell},\mathbf{x}^{\ell}}\left\{\mathbf{p}'\mathbf{y}^{\ell} - \mathbf{w}'\mathbf{x}^{\ell} : \mathbf{y}^{\ell} = f^{\ell}(\mathbf{x}^{\ell})\right\} \tag{1}$$

where $f^{\ell}(\bullet)$ is its production technology, $\mathbf{p} = \left(p_1,..., p_{n_1}\right)'$ is a ($n_1\times$ 1) vector of output prices, $\mathbf{y}^{\ell} = \left(y_1^{\ell},..., y_{n_1}^{\ell}\right)'$ is a ($n_1\times$ 1) vector of firm output quantities, $\mathbf{w} = \left(w_1,..., w_{n_2}\right)'$ is a ($n_2\times$ 1) vector of input prices, and $\mathbf{x}^{\ell} = \left(x_1^{\ell},..., x_{n_2}^{\ell}\right)'$ is a ($n_2\times$ 1) vector of firm input quantities. The underlying behavioral assumption is a bundle of output and input quantities for the ℓth firm $\left(\mathbf{y}^{\ell},\mathbf{x}^{\ell}\right)$ is chosen to maximize profits. Summing profit across firms yields an industry profit function defined by $\Pi(\mathbf{p},\mathbf{w}) = \sum \Pi^{\ell}(\mathbf{p},\mathbf{w})$. Then $\mathbf{y} = \left(y_1,..., y_{n_1}\right)'$ is a ($n_1\times$ 1) vector of industry output quantities such that $y_j = \sum_{\ell} y_j^{\ell}$ and $\mathbf{x} = \left(x_1,..., x_{n_2}\right)'$ is a ($n_2\times$ 1) vector of industry input quantities such that $x_j = \sum_{\ell} x_j^{\ell}$. The standard properties of a profit function using netput notation are that it is homogenous of degree one, nondecreasing, and convex in prices (Chambers 1988).[9]

Two important simplifying assumptions are made that are consistent with available data and that provide a more parsimonious empirical profit function specified ahead. First, output prices are aggregated into a weighted average flour price, $p = \sum_{i=1}^{n_1} s_i p_i$, where s_i is the quantity of output type i relative to total production. This assumption reduces the number of parameters to be estimated in the empirical model, while still reflecting potential quality changes as signaled by weighted flour prices.[10]

Second, it is convenient to assume the profit function is weakly separable in inputs, partitioning inputs into two subgroups of wheat and other inputs

$$\Pi = \Pi\left(p, \mathbf{w}\right) = \Pi\left(\pi^1\left(p, \mathbf{w}^1\right), \pi^2\left(p, \mathbf{w}^2\right), p\right) \tag{2}$$

In (2), π^1 and π^2 are micro-functions, $\mathbf{w^1} = \left(w_1, ..., w_{n_k}\right)'$ is a $\left(n_k \times 1\right)$ vector of input prices representing the different classes of wheat, and $\mathbf{w}^2 = \left(w_{n_{k+1}}, ..., w_{n_2}\right)'$ is a $\left(n_2 - n_k \times 1\right)$ vector of prices for the remaining inputs (e.g., capital, labour, energy).[11] The conditional factor demand equations for wheat by class may be obtained by applying Hotelling's Lemma to the micro-function π^1

$$\frac{\partial \pi^1}{\partial \mathbf{w}^1} = -\mathbf{x}^1(p, \mathbf{w}^1) \tag{3}$$

Hence, each optimal factor input for the industry varies with input prices and weighted output price.

The weak separability assumption above imposes specific restrictions across the wheat and other inputs groups. An implication of maintaining weak separability is that a marginal change in price of an input from outside of the wheat group (e.g., energy) has no effect on the ratio of marginal profits from any two inputs within the wheat group. This is equivalent to requiring symmetric factor demand elasticities between the wheat group and the other input group, or $\varepsilon_{i\ell} = \varepsilon_{j\ell}$ for $i \neq j \in \left\{1, ..., n_k\right\}$ and $\ell \in \left\{n_{k+1}, ..., n_2\right\}$ (Chambers 1988). Although weak separability imposes restrictions, the assumption offers flexibility to estimate price and substitution demand elasticities across wheat classes, yet retains sufficient degrees of freedom for estimation purposes.[12]

3.2 Empirical model

To complete the model specification, the factor demand equations in (3) are derived from a normalized quadratic profit function. The normalized quadratic is a flexible functional form that allows estimation of price and substitution elasticities (e.g., Shumway, Saez, and Gottret 1988, Featherstone and Moss 1994), as well as the explicit investigation of the interactions between input prices. The normalized quadratic function is given by

$$\Pi^*(w,y) = b_0 + \sum_{i=1}^{n_k} b_i w_i^* + \frac{1}{2}\left(\sum_{i=1}^{n_k}\sum_{j=1}^{n_k} b_{ij} w_i^* w_j^* \right) + b_t t + \sum_{j=1}^{n_k} b_{it} w_i^* t + \frac{1}{2} b_{tt} t^2 \tag{4}$$

In (4), normalized profit and input prices are defined by $\Pi^* = \Pi / p$ and $w_i^* = w_i / p$. A time trend (t=1,….,T) is included to capture potential changes in technology or other factors over time. Hence, the input demand equations are given by

$$-x_i = b_i + \sum_{j=1}^{n_k} b_{ij} w_j^* + b_{it} \mathrm{t} \text{ for } i = 1,\dots,n_k \tag{5}$$

The complete system of equations consists of the profit function in (4) and n_k demand equations in (5).[13] Homogeneity is consistent with normalizing the input prices and profit. Convexity of input prices can be imposed by reparameterizing the matrix **B** of input price coefficients into $\mathbf{B}^*$ as

$$\mathbf{B}^* = \begin{bmatrix} b_{1,1}^* & \cdots & b_{1,n_k}^* \\ \vdots & \ddots & \vdots \\ b_{n_k,1}^* & \cdots & b_{n_k,n_k}^* \end{bmatrix} = \begin{bmatrix} a_{1,1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ a_{n_k,1} & \cdots & a_{n_k,n_k} \end{bmatrix} \begin{bmatrix} a_{1,1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ a_{n_k,1} & \cdots & a_{n_k,n_k} \end{bmatrix}' = \mathbf{AA}' \tag{6}$$

where $\mathbf{B}^*$ is a positive semi-definite matrix (Lau 1978). Symmetry requires that $b_{ij}^* = b_{ji}^*$.

Factor demand price elasticities are given by the equation

$$\varepsilon_{ij} = \frac{\partial \ln x_i}{\partial \ln w_j} = \frac{b_{ij}^* w_j^*}{\hat{x}_i} \quad \text{for } i, j = 1,\dots, n_k \tag{7}$$

using the estimated b_{ij}^{*} and the predicted $\hat{x}_i$. Generalized factor ratio elasticities of substitution are defined as

$$\sigma_{ij} = \frac{\partial \ln\left(x_j / x_i\right)}{\partial \ln\left(w_i / w_j\right)} = \varepsilon_{ji} - \varepsilon_{ii} \text{ for } i, j=1,\ldots, n_k \tag{8}$$

which measure the effect of varying the factor price ratio in the *i*th direction on the factor quantity ratio x_j / x_i (Davis and Shumway 1996). Alternatively, equation (8) implies that the elasticity of substitution can be constructed as a difference between cross- and own-price elasticities. Like the Morishima substitution elasticities (Blackorby and Russell 1989), the generalized factor substitution elasticities are inherently asymmetric.[14]

4. Data and estimation issues

Annual prices and quantities for the empirical analysis for each of the five wheat classes are based on June to May marketing years, from 1974/1975 to 2001/2002. Descriptive statistics are provided in Table 1. Wheat quantity and price data were collected from U.S. Department of Agriculture's Economic Research Service, *Wheat Year Book*, annually from 1974 to 2001. Total flour production increased from 251 million cwt in 1974 to 421 million cwt in 2000, averaging 338 million cwt over the period. Total wheat food use (the sum of *HRW*, *HRS*, *SRW*, *SWW*, and *DUR* food use) increased from 545 million bushels in 1974 to 926 million bushels in 2001. Figure 1 presents food use by wheat class, showing food use has trended upwards over time. *HRW* and *HRS* dominated wheat food use and exhibited the most variation from 1974 to 2001. The average (standard deviation) share of total food use was 0.42 (0.03), 0.25 (0.02), 0.18 (0.01), 0.07 (0.01), and 0.07 (0.01) for *HRW*, *HRS*, *SRW*, *SWW*, and *DUR*, respectively.

Given the importance of protein content in wheat as input into flour production, we estimated the empirical model with wheat cash prices from major markets. In particular, the *HRW* price is represented by Kansas City No.1 (13% protein); *HRS* price by Minneapolis dark No.1 spring (14% protein); *SRW* price by Chicago No. 2; *SWW* price by Portland No.1; and *DUR* by Minneapolis No.1 hard amber durum. Over the study period from 1974 to 2001, input prices in U.S. dollars per bushel (standard deviation) were 3.89 (0.65), 4.04 (0.66), 3.37 (0.65), 3.82 (0.61), and 4.74 (1.07) for *HRW*, *HRS*, *SRW*, *SWW*, and *DUR*, respectively.[15] Flour prices for milling industry output were obtained from the *Milling and Baking News*. The series include flour prices of Kansas City bakers standard for *HRW*, Minneapolis spring standard for *HRS*, Chicago cracker for *SRW* and *SWW*, and Minneapolis semolina flour for DUR. These prices were used to form an annual weighted average flour price (*PFL*), which had mean $9.98/cwt with standard deviation 1.40.

4.1 Estimation issues

The complete system consisted of the weakly separable profit function in equation (4) and five factor demand equations in equation (5), including *HRW*, *HRS*, *SRW*, *SWW*, and *DUR*. Output price was used to normalize profit and input prices. Several econometric issues were addressed prior to selecting the final model, including diagnostic statistical tests on symmetry and curvature restrictions and on equation residuals. Summarizing these results: convexity and symmetry restrictions could not be jointly rejected at the 0.05 level using likelihood ratio test statistics;[16] hypothesis of *iid* residuals were not consistently rejected for each of the equations at the .05 level except for soft red winter wheat (see Table 2); and normality of residuals could not be rejected at the 0.05 level of significance except for one case (see Table 2).[17] Furthermore, to draw inferences on the model parameters, price elasticities, and substitution elasticities bootstrapped confidence intervals were constructed.[18] Given the results of the diagnostic testing, the final version of the six-equation system was estimated imposing symmetry and curvature restrictions using an iterative seemingly unrelated regression estimator with a first-order autocorrelation correction.[19]

5. Results and discussion

Parameter estimates, upper critical values, and lower critical values are presented in Table 3 for the wheat demand system. Nineteen of the twenty-eight estimated coefficients are statistically significant at the 0.10 level. The linear trend coefficients are negative and statistically significant for each demand equation, implying a positive trend in quantity demanded for wheat food use in each class over the study period that reflects changes in technology and other factors in the milling industry. R-square values, which explain variation in quantity of wheat for food use, ranged from 0.89 for the *HRS* and *SWW* equations to 0.97 for the *SRW* equation (Table 2).

Table 4 contains industry price elasticities at sample mean values for each demand equation. Signs of the own-price coefficient estimates are negative as required with the imposition of concavity, reflecting that flour millers reduce quantity demanded as own-price increases. The results indicate that the own-prices are inelastic for *HRW*, *SRW*, *SWW*, and *DUR* and elastic for *HRS*. The most inelastic is *SRW* at -0.03. The most elastic is *HRS* at -1.71, followed by *HRW*, *DUR*, and *SWW*, respectively. Cross-price effects are inelastic, except for the impact of a *HRW* price change on the quantity of *HRS*. *SRW* exhibited the most inelastic response to cross-price effects. For the *DUR* equation, the cross-price magnitudes are largest for *HRW* and *HRS* prices. Except for the cross-effects between *HRW* and *HRS*, the bootstrapped confidence intervals for the cross-price elasticities included zero at the 0.10 level of significance. [20]

To interpret measures of substitution across wheat classes, Table 5 reports generalized factor ratio elasticities of substitution at sample mean values. The substitution elasticity σ_{ij} measures the percentage change in the ratio of x_j to x_i for a one percent change in price w_i. Price variation in *HRW* and *HRS* is statistically significant for all of the corresponding factor ratios. For example, one percent increase in the price of *HRS* yields a 2.661 percent increase in the factor ratio of *HRW* relative to *HRS*. From (8) the value 2.661 = 0.949-(-1.712) is the proportional impact of the cross-price elasticity (effect on *HRW* quantity from varying *HRS* price) minus the own-price elasticity (effect on *HRS* quantity from varying *HRS* price). Likewise a one percent increase in the price of *HRS* yields a 1.694, 1.339, and 1.478 percent increase in the factor ratios of *SRW*, *SWW*, and *DUR* relative to *HRS*, respectively. Meanwhile, a one percent increase in the price of *HRW* yields a 2.386, 0.841, 1.230, and 1.170 percent increase in the factor ratios of *HRS*, *SRW*, *SWW*, and *DUR* relative to *HRW*, respectively. Alternatively, price changes in *SRW* yield inelastic and statistically insignificant substitution effects. Price changes in *SWW* are inelastic and significantly influence the factor ratios of *HRW* and *SRW* relative to *SWW*. Finally, price changes in *DUR* are inelastic and significantly influence only the factor ratios of *HRW* and *SRW* relative to *DUR*. If inputs are classified as substitutes (complements) based on a positive (negative) sign of the generalized factor ratio elasticity of substitution, then statistical evidence is found only for substitution among pairs of wheat classes. In all, based on the magnitude of the substitution elasticities, these results suggest that there is more potential for economically significant substitution between *HRW* and *HRS* than between any other pairs of wheat classes. However, because the magnitude of the elasticities remains bounded, substitution between *HRW* and *HRS* is limited implying they are not perfect substitutes.[21]

The substitution elasticities in Table 5 exhibit revealing and predominately asymmetrical responses over the study period. The own-price elasticities for *HRS* and *HRW* induce generalized factor elasticities of substitution between the two that are larger in magnitude and more symmetric relative to the other pairs of wheat classes. For instance, substitution elasticities with respect to price variation in *HRS* yield magnitudes that are all elastic and statistically significant. In contrast, substitution elasticities with respect to price variation in *SRW* yield magnitudes that are all inelastic and statistically insignificant. Thus, changes in the prices of the higher protein wheat tended to induce larger substitution effects across wheat classes. In contrast, changes in the prices of lower protein wheat tended to induce smaller substitution effects across wheat classes.

5.1 Further discussion

For comparison purposes, the own-price elasticities from consumer demand approaches for estimating U.S. wheat by class are presented in Table 6. Using prices from major market locations, Chai (1972) 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 for two study periods from 1929 to 1941 (pre World War II) and 1946 to 1963 (post World War II). Using average prices for each wheat class by U.S. region, Barnes and Shields (1998) reported two sets of price elasticities using an equation-by-equation OLS estimator from 1977 to 1995 and using a double-log demand system estimated with seemingly unrelated regression from 1981 to 1997. The equation-by-equation OLS estimates were qualitatively similar to the results reported by Chai (1972). In contrast, the elasticities from the double-log demand system indicated that *SWW* wheat was the most price responsive. The next most price responsive to own-price from the double-log system was the *HRW* equation, followed by *SRW*, *HRS*, and *DUR*.

Interestingly, except for *DUR*, the own-price elasticity estimates from the Barnes and Shields' (1998) double-log demand system fall outside of the 90% confidence intervals constructed for elasticities reported in Table 4. In contrast, and except for *HRS*, the own-price elasticity estimates from the Barnes and Shields' (1998) equation-by-equation OLS estimates fall inside of the 90% confidence intervals constructed for elasticities reported in Table 4. Evidence from the current and previous studies suggests that demand is more responsive to price for hard wheat relative to soft wheat classes. This is consistent with Koo, Mao and Sakuarai (2001), who reported that Japanese flour millers are more sensitive to the price of high quality wheat classes.

It is notable that price elasticities for U.S. flour milling in Table 4 are much smaller in magnitude than those for Japanese flour milling reported by Koo, Mao and Sakuarai (2001). For example, they reported an Allen own-price elasticity of -33.44 for Japanese demand of U.S. hard wheat and conjectured the large magnitudes were a result of using a production theory approach (as opposed to treating wheat as a consumer good). The findings discussed in the preceding paragraph compared elasticities between profit function and consumer demand approaches (albeit different time periods), but did not find dramatically different magnitudes in price elasticities. Nevertheless, there are obviously key differences in the Japanese and U.S. milling situation. For instance, the Japanese domestic production only accounted for about 8% of its total wheat supply in 1998 (Koo, Mao, and Sakuarai 2001). On average, U.S. domestic production accounted for 99% of its total wheat supply from 1974 to 2001 (USDA 2002). As a result, the Japanese flour milling industry has relied heavily on wheat imports while the U.S. four milling industry has relied predominately on domestic production.

6. Implications

Findings from the current research are of importance to industry agents, university researchers, and policymakers. In contrast to previous studies on demand for wheat food by class, which reported that post World War II demand for wheat is inelastic, we find that *HRS* is price elastic. Moreover, potential for substitution is strongest and most symmetric between *HRS* and *HRW*. In hindsight, the substitution response between *HRW* and *HRS* is apparent in the quantity series shown in Figure 1. As a result, we contend this insight provides a more thorough understanding of the economic substitutability between wheat classes and can help to better anticipate and respond to future changes in the quantity demanded for wheat food use.

These findings have relevant implications to like product determination in international trade disputes overseen by the USITC and the WTO. As an illustration, consider the recent investigation determining if the U.S. was materially injured by imports of hard red spring wheat from Canada (USITC 2003). The USITC concluded, while substitution between *HRS* and *HRW* is high when protein content between the classes overlapped, substitutability was low between the bulk of the remaining protein levels. Based on the current analysis using *HRS* prices with 14% protein content and *HRW* prices with 13% protein content, there is empirical evidence supporting substitution between the two classes of wheat at the given protein content levels. Yet even for *HRW* and *HRS*, substitution responses by U.S. millers are not overly large in comparison to results previously reported for Japanese millers.

These implications are also relevant for government price support and export programs. Chai (1972) argued that using an elasticity estimate from all wheat has limited and possibly misleading implications when applied to analysis of individual classes for wheat in domestic food use. Farnsworth (1961) went further and emphasized consequences of ignoring wheat by class relationships. She identified surplus problems and argued they arose from government price support and export programs that kept price spreads between different types and qualities of wheat narrower and less variable. Interestingly, the recent action by the Commodity Credit Corporation to release market loan rates by class reflects the government's recognition of problems that arise by treating wheat as a homogeneous product (U.S. Department of Agriculture 2002).

Of particular importance to some university and government policymakers is the introduction of new varieties of hard white wheat (*HWW*) in the U.S. *HWW* and *HRW* are reportedly close substitutes in baking quality, with the primary difference that *HRW* carries the polyphenol oxidase that may cause discoloration in processed product. Boland and Howe (1999) suggested that an alternative short-run economic incentive for *HWW* could be driven by domestic flour millers in the form of price premiums from millers to growers.[22] For sake of discussion, suppose *HRW* and *HWW* are perfect or nearly perfect economic substitutes. Under this scenario, any relative price increase for *HWW* would likely induce some millers to shift out of *HWW* into other hard wheat classes. For example, using the substitution elasticity from Table 5, a five cent premium in *HRW* would induce an expansion in the factor input ratio of *HRS* to *HRW* by three percent. The point is that potential substitution by millers between wheat classes needs to be considered when planning the introduction and distribution of a new wheat variety. For *HWW*, without some economically significant comparative advantage in the input or output markets, or technical advantage in processing, it is unlikely that industry itself would provide an economic incentive to produce *HWW*. Indeed, under provisions of the 2002 U.S. Farm Bill (Section 1616, Subtitle F, Title I – Commodity Programs), the CCC is making available $US20 million dollars a year for incentive payments to producers to encourage production of *HWW* for food use (in lieu of premiums from millers to producers).

7. Conclusions

To better understand market responses for wheat food use by class in the U.S., we conceptualized and specified an industry profit function with the different wheat classes as an input into flour production. The profit function and factor demand system from the normalized quadratic function were estimated, price and substitution elasticities assessed, and results compared to findings of previous studies.

This study demonstrates that price and trend variables accounted for 0.89 to 0.97 of the variation in domestic demand for wheat by class in the U.S. Own-price elasticities were more elastic for *HRW* and *HRS* than for *SRW*, *SWW*, and *DUR*. In contrast to previous studies, which reported inelastic own-price elasticities across all domestic wheat classes, we find that *HRS* has an elastic own-price effect. There appears to be more potential for economic substitution between *HRW* and *HRS* than among any other pair of wheat classes, while changes in the prices of the higher protein wheat tended to induce larger substitution effects across wheat classes. Finally, the empirical evidence suggests that U.S. flour millers have much smaller elasticities (i.e., are much less sensitive to price changes) relative to previously reported elasticities for Japanese millers.

There are limitations to this study. First, the empirical results are based on a weakly separable system with a profit function and conditional wheat demand equations. Ideally, the derived demand system should accommodate a complete set of factor demand equations. Second, testing different types of product differentiation for wheat food use in the U.S. needs further investigation. Third, exploring the tradeoffs between protein content levels and substitutability across wheat classes requires additional attention. Fourth, alternative time series or cross sectional data sources should be used to examine seasonality and cross-price effects. Even with such limitations, the findings of this study provide an important step towards understanding the economic substitution of wheat by class among U.S. flour millers.

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Table 1. Descriptive statistics for nominal price and quantity data from 1974 to 2001.

Variable	Mean	St. Dev.	Min	Max
Quantity of Flour (1000 cwt)	337860.00	53861.00	251100.00	421270.00
Price of Hard Red Winter ($US/bu)	3.89	0.65	2.81	5.69
Price of Hard Red Spring ($U.S./bu)	4.04	0.66	2.88	5.72
Price of Soft Red Wheat ($U.S./bu)	3.37	0.65	2.19	4.83
Price of Soft White Wheat ($U.S./bu)	3.82	0.61	2.90	5.27
Price of Durum ($U.S./bu)	4.74	1.07	3.30	7.03
Price of Flour ($U.S./cwt)	9.98	1.40	7.01	13.96
Quantity of Hard Red Winter (million bu)	310.04	47.49	251.00	387.00
Quantity of Hard Red Spring (million bu)	184.29	43.71	128.00	270.00
Quantity of Soft Red Wheat (million bu)	135.18	17.38	94.00	155.00
Quantity of Soft White Wheat (million bu)	55.71	14.98	31.00	85.00
Quantity of Durum (million bu)	55.07	18.37	32.00	81.08

Table 2. Summary and test statistics for normalized quadratic models.

	Equation					
	Profit	HRW	HRS	SRW	SWW	DUR
Model I[a]						
WW [b]	-0.582	-1.643	-1.325	-3.727*	-1.762	-4.120*
KSL[c]	0.131	0.143	0.126	0.069	0.114	0.096
R-square	0.917	0.905	0.894	0.926	0.793	0.862
Model II[d]						
WW [b]	1.601	0.031	0.031	-1.983*	-0.775	-1.580
KSL[e]	0.070	0.081	0.082	0.093	0.177*	0.117
R-square	0. 907	0.921	0.889	0.968	0.893	0.951

[a]Model I - not corrected for autocorrelation with curvature and symmetry imposed. Log-likelihood value -536.241.
[b]Wald-Wolfowitz runs test (Mittelhammer 1996). * reject *iid* residuals at the 0.05 level with critical value 1.96.
[c] Kolmogorov-Smirnov-Lilliefors Normality Test of Errors (Mittelhammer 1996). Critical value of 0.1705 at the 0.05 level with 27 observations.
[d]Model II - corrected for first-order autocorrelation with curvature and symmetry imposed. Log-likelihood value -509.797.
[e] Kolmogorov-Smirnov-Lilliefors Normality Test of Errors. Critical value of 0.1738 at the 0.05 level with 26 observations.

Table 3. Parameter estimates from the normalized quadratic system. Study period from 1974 to 2001.[a]

Coefficient	Coefficient Estimate	Lower Critical Value[b]	Upper Critical Value[b]
b_0	255.405*	249.020	283.170
b_1	-172.736*	-241.948	-110.282
b_2	-167.843*	-296.087	-138.963
b_3	-115.462*	-146.077	-110.130
b_4	-35.324*	-71.517	-23.174
b_5	-22.567*	-43.648	-14.569
b_{11}	701.168*	343.982	1028.776
b_{12}	-743.413*	-1038.169	-395.450
b_{13}	8.156	-38.954	94.168
b_{14}	-54.432*	-217.136	-0.281
b_{15}	-45.053	-85.336	28.923
b_{22}	806.844*	500.517	1230.319
b_{23}	6.022	-75.195	65.858
b_{24}	53.460	-20.756	197.348
b_{25}	33.155	-50.249	74.820
b_{33}	11.651*	3.371	55.393
b_{34}	-4.028	-35.304	16.111
b_{35}	-11.987	-16.108	12.615
b_{44}	5.406*	6.628	104.355
b_{45}	6.671	-15.060	24.417
b_{55}	14.469*	2.295	35.337
b_t	6.342*	4.842	8.345
b_{1t}	-5.020*	-6.016	-4.548
b_{2t}	-6.315*	-6.407	-4.857
b_{3t}	-1.689*	-1.909	-1.553
b_{4t}	-1.774*	-1.911	-1.411
b_{5t}	-2.386*	-2.440	-2.053
b_{tt}	-0.004	-0.125	0.104

[a] Total profit is scaled by 100,000 in estimation.
[b] 90% confidence interval

Table 4. Price elasticity estimates at the sample mean.

Price	Quantity				
	Price Elasticities				
	HRW	HRS	SRW	SWW	DUR
HRW	-0.864*	1.522*	-0.023	0.366	0.306
HRS	0.949*	-1.712*	-0.017	-0.373	-0.234
SRW	-0.009	-0.011	-0.028*	0.024	0.071
SWW	0.066	-0.108	0.011	-0.036*	-0.045
DUR	0.067	-0.082	0.040	-0.054	-0.118*

* 90% confidence interval does not contain zero.

Table 5. Generalized factor ratio elasticities of substitution at the sample mean.

Price change ith direction	Substitution Elasticities σ_{ij}				
	j=HRW	*j*=HRS	*j*=SRW	*j*=SWW	*j*=DUR
i=HRW		2.386*	0.841*	1.230*	1.170*
i=HRS	2.661*		1.694*	1.339*	1.478*
i=SRW	0.020	0.018		0.052	0.099
i=SWW	0.102*	-0.072	0.047*		-0.009
i=DUR	0.185*	0.037	0.159*	0.064	

* 90% confidence interval does not contain zero.

Table 6. Estimated own-price elasticities from previous studies.

	Equation				
	HRW	HRS	SRW	SWW	DUR
Chai (1972)					
OLS single-equation 1929-1941	-1.808	-0.759	-0.447	-0.428 [a]	-0.087 [a]
OLS single-equation 1946-1963	-0.617 [a]	-0.725	-0.091 [a]	-0.022	-0.106 [a]
Barnes and Shields (1998)					
OLS single-equation 1977-1995	-0.746 [a]	-0.468	-0.024 [a]	-0.137 [a]	-0.146 [a]
ITSUR double-log system 1981-1997	-0.420	-0.205	-0.239	-0.769	-0.161 [a]

[a] own-price elasticities contained in 90% bootstrapped confidence intervals constructed for elasticities reported in Table 4.

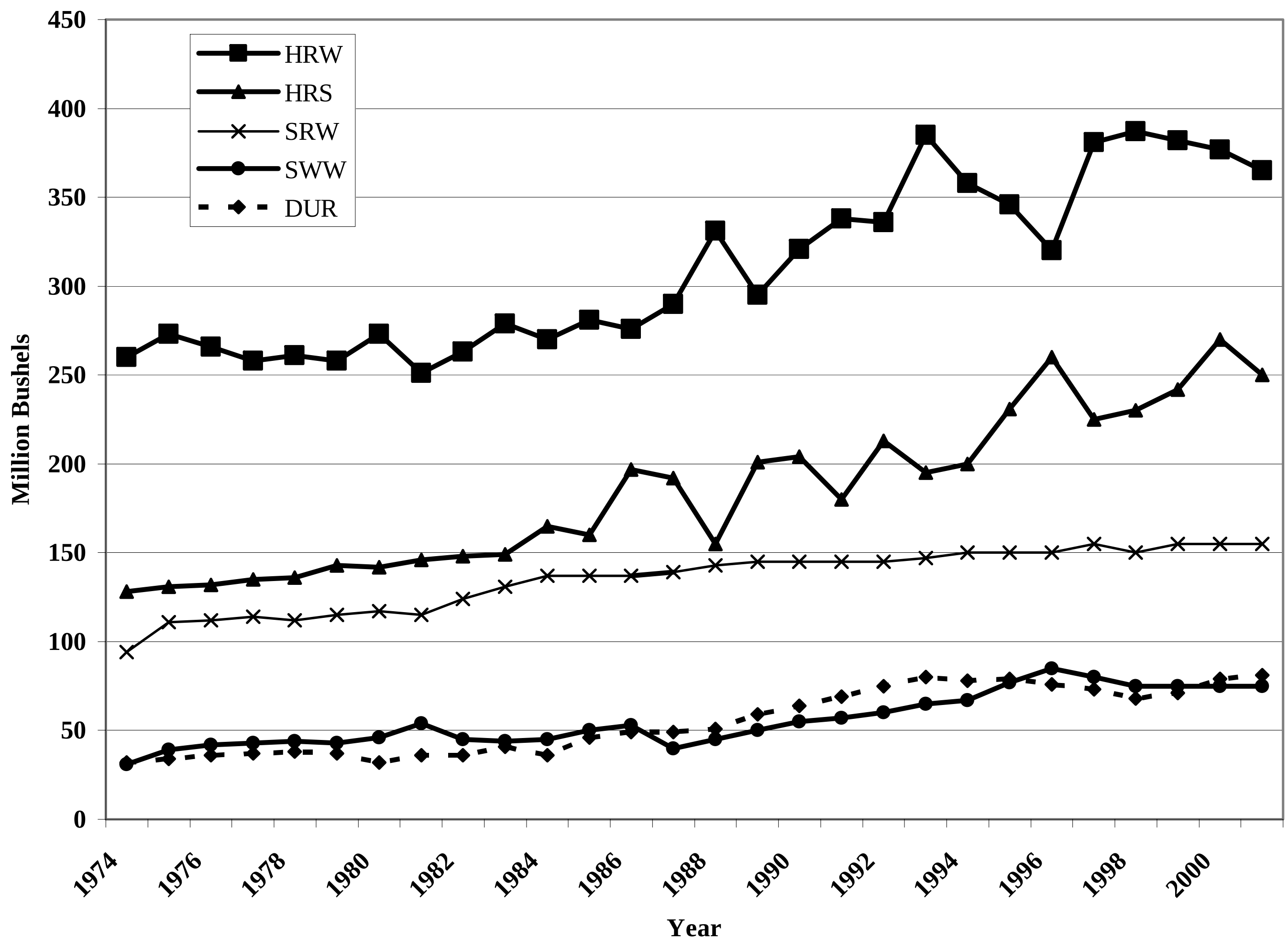

Figure 1. Domestic food use in the U.S. by wheat class from 1974 to 2001.

Footnotes

[1] In like product determinations the United States International Trade Commission generally considers physical characteristics and uses, interchangeability, channels of distribution, customer and producer perceptions of the products, common manufacturing facilities, production processes, and production employees, and where appropriate price.

[2] See USITC (2003) for an extensive survey of this literature, as well as Faridi and Faubion (1995).

[3] See Choi (page 33) for discussion of a 'Relevant Market' with regards to the GATT and the WTO.

[4] Hard white wheat is not explicitly delineated in this analysis because of the lack of consistent time series of data.

[5] Over the period from 1973 to 1998, the average ratio of bushels of wheat used for food to bushels of wheat ground for flour was 97% (U.S. Department of Agriculture).

[6] Blakeslee (1980), and others, assumed perfect substitutability across wheat classes in studies that pursued alternative objectives. He reported inelastic demand for all wheat from 1954 to 1974 with an own-price elasticity of -0.012.

[7] Wohlgenant (1989) provides theoretical and empirical insight into issues between primary and derived demand relationships for agricultural commodities.

[8] Davis (1995) examined fundamental assumptions of product differentiation, arguing that the assumption of product differentiation does not necessarily generate any representative agent demand systems unless additional assumptions are made. Although this is a relevant issue, it is not pursued but remains an alternative for future research.

[9] Chambers and Pope (1996) and (Chambers 1988) have examined other forms of aggregation and implications.

[10] An alternative approach, used in earlier drafts of this paper, specified a dual cost function treating flour as a homogenous output. This specification ignored any quality differences across flour types.

[11] From 1983 to 1998 at the Kansas City Milling center, the cost of wheat as input into flour production made up 91% of its wholesale price (Table 24, USDA-ERS).

[12] Limited degrees of freedom are not the only obstacle to overcome if additional inputs are used in the empirical analysis. For instance, the marketing year of annual quantity data are from June to May, which is not necessarily consistent with available industry data for other quantity inputs.

[13] Parameters for the supply equation can be recovered using standard techniques from general demand restrictions.

[14] Davis and Shumway (1996) discuss properties of and relationships between the Morishima elasticity of substitution and the generalized factor ratio elasticity of substitution defined in equation (8).

[15] Alternatively, an empirical model using average price data by region from the U.S. could have been reported. However, it is maintained that the empirical model with cash prices from major markets is likely more reflective of industry behavior. This is because *HRW* and *HRS* prices are sensitive to protein content across regions (Parcell and Stiegert 1998) and these quality impacts from protein may likely be averaged out in regional price data.

[16] Except where explicitly indicated statistical tests on multiple equation systems using likelihood ratio test statistics were calculated with the adjusted likelihood ratio test statistic for systems estimation $LR[MT-.5(Nu+Nr)-.5M(M+1)]/(MT)$ where LR-unadjusted log-likelihood value, M-#

equations, *T*-# observations, *Nu*-#parameters in unrestricted model, *Nr*-#parameters in restricted model (Moschini, Moro, and Green 1994). The curvature and symmetry tests were computed with and without first-order autocorrelation corrections of the residuals (see footnote 19) and are available upon request.

[17] Several statistical hypotheses related to weak separability were also investigated. For these statistical tests, curvature and symmetry restrictions were not imposed and prices were normalized by their respective mean values. [See Holt and Bishop (2002) for further discussion on imposing and testing restrictions in normalized quadratic functions.] Regressing quantities of wheat food use on wheat, capital, labour, and energy prices, the null hypotheses that capital, labour, and energy price coefficients were jointly equal to zero were rejected in the *HRW*, *HRS*, and *DUR* equations. Next, joint restrictions $\varepsilon_{i\ell} = \varepsilon_{j\ell}$ for $i \neq j \in \{1, ..., n_k\}$ and $\ell \in \Lambda = \{\text{capital,labour,energy}\}$ across the five factor demand equations were tested. The joint null hypothesis was not rejected for the model with first-order autocorrelation but it was for the model with no autocorrelation (see footnote 19 discussing autocorrelation correction). Although there is mixed evidence about weak separability, factor demand models were estimated with only wheat prices. Additional results for separability tests are available upon request.

[18] Bootstrap estimates were obtained by (a) resampling the residuals of the model corrected for autocorrelation, (b) predicting profit and quantities of wheat with the autocorrelated model, (c) reestimating the system with predicted values, and (d) then recalculating the elasticities. This process was repeated 1000 times to generate distributions of price and substitution elasticities. Then 90% confidence intervals for each elasticity were constructed based on the percentile method, which required ordering the estimated elasticities and then selecting outcome 50 (0.05*1000) for the lower critical value and outcome 950 (0.95*1000) for the upper critical value

(see Mittelhammer, Judge, and Miller 2000). For hypothesis testing, if the bootstrapped confidence interval for the elasticity contained zero, then the elasticity value was considered not significantly different from zero at the 0.10 level. Computation of predictions with the autocorrelated model follows standard methods discussed in Reinsel (1993). Initial starting values were obtained by setting all values to zero except the intercepts in the demand equations. At each Monte Carlo iteration robust starting values were obtained using the nonderivative optimization method Nelder-Meade, which were then fed into the Newton-Raphson optimizer in GAUSS for final coefficient estimates.

[19] The first-order autocorrelation correction followed Berndt and Savin (1975), which has been adopted by Piggott et. al. (1996) and Holt and Goodwin (1997), specifying a common correlation coefficient across the system of equations. The autocorrelation coefficient, ρ, is positive and significant (using the log-likelihood values of the models with first-order autocorrelation correction and without the likelihood ratio (*LR*) statistic is -2[(-536.2411)-(-509.7967)]=33.46>3.84 critical value with 1 degree of freedom at the 0.05 level).

[20] One explanation for the insignificant cross-price effects is the individual firm elasticities offset one another. Discarding the separability notation that delineates between groups of inputs, price elasticities of demand from equation (3) can be defined by

$$\varepsilon_{ij} = \frac{\partial x_i}{\partial w_j}\frac{w_j}{x_i} = \sum_{\ell}\left(\frac{\partial x_i^{\ell}}{\partial w_j}\frac{w_j}{x_i^{\ell}}\right)\left(\frac{x_i^{\ell}}{x_i}\right) = \sum_{\ell}\varepsilon_{ij}^{\ell}\left(\frac{x_i^{\ell}}{x_i}\right)$$

Given above assumptions, then the aggregate demand elasticities ε_{ij} are a share weighted average of the individual firm elasticities ε_{ij}^{ℓ}. A less realistic and more restrictive interpretation is that the elasticities are identical across firms, then $\varepsilon_{ij} = \varepsilon_{ij}^{\ell}\ \forall \ell$. Assuming the individual firm elasticities are not identical, the relevant insight from the above expression is that if a certain class of wheat is a complement for one firm and substitute for another firm then individual firm's elasticities can offset one another and the magnitude of the industry cross-price elasticity will be reduced and potentially rendered insignificant. Alternatively, confounding impacts of farm programs and polices or data may be contributing to the insignificant of cross-price effects over the study period. This emphasizes the need to consider conceptual extensions to the current model and alternative time series or cross sectional data sources to further examine cross-price effects.

[21] McCloskey (1985) argues that an insightful analysis should extend beyond statistical significance and consider the magnitude of the estimated economic effects.

[22] Initially, *HWW* breeders and proponents in the midwestern U.S. hoped that short-run economic incentives would come from competing in international markets with Australian white wheat exports. However, after accounting for transportation costs and other factors, it appears unlikely that U.S. exports of *HWW* would be important short-run sources of economic incentives.