Agricultural Marketing Policy Center

Harvest-Time Protein Shocks and Price Adjustment in U.S. Wheat Markets

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Abstract

Dynamic relationships between three classes of wheat are investigated using threshold VAR models incorporating the effects of protein availability. Changes in the stock of protein are found to generate significant impulse responses in the price of hard red spring wheat and hard red winter wheat but not soft red wheat. These impulse responses to identical changes in protein stocks are larger when the absolute deviations of protein stocks from normal levels are large. Shocks to the prices of individual classes of wheat result in complex impulse responses in the prices of the other wheat varieties. Notably, however, a shock to the price of hard red winter weak appears to result in little or no impulse response in the price of hard spring wheat, though, importantly, the opposite is not true.

Agricultural commodities such as wheat are typically heterogeneous, with quality characteristics that differ across space, time, and variety. The extent to which market prices account for such quality differences has been an important issue for the overall efficiency of markets for agricultural commodities. The benefits associated with accurate measurement of qualities by buyers and sellers in a market must be weighed against the potential costs associated with such an accurate quality assessment. Some characteristics (foreign matter, shrunken and broken kernels, etc.) are easy to measure while others (valorimeter and farinograph measures) are much more difficult and expensive to identify.

Protein content is one of the most basic quality characteristics shaping the potential utility of a particular class of wheat for various uses. It plays such an important role in price interrelationships among different types and grades of wheat that it also forms the basis for U.S. standard variety grades. For example, higher protein wheat varieties such as dark northern spring and hard red winter typically command a price premium over wheat varieties with lower protein contents (for example, see Espinosa and Goodwin, 1991), and that the price premium varies over time almost surely in accord with shifts in supply and demand for that attribute (Parcell and Stiegert, 1998), as implied by the theoretical hedonic pricing framework developed by Rosen (1974).

Several studies have examined the dynamics of domestic and international wheat price relationships (see, for example, Goodwin and Schroeder, 1991; International Trade Commission, 1994; Mohanty, Meyers, and Smith,1999). However, relatively little attention has been directed toward interrelationships among different types of wheat prices and quality shocks that may relate to the aggregate level of quality. Failure to account for these shocks is likely to distort estimates of these relationships and provide misleading assessments of the extent to which prices of different types of wheat are related to one another and, particularly, the extent to which different types of wheat are substitutes for one another.[1]

In this paper, we are primarily concerned with the aggregate market for protein (wheat gluten) and its effect of price relationships among different classes of wheat. We consider multivariate time-series models for three classes of wheat—hard red spring, hard red winter, and soft red winter. We are interested in quantifying the relationships between the protein content associated with each year's harvest for each type of wheat and the differentials (reflecting protein supply and demand effects) between various classes of wheat. Monthly price data are used in conjunction new data constructed by the authors that report the average (aggregate) protein content associated with each year's U.S. harvest. The relationships between wheat prices and protein content may vary substantially from year-to-year, depending on overall wheat yields and other quality factors.[2] Further, protein content in any given year may be affected by the characteristics of the market for protein in preceding years, since grain stocks are held from year to year and production practices and variety choices may be important considerations in the realized protein content of a wheat crop.

We use nonstructural time-series models that also allow for costly adjustment by incorporating threshold procedures to evaluate the effects of protein content shocks on the time paths of wheat prices. We account for protein availability effects on price interrelationships from year to year and quantify the extent to which shocks in the levels of protein in a particular type of wheat affect the differentials in wheat prices among the individual wheat classes. Our analysis uses dynamic impulse responses to track price responses to shocks in the protein market and other shocks to specific wheat class prices.

[1] The issue of elasticities of substitution among wheat classes has been addressed by two recent studies by Marsh and Barnes and Shields using structural models of derived demand estimated with annual data. Both studies, while providing different estimates, find that wheat is not just wheat, in the sense that elasticities of substitution among different classes of wheat are by no means as large as has been suggested by some researchers (for example, Alston, Sumner and Gray).

[2] Parcell and Steigert (1998) and Stiegert and Blanc both report that the effect of a marginal increase in protein on protein premiums varies among different classes of wheat such as hard red spring, hard red winter and soft red winter.

The analysis provides new insights about the substitutability of different classes of wheat among end uses, a critical issue in recent trade dispute cases. For example, if hard red spring wheat and hard red winter wheat are perfect or very close substitutes, as suggested by Canadian Wheat Board expert witnesses in testimony before the International Trade Commission on behalf of the Canadian Wheat Board in September, 2003, then hard red winter prices are likely to respond rapidly in similar ways to a shock in hard red spring prices, and vice versa. This does not appear to be the case. Shocks to hard red spring wheat prices do generate substantial responses in hard red winter wheat prices. However, shocks to hard red winter prices generate relatively weak responses in hard red spring prices, suggesting that hard red winter wheat is an imperfect substitute for hard red winter wheat.

The paper is organized as follows. Empirical methods are discussed in the next section. The data are then described, empirical results are presented and discussed, and a summary and conclusion are provided.

Empirical Methods

The primary objective of the empirical analysis is to evaluate the extent to which dynamic relationships among prices for different classes of wheat are affected by shocks to the quality of the overall U.S. wheat harvest. In particular, we are interested in the role played by protein content—one of the major determinants of the quality and functionality of different classes and grades of wheat for different uses. Certainly, a wide variety of wheat characteristics may be pertinent to the quality of any given quantity of wheat. These include factors such as variometer and farinograph measures, foreign materials, falling numbers, ash content and so forth.[3] However, in terms of the aggregate wheat market and the price relationships between different types of wheat, both the results of several hedonic studies and current industry pricing practices indicate that each wheat harvest's protein content is likely to be the most relevant factor influencing dynamic relationships among the prices of different types of wheat.

In the spirit of the relatively extensive literature that has addressed these issues, we begin by considering a standard vector autoregression (VAR) model that includes prices of the three major wheats—Dark Northern Spring (DNS) in Minneapolis, Hard Red Winter (HRW) in Kansas City, and Soft Red Winter (SRW) in Chicago. DNS and HRW wheats typically have much higher protein contents than SRW and are directed toward end-uses that require stronger gluten content (e.g., breads). In contrast to previous studies, we also include a measure of the overall protein content implicit in stocks at any point in time. Our specific measure of this protein content variable is described in the following section.

A standard VAR model can be written as:

$$y_t = \Gamma X_t + e_t,$$

where y_t is a vector of endogenous variables for which dynamic adjustment paths are to be evaluated, Γ is a matrix of parameters to be estimated, e_t is a vector of random error terms, and $X_t = [1, y_{t-1}, ..., y_{t-j}, Z_t]$ where Z_t is a matrix of observations on other exogenous variables such as protein content.

In addition to estimating a simple VAR model, we are interested in considering the potential for nonlinearities in the underlying relationships represented by the VAR model. To this end, we appeal to recent developments in the time series literature that consider nonlinearities in the relationships inherent in nonstructural VAR type models. We hypothesize that adjustments to shocks in the inherent qualities of wheat by end-users (e.g.,

[3] See Espinosa and Goodwin for a detailed discussion of how different quality factors are related to wheat prices.

bakers, millers, and food processors) are costly. In particular, most production processes are tightly calibrated and have specific quality requirements. End-users may be able to make adjustments in production processes, though these adjustments are likely require significant technological modifications and to be costly.[4]

To account for such effects, we utilize a threshold modification to the standard VAR modeling framework. In particular, we allow the underlying structure of the model (represented by the nonstructural, reduced-form parameters of the VAR system of equations) to vary according to implied protein availability in the market. Specifically, we consider a threshold defined by deviations from normal levels of protein in the market. The "normal" level of protein is defined by using a regression of protein availability on a third-order fourier series expansion, which is intended to capture the large degree of seasonality that accompanies the wheat harvests and subsequent adjustments to stocks.

We define the "normal" level of protein (given by a function *f(t)* consisting of a fourier series expansion) by $\hat{p} = f(t)$. Departures from normal levels are therefore determined as:

$$P_t - f(t) = v_t$$

We allow for three regimes, which are defined on the basis of the value of v_t. One is a normal protein regime, which obtains when the value of v_t lies between a lower bound, c_1, and an upper bound, c_2. The second regime occurs when v_t lies below the lower bound of the normal range, c_2, and protein is in relatively short supply. The third regime occurs when v_t exceeds the upper bound of the normal range, c_2, and protein is relatively plentiful. A switch between any pair of regimes from one period to the next is triggered by changes in protein levels that cause larger enough changes in v_t. For example, an increase in protein that results in v_t moving from within the normal protein range defined by c_1 and c_2 and exceeding c_2 causes a change in regime. The regime switching model is thus given by:

$$y_t = \begin{cases} \Gamma^{(1)} X_t & if \quad v_t < c_1 \\ \Gamma^{(2)} X_t & if \quad c_1 \le v_t \le c_2 \\ \Gamma^{(3)} X_t & if \quad v_t > c_2 \end{cases}$$

where $\Gamma^{(i)}$ represents the parameter estimates associated with the i^{th} regime and c_1 and c_2 are the initially unknown threshold parameters that have to be estimated. An alternative representation of this model is as follows:

$$y_t = \delta_1\Gamma^{(1)} + \delta_2\Gamma^{(2)} + (1 - \delta_1 - \partial_2)\Gamma^{(3)},$$

where $\delta_1 = 1$ if $v_t < c_1$ and zero otherwise, and $\delta_2 = 1$ if $c_1 \le v_t \le c_2$ and zero otherwise.

Several different threshold modeling procedures have been developed. Here we utilize grid search procedures to find the values for the thresholds, c_1 and c_2, that minimize the log of the determinant of the residual covariance matrix, a procedure equivalent to maximizing a normal likelihood function. We constrain the grid search procedures to require each regime to have at least twenty-five observations. The parameters describing the two alternative regimes are estimated conditional on the optimal threshold values for c_1 and c_2.

Once the parameters of the standard and regime switching VAR models have been estimated, standard methods of inference can be used to evaluate the relationships among the prices and protein variable. Here we utilize standard impulse response functions to evaluate the dynamic relationships among wheat class prices implied by the alternative parameters. In threshold models, several versions of the impulse responses could be evaluated because, in these models, impulse responses may not be unique for alternative

[4] This is widely recognized by the milling industry. In the September 2003 International Trade Commission (ITC) antidumping hearings with respect to Canadian dumping of hard red spring wheat and durum wheat, in oral testimony before the ITC U.S. milling industry executives indicated that they tended to determine blends of different wheat at the beginning of each marketing year just after harvest once the quality characteristics of different wheat classes were known. Thereafter, they were generally reluctant to change those blends.

observations or sizes of shocks. Potter's nonlinear impulse response analysis procedures could be used to evaluate the responses at a particular observation and allow for switching among regimes over the period of the response. Alternatively, impulses could be calculated at every observation and mean responses or some other summary measure then reported. Finally, impulse responses could be evaluated at each alternative regime with no shifting between regimes allowed during the response. Here we adopt the latter approach in that it yields the clearest inferences regarding the differences in regimes.

Data and Empirical Results from a Standard VAR Model

We use monthly averages of daily cash prices for three alternative classes of wheat—DNS in Minneapolis, HRW in Kansas City, and SRW in Chicago. The price data were collected from the Bridge database. Average protein content for all classes of U.S. wheat (HRW, DNS, SRW, durum, and white wheats) for each crop year were provided by annually published U.S. Wheat Associates *Grain Quality Reports*. Quarterly stocks data were obtained from unpublished NASS data. An aggregate weighted average protein content was then calculated for the total U.S. wheat harvest in each crop year using USDA statistics on production for each class in each year to form weights. The quarterly stocks data were then multiplied by the protein content of the crop to obtain "protein stocks" for each quarter of the year. This protein stocks variable was then regressed on the terms of a third order Fourier series expansion. The data cover the 1989-2003 crop years.

The implied pattern of seasonality in protein is illustrated in figure 1. Note the presence of a large increase in stocks with the influx of the winter wheat harvest in June and July and then a second smaller increase that occurs with the spring wheat harvest in the late fall. Deviations from normal protein levels are represented by the deviations from the seasonal patterns presented in figure 1. We then utilize cubic spline smoothing to interpolate the quarterly protein stock measures to obtain monthly observations. Such interpolation is most likely to adequately represent data at a higher frequency in cases where movements in the variable between observations are likely to be smooth and gradual. This is certainly the case for a highly aggregated variable such as the total protein stocks implied for the aggregate U.S. market. The observed and interpolated protein stocks series are illustrated in figure 2. The blocks represent observed data while the line represents the interpolated data used to convert the series from quarterly to monthly frequencies.

Figure 1: Estimated Seasonality in Protein Stocks Variable

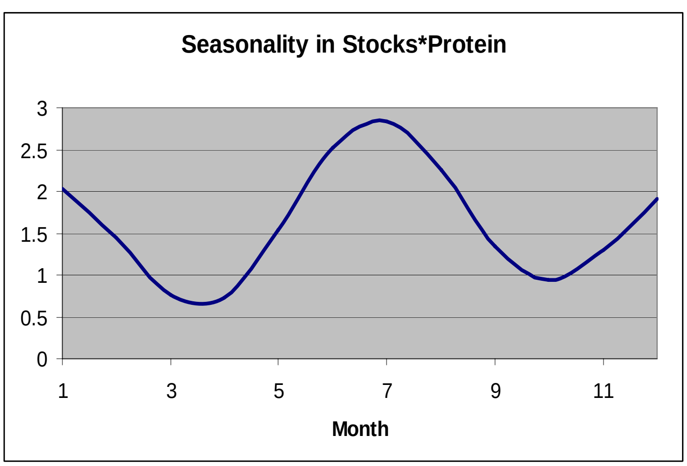


Figure 2: Actual and Interpolated Protein Stocks Variable

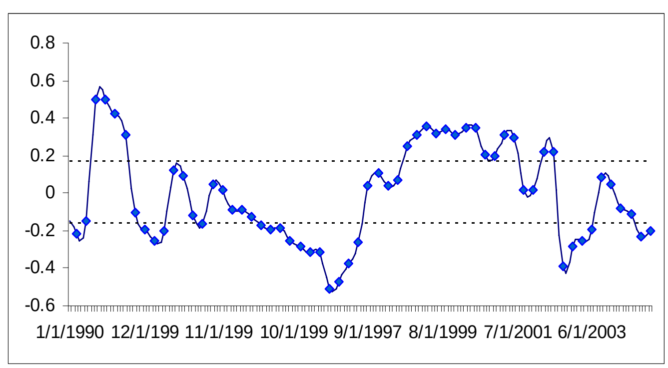


Table 1 presents parameter estimates for a standard VAR model of the prices for Dark Northern Spring, Hard Red Winter and Soft Red Winter wheat. Parameter estimates for nonstructural models of this form are usually of limited interest and inferences are more efficiently extracted from impulse responses. However, the coefficients on the protein stocks variable in the three equations are certainly of interest in their own right. These coefficients are negative in all three cases, suggesting that above-normal stocks of protein are likely to depress prices for each class of wheat. The coefficient is largest in the Kansas City hard red winter price equation. The negative effect is also relatively large for the Minneapolis hard red spring price. The effect for soft wheat prices in Chicago is much smaller and not statistically significant.

These results are consistent with *a priori* expectations. They imply that positive shocks to the aggregate protein content of wheat in the U.S. market have negative effects on hard red winter and hard red spring wheat prices—classes of high protein wheat generally directed to uses that require varieties of wheat with high gluten content. In contrast, the effect is not statistically significant in the case of soft red winter wheat in Chicago. Soft wheat varieties typically have much lower protein content and are directed toward uses that call for lower gluten wheat (e.g., cakes and crackers rather than bread).

Table 1: Standard VAR Model of Wheat Prices: Parameter Estimates

Dependent Variable	Explanatory Variable	Parameter Estimate	Standard Error	t Ratio
Chicago Price	Constant	37.3687	17.1231	2.18
	Protein Stocks (t)	-20.7671	13.1919	-1.57
	Chicago Price (t-1)	0.7734	0.1183	6.54
	Kansas City Price (t-1)	0.2567	0.1234	2.08
	Minneapolis Price (t-1)	-0.0638	0.0922	-0.69
	Chicago Price (t-2)	0.0341	0.1184	0.29
	Kansas City Price (t-2)	-0.1826	0.1220	-1.50
	Minneapolis Price (t-2)	0.0585	0.0912	0.64
Kansas City Price	Constant	67.6815	17.8796	3.79
	Protein Stocks (t)	-41.1863	13.7747	-2.99
	Chicago Price (t-1)	-0.0504	0.1235	-0.41
	Kansas City Price (t-1)	1.0444	0.1288	8.11
	Minneapolis Price (t-1)	0.0112	0.0962	0.12
	Chicago Price (t-2)	0.0891	0.1237	0.72
	Kansas City Price (t-2)	-0.2491	0.1274	-1.96
	Minneapolis Price (t-2)	-0.0217	0.0952	-0.23
Minneapolis Price	Constant	65.5465	19.3841	3.38
	Protein Stocks (t)	-33.5678	14.9338	-2.25
	Chicago Price (t-1)	-0.2288	0.1339	-1.71
	Kansas City Price (t-1)	0.5022	0.1397	3.60
	Minneapolis Price (t-1)	0.6614	0.1043	6.34
	Chicago Price (t-2)	0.2000	0.1341	1.49
	Kansas City Price (t-2)	-0.4948	0.1381	-3.58
	Minneapolis Price (t-2)	0.1993	0.1032	1.93

Impulse responses for the standard VAR model are presented in Figures 3-6. Figure 3 illustrates the dynamic paths of adjustment in prices to a positive one-unit shock to the protein stocks variable. The largest impact occurs with respect to the Kansas City price—a result entirely consistent with a simple consideration of the VAR model protein coefficients reported in table 1. The impulse results indicate that a one unit increase in protein generates a 42 cent per bushel decrease in the Kansas City price and a 34 cent per bushel decrease in the Minneapolis price. In contrast, the soft wheat price in Chicago shows only a small negative response to the same protein shock. In every case, the largest price response occurs two months after the shock, and responses take ten or more months to die out. This suggests that end users are likely to be somewhat slow to adjust to protein shocks and that market effects from such shocks persist for several months. This finding seems to be consistent with statements by U.S. millers at the 2003 ITC hearings on CWB dumping that they tend to determine blends of different varieties of wheat for milling on an annual marketing year basis after harvest and to be relatively unresponsive to price changes.

Adjustments to price shocks are modest once protein shocks are accounted for. Minneapolis DNS and Kansas City HRW prices appear to be more closely linked with one another than with Chicago SRW prices. The results appear to imply a price leadership role for the Minneapolis market in the Kansas City-Minneapolis relationships. An innovation in the Kansas City price results in almost no impulse response in the Minneapolis price while an innovation the Minneapolis price results in a

Figure 3: Standard Impulse Responses to Protein Shocks

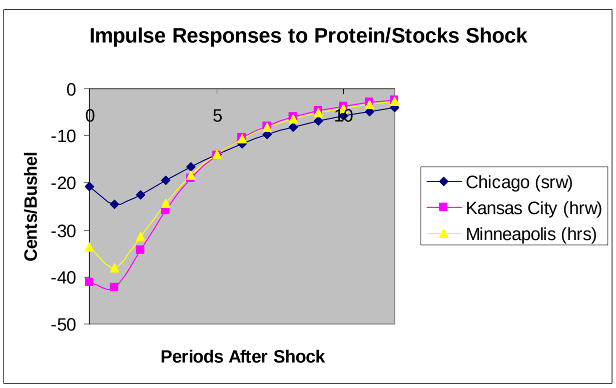


Figure 4: Standard Impulse Responses to Chicago Price Shocks

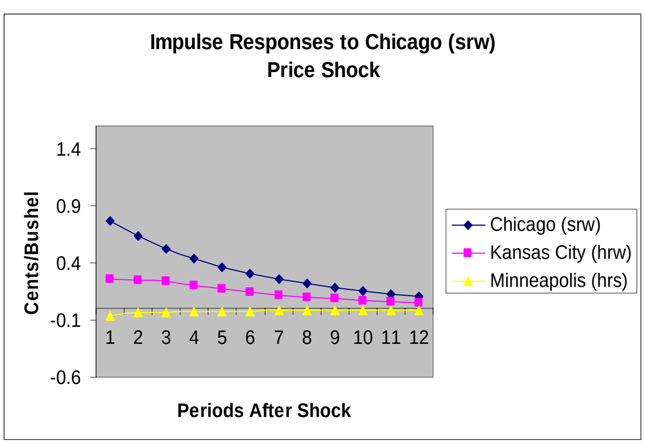


Figure 5: Standard Impulse Responses to Kansas City Price Shocks

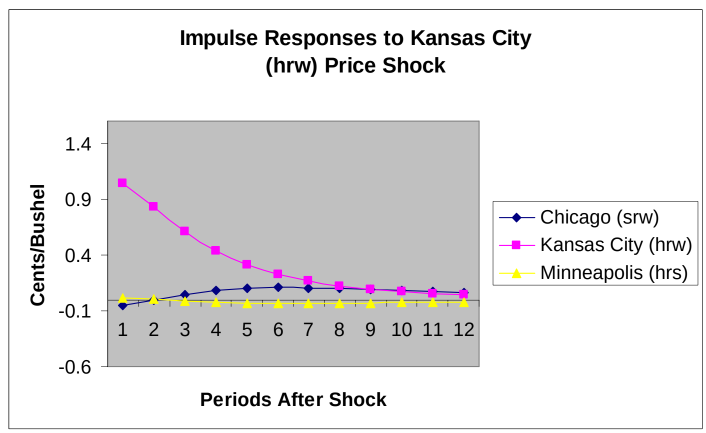
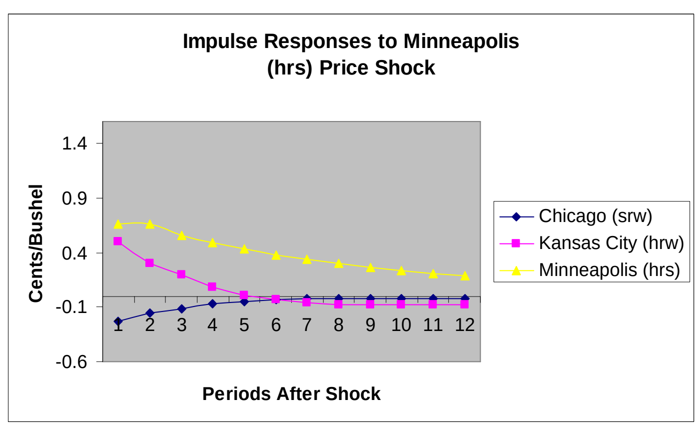


Figure 6: Standard Impulse Responses to Minneapolis Price Shocks



smaller adjustment in the same direction in the Kansas City price that peters out after about 6 months.

Empirical Results from a Threshold Model

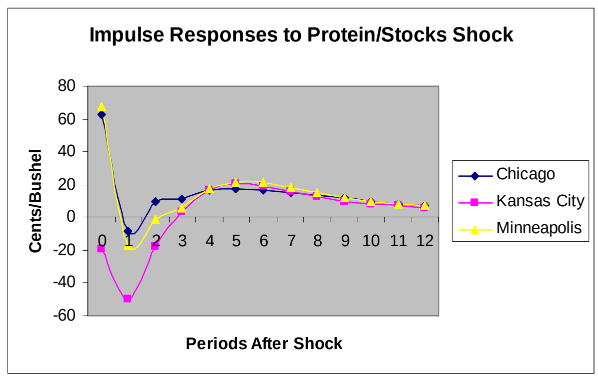
Price adjustment patterns, as discussed above, may reflect adjustment costs associated with changes in production technologies that may be needed to respond to substantial changes in wheat protein availability. Table 2 reports estimates from a threshold VAR model that allows shifting between regimes according to the absolute value of the size of shocks to the overall protein stocks available in the market. The optimal threshold model has a threshold value for the lower bound of the normal regime, c_1, of – 0.5702 and a threshold value for the upper bound of the normal regime of + 0.5072.[5] Hansen's test statistic for the comparison of the threshold and standard VAR models is 67.48 and has a p-value of 0.0001, implying the rejection the null hypothesis that there is no difference in the explanatory power of the standard VAR model and the threshold model, and indicating that the threshold model provides a better fit than the standard VAR model presented in table 1.

The band implied by the estimated thresholds that define the three alternative regimes — low protein, normal protein, and high protein — is illustrated in figure 2. Switching among regimes is relatively infrequent, reflecting the fact that the overall availability of protein in the market adjusts slowly, at least between harvests. This implies that the market tends to remain in a regime for an extended period of time rather than jumping back and forth between alternative regimes on a month to month basis.

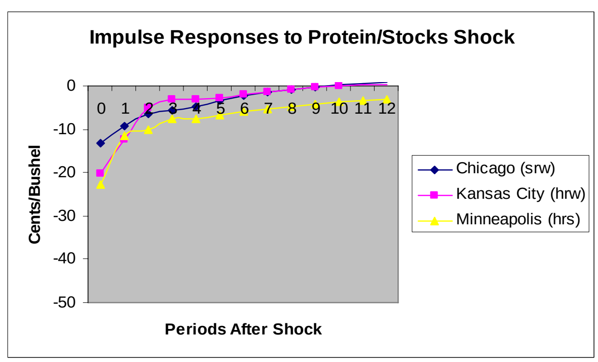
In the threshold model, as in the standard VAR model, protein stocks have different effects on the prices of each type of wheat. The coefficients for protein stocks are not significantly different from zero for the Chicago soft red wheat price in all three regimes, with absolute t-values ranging from 0.37 to 1.39. A similar result was obtained in the standard VAR model, in which the protein stock coefficient had no statistically significant effect on the Chicago SRW price. Perhaps surprisingly, the protein stocks coefficients are also not statistically significant in the Kansas City Hard Red Winter and Minneapolis Hard Red Spring price equations. However, there is considerable evidence from hedonic studies that protein premiums are important for hard wheat prices (Espinosa and Goodwin; Steigert and Blanc). An examination of the impulse response functions of the three prices for a one unit positive shock to protein levels in the three regimes provides evidence that supports that view. These impulse responses are presented in figures 7(a) – 7(c).

Figure 7: Impulse Responses to Protein Shocks

(a) Low Protein Regime



(b) Normal Protein Regime



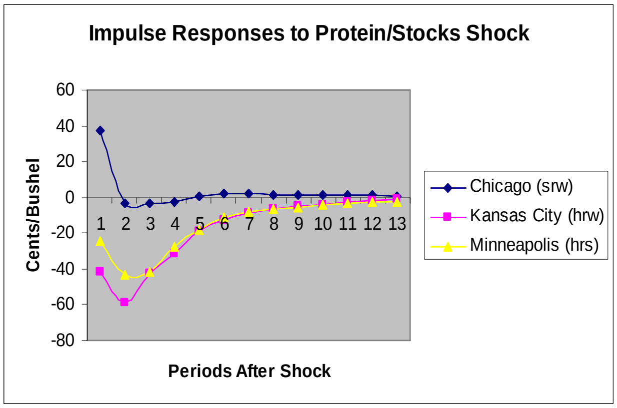
[5] Note that the estimation procedure did not constrain the upper and lower values for the normal regime band for v_t to have the same absolute values (that is, to be symmetric around an expected value for v_t of zero) and there were small differences in the estimated absolute values of c_1 and c_2 beyond the fourth decimal point.

Table 2: Threshold Switching Regime Model Parameter Estimates

		Low Protein Regime			Normal Protein Regime			High Protein Regime		
Dependent Variable	**Explanatory Variable**	**Parameter Estimate**	**Standard Error**	**t Ratio**	**Parameter Estimate**	**Standard Error**	**t Ratio**	**Parameter Estimate**	**Standard Error**	**t Ratio**
Chicago	Constant	91.2455	80.2143	1.14	38.3200	20.1305	1.90	85.9199	35.7230	2.41
Price	Chicago Price (t-1)	0.3020	0.2585	1.17	0.3803	0.1779	2.14	1.3042	0.2033	6.41
	Chicago Price (t-2)	0.2674	0.2741	0.98	0.0725	0.1761	0.41	-0.2871	0.1871	-1.53
	Kansas City Price (t-1)	0.3088	0.2961	1.04	0.8063	0.2027	3.98	-0.3652	0.2121	-1.72
	Kansas City Price (t-2)	-0.0627	0.3028	-0.21	-0.6208	0.2067	-3.00	0.1911	0.1850	1.03
	Minneapolis Price (t-1)	0.0775	0.2376	0.33	-0.2506	0.1742	-1.44	-0.0265	0.1178	-0.23
	Minneapolis Price (t-2)	-0.2767	0.2339	-1.18	0.4807	0.1636	2.94	-0.0358	0.1194	-0.30
	Stocks (t)	37.3341	48.3475	0.77	62.6459	44.9082	1.39	-13.1946	36.0585	-0.37
Kansas City	Constant	201.2043	84.1474	2.39	59.1220	21.1176	2.80	144.7974	37.4746	3.86
Price	Chicago Price (t-1)	-0.5543	0.2712	-2.04	-0.2682	0.1866	-1.44	0.6244	0.2133	2.93
	Chicago Price (t-2)	0.2000	0.2875	0.70	0.2741	0.1847	1.48	-0.0868	0.1963	-0.44
	Kansas City Price (t-1)	0.8569	0.3106	2.76	1.4332	0.2126	6.74	0.1662	0.2225	0.75
	Kansas City Price (t-2)	0.1494	0.3177	0.47	-0.7680	0.2169	-3.54	-0.0640	0.1941	-0.33
	Minneapolis Price (t-1)	0.1027	0.2492	0.41	-0.0835	0.1827	-0.46	0.0378	0.1236	0.31
	Minneapolis Price (t-2)	-0.3899	0.2454	-1.59	0.2628	0.1716	1.53	-0.0371	0.1253	-0.30
	Stocks (t)	-41.7298	50.7181	-0.82	-18.9708	47.1102	-0.40	-20.1873	37.8266	-0.53
Minneapolis	Constant	213.1673	93.6090	2.28	63.0232	23.4920	2.68	106.6062	41.6883	2.56
Price	Chicago Price (t-1)	-0.3615	0.3017	-1.20	-0.5606	0.2076	-2.70	0.2421	0.2373	1.02
	Chicago Price (t-2)	-0.1042	0.3198	-0.33	0.4409	0.2055	2.15	0.0131	0.2184	0.06
	Kansas City Price (t-1)	0.3098	0.3456	0.90	1.0251	0.2365	4.33	-0.1928	0.2475	-0.78
	Kansas City Price (t-2)	-0.1675	0.3534	-0.47	-0.7498	0.2412	-3.11	-0.2158	0.2159	-1.00
	Minneapolis Price (t-1)	0.6789	0.2772	2.45	0.5615	0.2033	2.76	0.5412	0.1375	3.94
	Minneapolis Price (t-2)	-0.0554	0.2730	-0.20	0.1855	0.1909	0.97	0.3566	0.1394	2.56
	Stocks (t)	-24.6478	56.4209	-0.44	67.1056	52.4073	1.28	-22.7985	42.0798	-0.54
Threshold Parameters			< -0.5702						> 0.5702	
Proportion of Observations			0.2889			0.3389			0.3722	
Hansen's Test of Thresholds			67.4800							
Hansen's Test P-Value			0.0001							

Figure 7: Impulse Responses to Protein Shocks

(c) High Protein Regime



In the low protein regime (figure 7(a)), an increase in protein initially lowers the Kansas City price but increases both the Minneapolis and Chicago prices. Thereafter, prices for all three types of wheat fall below their pre-shock levels and then, by period three, recover somewhat and adjust to their long run equilibrium values. In the normal protein regime (figure 7(c)), as expected, all three prices initially decline as a result of a protein shock and then also gradually adjust to their long run equilibrium values. However, in low protein regime, the initial declines in the Kansas City and Minneapolis hard wheat prices are about twice as large as the decline in the Chicago soft wheat price.

In the high protein regime (figure 7(c)), the initial effect of the protein shock is to substantially reduce the Minneapolis and Kansas City hard red wheat prices, but the impact on the Kansas City hard red winter wheat price is about twice as large as the impact on the Minneapolis hard red spring wheat price (about a 40 cent per bushel decrease as compared to a 20 cent per bushel decrease). In this regime, as a result of the protein shock, the Chicago soft wheat price initially increases. Subsequently, in period 2 (two months after the shock), the prices of all three classes of wheat decline before gradually converging to their long run equilibrium values.

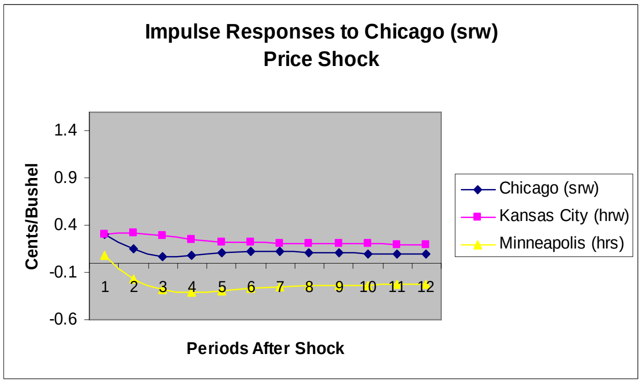
A comparison of the three price impulse responses to a one unit shock in protein stocks presented in figure 7 provides useful insights. First, as expected, an increase in protein reduces the prices of the two hard wheat varieties either immediately or within two periods. Impacts on the price of soft red wheat are different and generally smaller in magnitude, a finding consistent with the fact that soft wheat with low protein has different end uses that do not require high protein content. Second, the effects of protein shocks on Minneapolis hard red spring wheat prices and Kansas City hard red winter wheat differ in magnitude (being larger for Kansas City hard red winter wheat), while generally resulting similar patterns in the impulse responses for the two types of wheat. Third, the threshold model implies that there are larger impulse responses to a one unit shock to protein when initial protein levels are either above or below the normal range. When initial protein levels are in the normal range, prices react but, especially in the case of hard red winter wheat, the adjustments are smaller than when initial protein levels deviate substantially from normal protein levels. This result is consistent with the hypothesis that changes in protein levels may have larger effects on prices when protein stocks are substantially different than their long run average values than when protein stocks are close to those average values.[6]

In the threshold VAR models, when protein levels are either high or low (outside the normal protein range defined by c_1 and c_2) the price adjustments resulting from one unit shocks in the Chicago, Kansas City and Minnesota prices in the threshold model are generally similar to those obtained using the standard VAR model. Figures 8(a) and 8(c) show that, in the regimes in which protein levels are either low or high, a positive shock to the Chicago soft red winter wheat price results in a similar initial increase in the Kansas City hard red winter price but has almost no effect on the Minneapolis hard red spring price. Subsequently, although the Chicago and Kansas City impulse responses

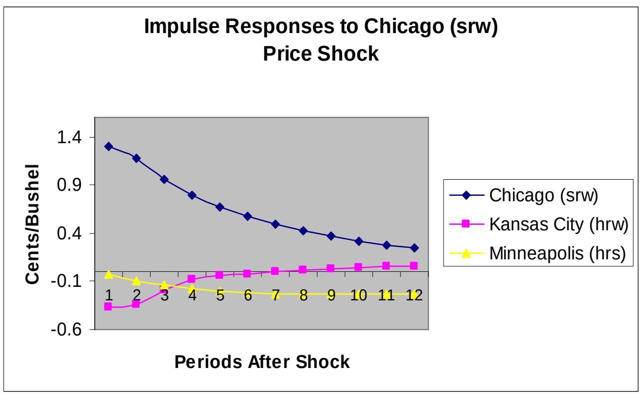
[6] Note that the terminology may be somewhat confusing here. All impulse response diagrams illustrate responses to equivalent one-unit shocks. However, the regimes are defined by the size of the protein shock. We could have presented shocks that differed in terms of the size of the shocks in alternative regimes. In such a case, the differences in impulse responses would be exaggerated. Comparing the impulses at a common level of shock allows a clearer view of how the underlying structures of the models differ across regimes.

Figure 8: Impulse Responses to Chicago Price Shocks

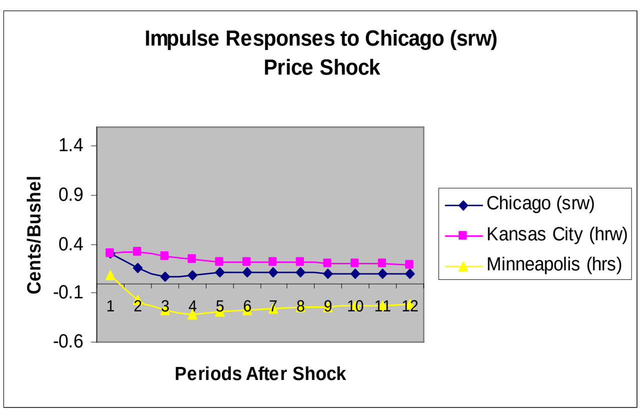
(a) Low Protein Regime



(b) Normal Protein Regime



(c) High Protein Regime



diverge to some degree in periods two and three, thereafter their convergence paths are very similar. However, the Minneapolis price responses are negative after the first period and remain negative over the entire twelve period (one year) adjustment period presented in figures 8(a) and 8(c). In contrast, in the normal protein regime (figure 8(b)), a shock to the Chicago price generates almost no initial response in the Minneapolis price and an initial negative response in the Kansas City price. The impulses responses in figure 8(b), therefore, indicate that a shock to the Chicago price does not generate similar effects on either the Minneapolis price or the Kansas City price when protein levels are normal. Taken together, the impulse responses presented in figures 8(a) – 8(c) indicate that when protein levels are either relatively low or relatively high, soft red winter wheat prices affect hard red winter wheat prices, but that shocks to soft red winter prices have little or no effect on hard red spring prices, regardless of the protein regime.

Figures 9(a) – 9(c) show the effects of a one unit positive shock to the Kansas City price on the prices of three types of wheat in each protein regime. A shock to the Kansas City price has very little effect on the Minneapolis price in any of the three protein regimes. In the low and high protein regimes, such a shock causes an initial 58 cent decrease in the Chicago price, which then converges to its long run equilibrium level. In the normal protein regime, a shock to the Kansas City price causes a substantially increase in the Chicago price, which, after the second period converges to its long run equilibrium. Thus, the impulse responses presented in figures 9(a) – 9(c) suggest that shocks to hard red winter prices affect soft red winter prices in a qualitatively similar way when protein levels are relatively normal, but have little effect on hard red spring prices.

Figure 9: Impulse Responses to Kansas City Price Shocks

(a) Low Protein Regime

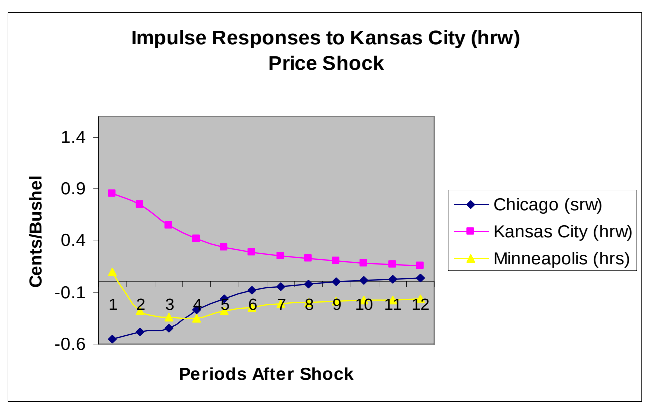
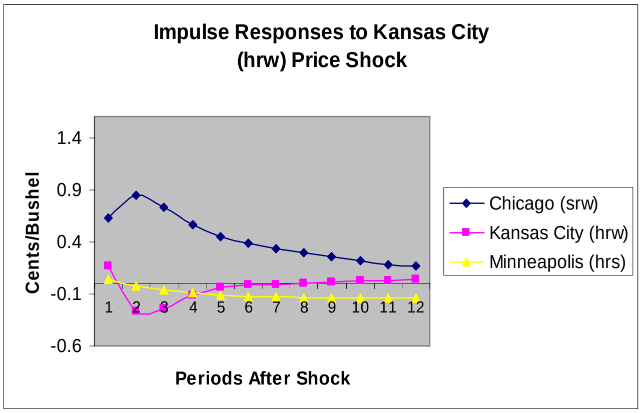
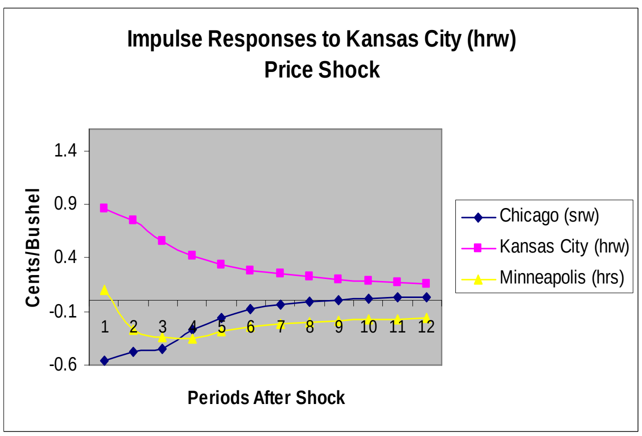


Figure 9: Impulse Responses to Kansas City Price Shocks

(b) Normal Protein Regime



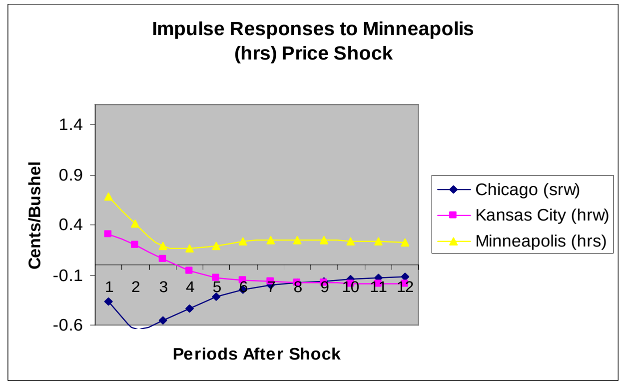
(c) High Protein Regime



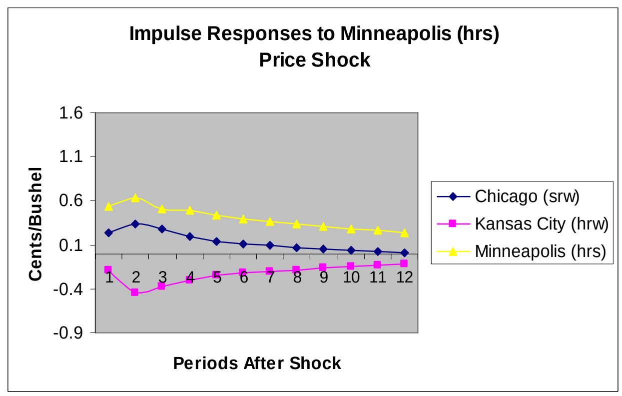
Impulse responses for a one unit shock to the Minneapolis price are presented in Figures 10(a) – 10(c). These responses suggest that when protein levels are either relatively low or relatively high a positive shock to the Minneapolis price causes a similar positive response in the Kansas City price, but results in a lower Chicago price. When protein stocks are in the normal range, a positive shock to the Minneapolis price causes an similar shock to the Chicago price but not to the Kansas City price.

Figure 10: Impulse Responses to Minneapolis Price Shocks

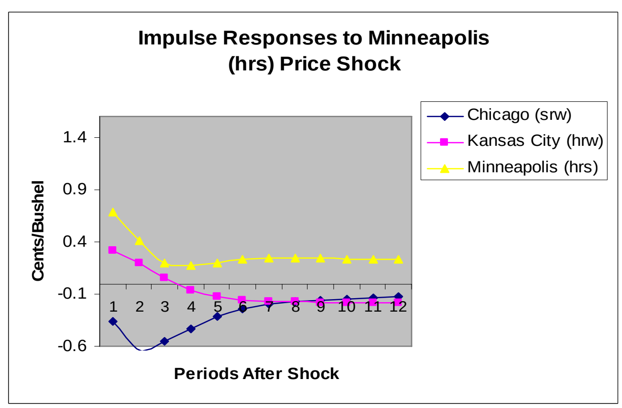
(a) Low Protein Regime



(b) Normal Protein Regime



(c) High Protein Regime



An important implication of the impulse responses presented in figures 7 - 9 is that when protein levels are relatively high or low, hard red winter wheat prices respond to shocks in hard red spring prices but the opposite does not hold true. A second result is that, when protein levels are relatively high or low, shocks to soft red winter prices affect hard red winter prices. These findings suggests that wheat is not just wheat and that soft red winter is by no means a perfect substitute for hard red winter or hard red spring. Similarly, the threshold model results also suggest that cross market linkages between hard red spring wheat and hard red winter wheat are complex and not consistent with the proposition that millers and bakers behave as if hard red spring wheat and hard red winter wheat are very close substitutes.

Conclusion

This study has utilized new data and innovative econometric techniques to address a longstanding issue in discussions about wheat markets — the dynamic relationships between the prices of different classes of wheat. The data-related innovation consists of the development of a measure of the aggregate stock of protein in the U.S. wheat crop that is then utilized in the time series analysis to account for potential impacts on the structure of wheat prices among important classes of wheat. Data on average protein content by class of wheat were combined with USDA statistics on production by class and quarterly data on wheat stocks to obtain protein stocks for each quarter of the year. A third order Fourier expansion was then utilized to obtain estimates of normal protein levels that accounted for quarterly seasonal effects. The quarterly data were then interpolated using cubic splines to obtain month-by-month estimates of protein stocks.

The econometric and modeling innovation with respect to wheat price dynamics is the utilization of a threshold modification of the VAR model to account for potential adjustment costs associated with changing use patterns of different classes of wheat. The results from the estimated threshold variant of the VAR model were also compared with those from a standard VAR model in which adjustment costs are ignored.

The major findings of the research are as follows. In the standard VAR model, a positive one unit shock to protein stocks has the largest and statistically significant negative effect on the Kansas City hard red winter price and a smaller but still substantial effect on the Minneapolis hard red spring price, as measured by impulse responses. The impulse response of the Chicago soft red price was not statistically significant and small.

Similar effects were identified in the threshold model in which three regimes were identified: a “low” protein regime, a “normal” protein regime, and a “high” protein regime. In the normal protein regime, absolute deviations of protein levels from long run expected or normal seasonal levels in aggregate wheat stocks are relatively small and fall within a range defined by lower and upper bounds. In the low protein regime, deviations in seasonal protein levels fall below the lower bound of the normal band while in the high protein regime they exceed the upper bound of the normal band. The range within which protein levels are deemed to be normal was computed in the econometric estimation procedure.

In the threshold models, the impulse response effects of a unit change in the protein stock level are generally similar to those reported for the standard VAR model in the low protein and high protein regimes. Price impulse responses are relatively small when protein levels are close to their seasonal averages (the normal regime) but, nevertheless, are consistent with the hypothesis that hard red winter and hard red spring prices are inversely related to the availability of protein. In the low protein and high protein regimes, the impulse responses are much larger for hard red spring wheat and hard red winter wheat and the initial impulse response of the Kansas City hard red winter price is considerably larger than the initial impulse response of the Minneapolis hard red spring price. These results are consistent with the hypothesis that buyers of different classes of wheat (millers, etc.) face relatively large adjustment costs when they change their patterns of use.

The effects of price shocks for a specific class of wheat also depend on the protein regime in the threshold models. However, one interesting result is that shocks to the Kansas City hard red winter price result in very modest impulse responses on the part of Minneapolis Hard red spring prices. In contrast, when protein levels are either relatively low or relatively high, shocks to the Minneapolis price generate qualitatively similar but quantitatively smaller impulse responses on the part of the Kansas City price. In addition, an exogenous shock to the Chicago soft red price generates very weak impulse responses in the Minneapolis price, although somewhat stronger impulse responses in the Kansas City price when protein availability is either relatively low or relatively high.

These results also provide some further insights about a long-standing argument between the Canadian Wheat Board and U.S. wheat producers. Fairly consistently, in a variety of wheat trade cases brought before the U.S. ITC between 1992 and 2004, the CWB and its expert witnesses have claimed that wheat is just wheat and, in particular, hard red winter and hard red spring are almost perfect substitutes for one another. The evidence from this study tends to suggest that such is not the case. The markets may be related but exogenous shocks in the price of hard red winter wheat simply do not generally result in similar impulse responses in the price of hard spring wheat.

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