Topics in Money and Securities Markets

July, 1993 No. 113

CHARACTERISTICS OF FLUCTUATIONS IN WHEAT PRICES

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This paper examines the characteristics of fluctuations in the prices of the major types of wheat grown in the United States. It focuses primarily on seasonal price variation and the behavior of the spreads between the prices of different wheat types and between wheat and corn. Section I provides a description of the data and some observations about the movement of wheat prices in general. Section II discusses demand substitution of different wheats. Section III estimates the seasonal factors associated with the prices of wheat and corn. Section IV provides an analysis of the price spreads between the types of wheat grown in the U.S. and an assessment of relative substitutability. The appendix contains a brief discussion of the effects of U.S. government agricultural policies on the price of wheat. The paper assumes the reader is familiar with wheat and wheat flour milling as described in *Topics in Money and Securities Markets*, "Wheat: Product Descriptions and Milling Processes," September 1992.

I. THE DATA

The data consists of spot cash market commodity prices prevailing on Thursdays between January 5, 1978 and December 26, 1991 from the United States Department of Agriculture, and, for hard red spring wheat, the Minneapolis Grain Exchange. The commodity prices are fully identified as:

hard red winter wheat	terminal elevator bids for No. 1 hard red winter wheat of "ordinary protein" delivered by rail to Kansas City,
hard red spring wheat	cash transaction prices for No. 1 hard red spring wheat of 12% protein delivered by rail to Minneapolis,
soft red winter wheat	terminal elevator bids for No. 2 soft red winter wheat for delivery within 30 days to Chicago by rail or truck,
durum	terminal elevator bids for No. 1 hard amber durum delivered by rail to Minneapolis, and
corn	terminal elevator bids for No. 2 yellow corn to arrive within 30 days to Chicago, rail and truck delivery

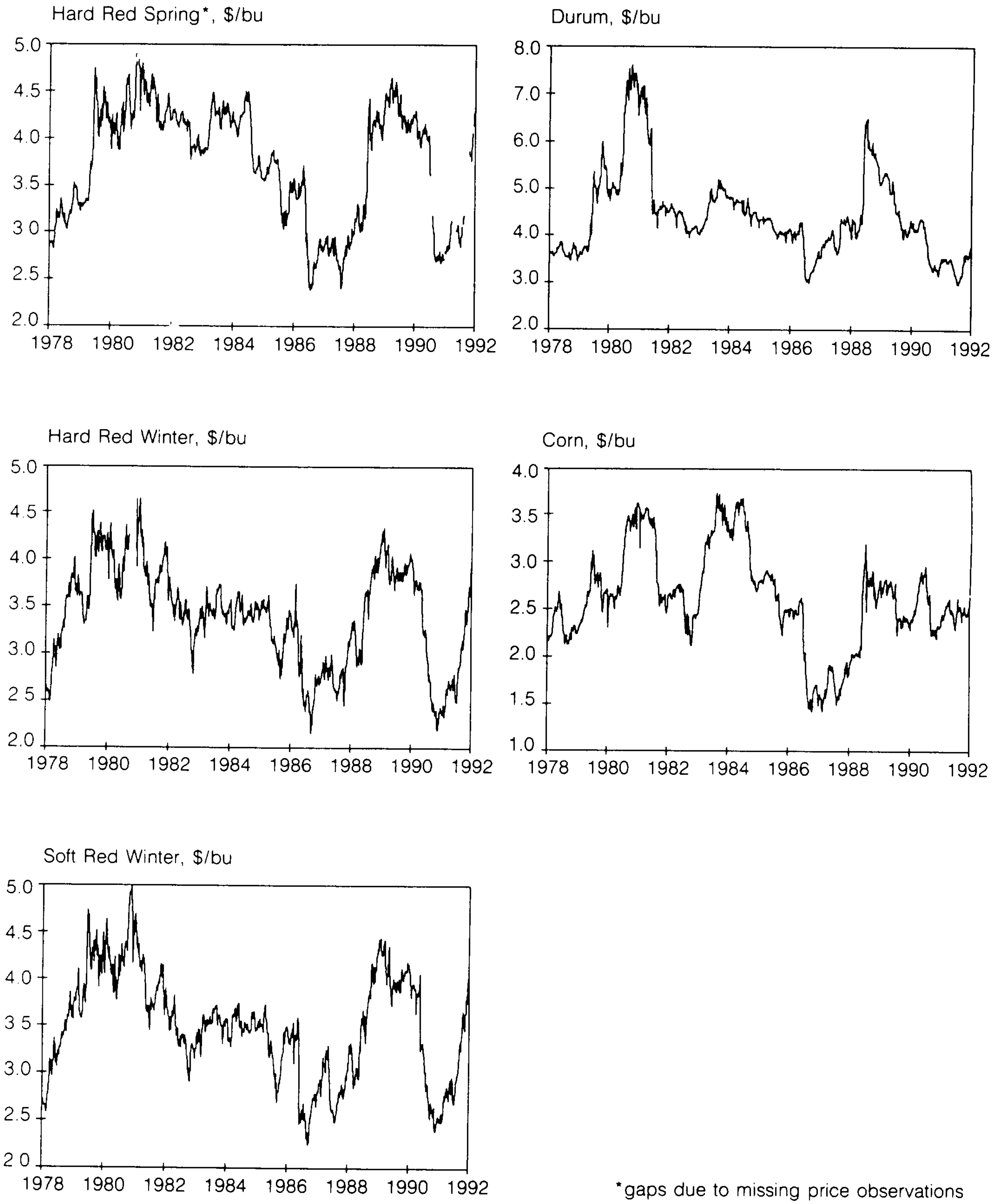
These prices are recorded primarily by the U.S.D.A. through daily canvassing of market participants. They are usually reported the following week in the U.S.D.A. publication *Grain and Feed Market News*.

The panels of Figure 1 show the evolution of the prices of the four wheats and corn over the sample interval. The panels of Figure 2 show pairwise scatterplots of wheat prices over the same interval, and Figure 3 shows similar scatterplots of wheat prices versus corn. It is immediately obvious from these graphs that wheat prices vary considerably over time and often exhibit sharp movements. It is also apparent that hard red winter (HRW), hard red spring (HRS) and soft red winter (SRW) prices are closely linked to each other, while corn and durum wheat prices are not as closely linked to other prices.

II. SUBSTITUTABILITY

It is possible that the degree of linkage among wheat prices results from demand substitution among different wheat types. This substitutability stems from the fact that some wheats have more than one primary use.

Figure 1. Wheat and Corn Prices



*gaps due to missing price observations

Figure 2. Scatterplots of Wheat Prices, 1978–1991 (dollars per bushel)

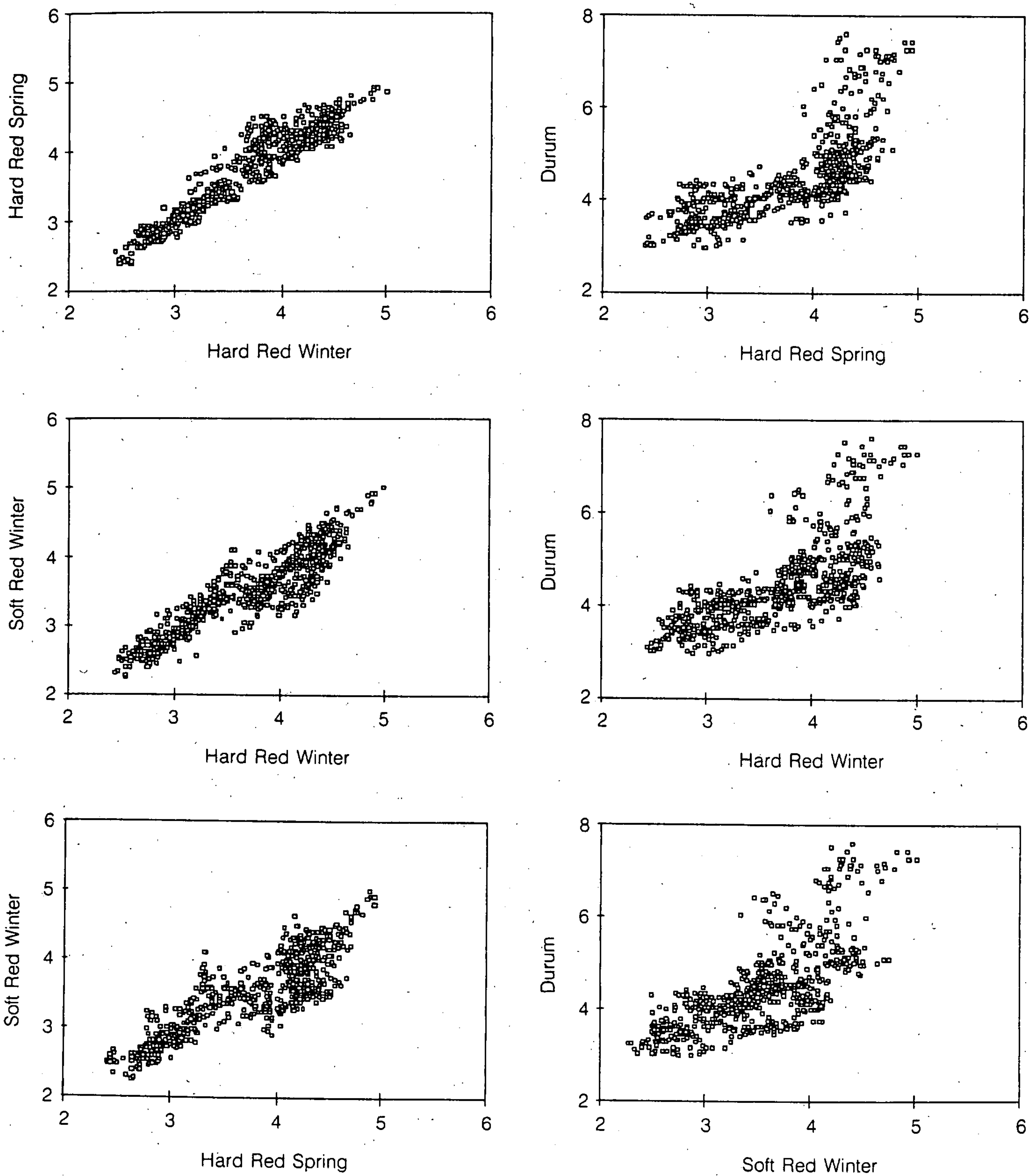
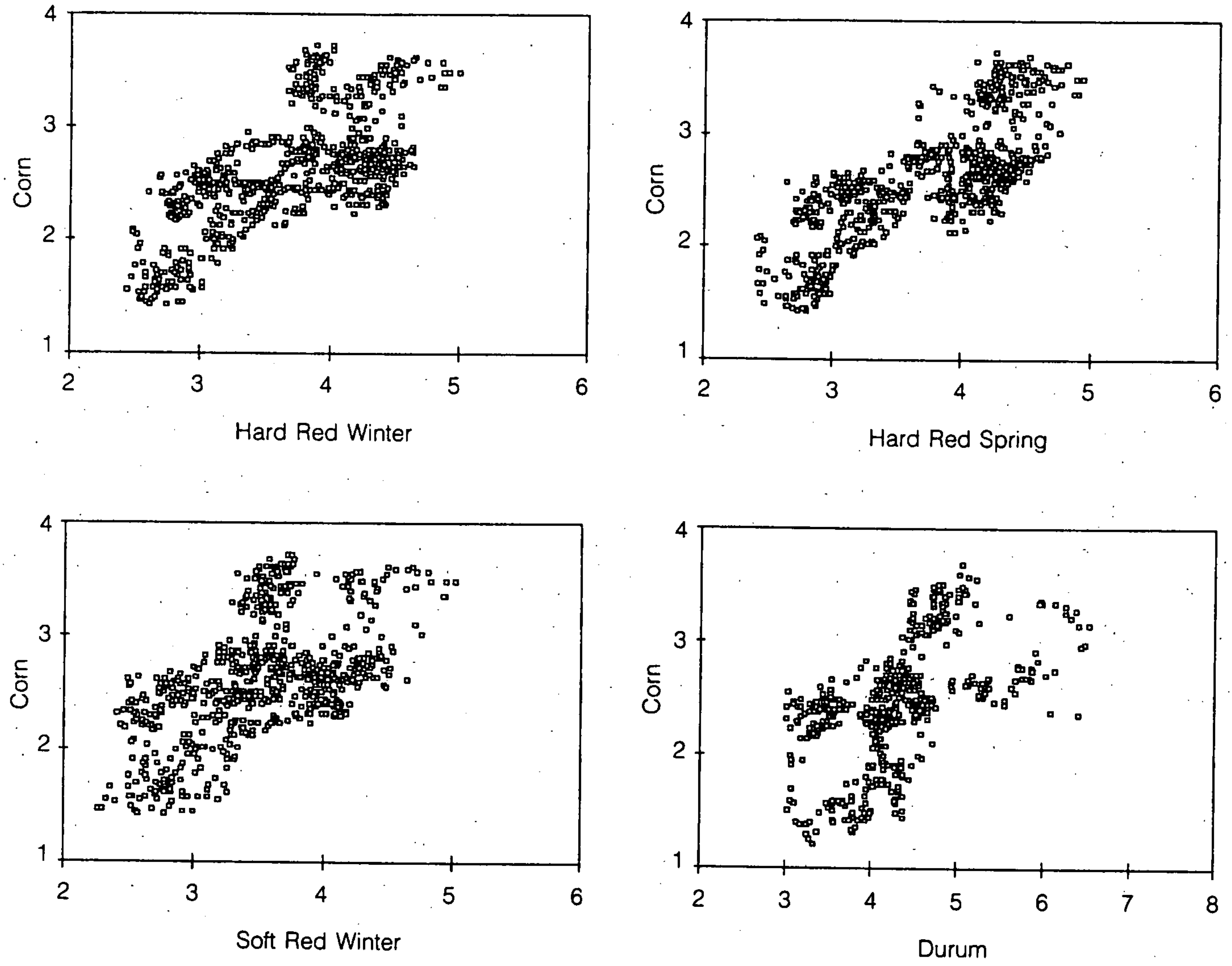


Figure 3. Scatterplots of Wheat Prices vs Corn Prices, 1978–1991 (dollars per bushel)



The principal substitution involves that of HRW for SRW and HRS. SRW, accounting for about 16% of U.S. wheat production, generally has the lowest protein level and is used for cookie, cake, and cracker flour. HRS, about 23% of the U.S. crop, usually has the highest protein content and is used primarily for bread. HRW, accounting for 44% of U.S. wheat production, generally falls between HRS and SRW in protein content. As a result, lower protein HRW wheat can be substituted for SRW wheat in cookie and cake flour and higher protein HRW wheat can be substituted for HRS in bread flour. Thus, HRW wheat is the dominant wheat because of the size of the crop and its broad range of uses.

There are several other end products for which different wheat types may be used. For example, there is some substitution of HRS for durum. Durum wheat, which accounts for about 6% of the annual U.S. crop, is used almost exclusively for pasta products. HRS wheat can be substituted for durum in pasta manufacturing in proportions up to 50%, depending on regional taste preferences. (The practice of blending HRS wheat with durum is less popular in the U.S. than in Canada, due to the American preference for the "al dente" pasta that durum provides.) Strengthening this linkage are the facts that these wheats are grown in the same general area of the country and that farmers can switch easily between the two whenever relative prices make it economically advantageous to do so.

Between 10% and 20% of total wheat production is used for animal feed each year, leading to some substitutability between wheat and corn, especially at times of low wheat prices. This substitution can involve any of the several types of wheat. As a feed, wheat has a higher nutritional value than any of the other major feed grains like corn, oats, and barley. Its use is limited, however, because it is usually relatively expensive and because animal diets cannot be changed frequently. As a result, wheat will not be substituted for other grains in animal feed unless its economic benefit is expected to last for some time. While feeding is not a major use of wheat, it effectively serves as a vent in years of exceptionally large overall supply and when quality problems lead to an abundance of feed-quality wheat.

There is also some demand substitution among different wheats by foreign importers. This substitution, however, is based purely on price. While many wheat importers desire wheat with specific quality characteristics, there are others who will simply buy the cheapest available product. This is particularly true of north African countries where wheat is used to make flatbreads. Here, the protein level is often unimportant, so any wheat is satisfactory. This type of substitution is influenced by the Export Enhancement Program of the U.S.D.A., which provides subsidies for wheat destined for particular countries at particular times.

III. SEASONAL PRICE FLUCTUATIONS

This section examines the extent to which fluctuations in wheat prices show regular seasonal patterns. Seasonality is important because U.S. wheat is harvested once a year but consumed throughout the year, necessitating storage of most of the crop. Since storage is not without cost, prices should rise after a harvest and fall as the next harvest approaches. This regular and predictable variation needs to be removed before the stochastic variation in prices can be examined. We first describe a model of seasonal price fluctuation, followed by empirical results.

A Model of Seasonal Price Fluctuation

Let $p_o(t)$ denote the observed price of wheat at time t, where t is measured in decimal years (January 1, 1991 = 1991.00 + 1/365 or 1991.00274, January 2, 1991 = 1991.00548, etc.). We assume that the observed price $p_o(t)$ can be expressed as the sum of a regular (i.e. non-stochastic) seasonal component, s(t) and a deseasonalized stochastic component p(t):

$$p_o(t) = s(t) + p(t) \tag{1}$$

The seasonal component represents the regularly recurring cyclical price movement from any fixed point of the year. The seasonal component is thus a periodic function of time with an average value of zero and a periodicity of one year. Algebraically, this is stated as follows:

$$s(t + \Delta t) = s(t) \quad \text{for all values of t and all } \textit{integer} \text{ values of } \Delta t \tag{2}$$

$$\int_t^{t+1} s(\tau) \cdot d\tau = 0 \quad \text{for all values of t} \tag{3}$$

It is assumed here that the deseasonalized component of prices follows something like a Gaussian random walk with zero drift.

Identifying the seasonal pattern involves specifying the nature of the s(·) function in equation (1) for the time series under consideration. This is done using Fourier analysis, as described in the appendix to *Topics in Money and Securities Markets*, "Characteristics of Fluctuations in the Prices of Crude Oil and Its Refined Fuels", January 1991. Once the seasonal components of wheat prices have been estimated, seasonally adjusted prices can be computed by subtracting from the observed prices their seasonal components.

Empirical Results

Figure 4 shows the seasonal components of the wheat and corn price series. Except for SRW, each of the price series displays statistically significant patterns of seasonal variation. Observe, however, that the pattern for SRW is nearly identical to that of HRW. Both wheats have seasonal lows at harvest in early August, with prices which rise monotonically over the next five months, peaking in the spring. This pattern of price fluctuation reflects the expected return on wheat held in storage from the time of harvest until it is milled at some later date. The regular decline of prices from the spring

Figure 4. Seasonal Components of Wheat and Corn Prices
H denotes approximate time of harvest.

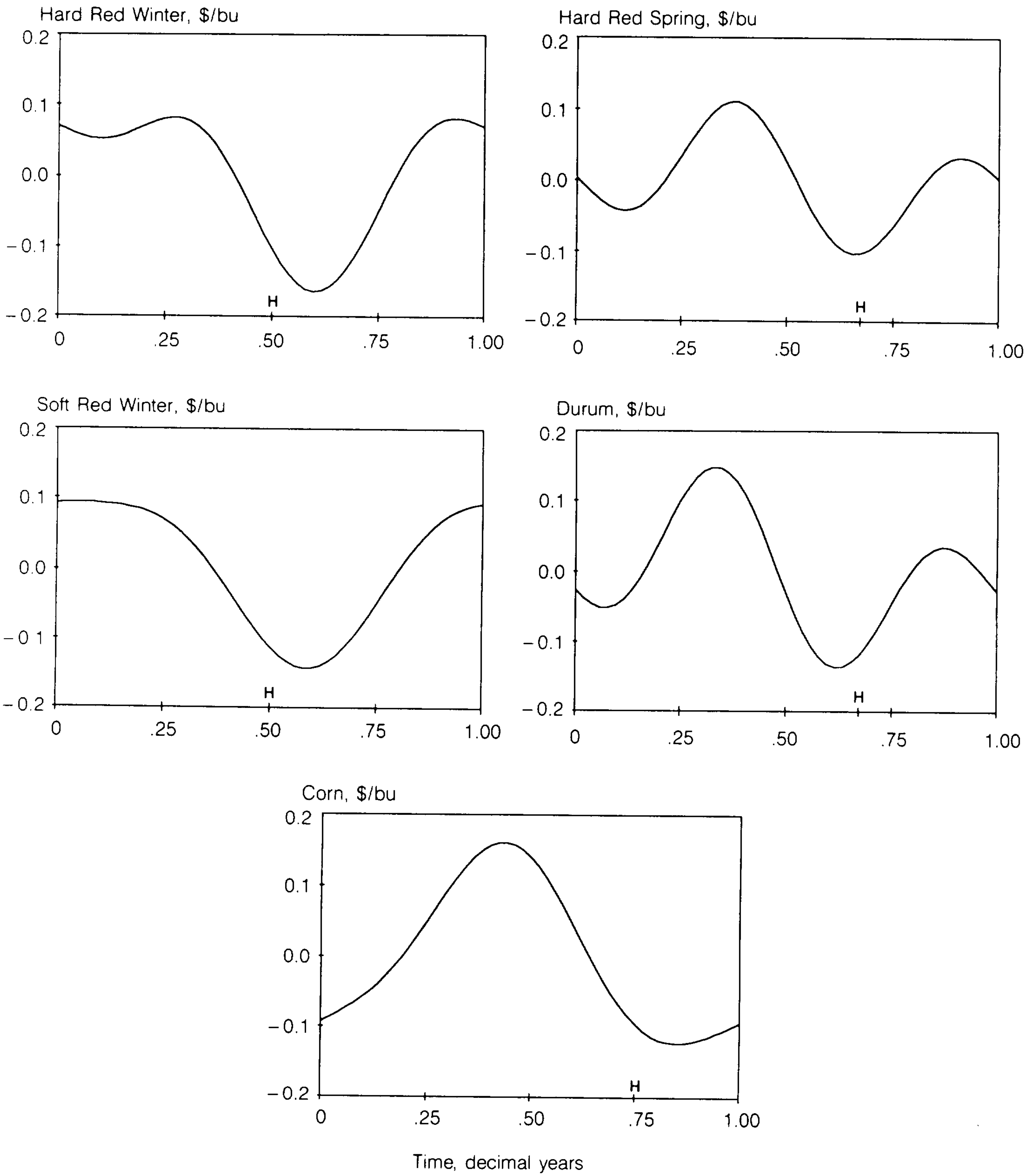


Table 1: Correlation of Deseasonalized Price Changes

1 week differences

	SRW	HRW	HRS	Durum	Corn
SRW	1.0000	0.6303	0.5831	0.1535	0 4160
HRW	0.6303	1.0000	0.6099	0.2023	0.4169
HRS	0.5831	0.6099	1.0000	0.3575	0.4179
Durum	0.1535	0.2023	0.3575	1.0000	0.1736
Corn	0.4160	0.4619	0.4179	0.1736	1 0000

4 week differences

	SRW	HRW	HRS	Durum	Corn
SRW	1.0000	0.6972	0.6210	0.2977	0 3563
HRW	0.6972	1.0000	0.6809	0.3789	0.4943
HRS	0.6210	0.6809	1.0000	0.5327	0 4287
Durum	0.2977	0.3789	0.5327	1.0000	0.3033
Corn	0.3563	0.4943	0.4287	0.3033	1.0000

8 week differences

	SRW	HRW	HRS	Durum	Corn
SRW	1.0000	0.7629	0.6154	0.3712	0.3285
HRW	0.7629	1.0000	0.7358	0.4529	0.5090
HRS	0.6154	0.7358	1.0000	0.6061	0.4634
Durum	0.3712	0.4529	0.6061	1.0000	0.3999
Corn	0.3285	0.5090	0.4634	0.3999	1.0000

through the summer suggests that there is little incentive to hold crops in storage just prior to harvest.

The seasonal pattern of corn prices displays two important differences from the patterns for HRW and SRW. First, its seasonal pattern is out of phase with those of HRW and SRW. This is due to corn's later planting and harvest times. Second, corn prices rise more slowly immediately after the harvest, but more rapidly in the spring. This may reflect different storage and marketing patterns.

The seasonal patterns for HRS and durum are more complex. Like the winter wheats, they both show seasonal declines after planting, hitting seasonal lows in late August. Their post harvest price increases, however, last only until early December after which prices fall through February. This pattern reflects the peculiarities of wheat flows during the winter in the north central United States when the Great Lakes and upper Mississippi are not navigable. During this time, there is no export bid and thus reduced incentive to hold stocks until the lakes open up again in March. At this time, countries that receive wheat shipped through the Great Lakes start to bid again and prices start to rise. Similarly, there exists a "river opening bid" for wheat shipped down the Mississippi, suggesting that wheat flows south to the Gulf of Mexico are also interrupted during the winter.

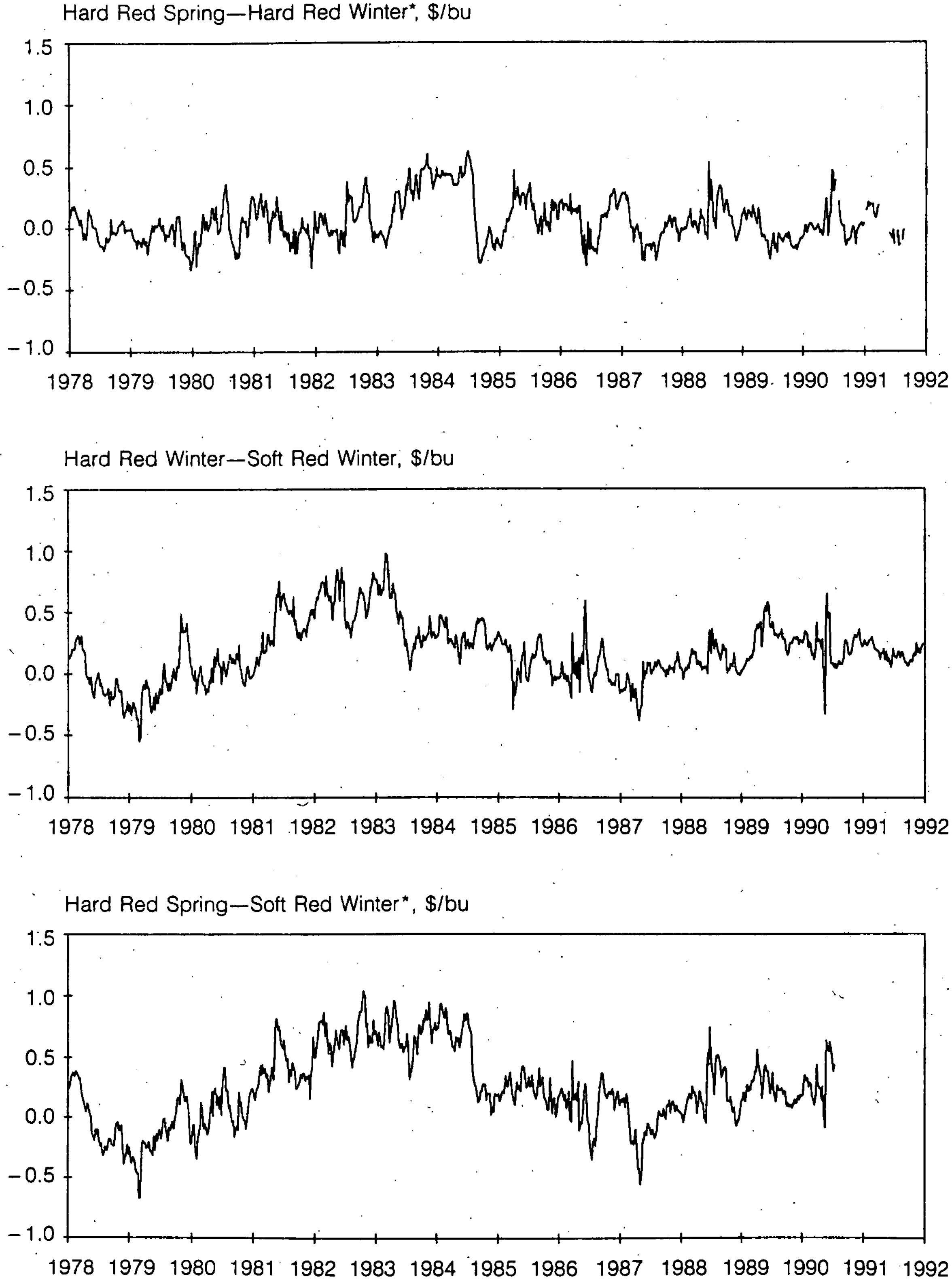
IV. PRICE SPREADS

Once the seasonal elements of wheat prices have been estimated, one can examine the characteristics of changes in the deseasonalized prices. In particular, it becomes possible to analyze the evolution of wheat prices and wheat price spreads to determine what types of processes are at work.

One possible description is that wheat prices follow uncoupled random walks with cross-correlated increments. This means that the individual series all follow random walks with an identifiable correlation structure in the price changes (See *Topics in Money and Security Markets*, "The Correlation Structure of Wheat Prices", August, 1992 for a discussion of the correlation structure of wheat prices).

Such a description would have two important implications for the behavior of price spreads. First, it would imply that the correlation of price changes of any two wheats would be invariant with respect to the length of the differencing interval. This means that as the differencing interval increases one would expect to see no regular variation in the correlation coefficients. Empirical evidence is inconsistent with this statement. Table 1 shows the correlations of changes in the deseasonalized prices over one week, four

Figure 5. Deseasonalized Price Spreads of Major Wheats



*gaps due to missing price observations

week, and eight week differencing intervals. Note that the correlation rises as the differencing interval increases in most cases. Thus, it is clear that the correlation is *not* invariant with respect to the length of the differencing interval.

Second, it says that the variance of the price spread of any two wheats should scale linearly with time. This suggests that a widening of the spread over any interval is as likely to be followed by a further widening as it is by a narrowing. Figure 5 shows the price spreads of HRS and HRW, HRW and SRW, and HRS and SRW over the sample interval. While the spreads vary widely, there appears to be a tendency for the spreads to fluctuate around a certain level, particularly in the case of the spread between HRS and HRW.

Figure 5 suggests another possibility, that the price spreads evolve over time as mean reverting processes which tend to return to some "normal" level. The speed with which prices return to normal levels could be used to measure the extent to which any two commodities in question might be substitutes.

A Test for Mean Reversion

Let $p_{spread}(t_k)$ be the spread between the seasonally adjusted prices of two commodities at time t_k, denominated in dollars per bushel, where t_k, t_{k+1}, etc., represent weekly observations. Let C be the "normal" level of the spread. If the process is mean reverting, one would expect any observation greater than C to be followed by a narrowing of the spread, and one would expect any observation less than C to be followed by a widening of the spread.

Algebraically, the change in the spread between times t_k and t_{k+1} can be written as:

$$p_{spread}(t_{k+1}) - p_{spread}(t_k) = \alpha \cdot [C - p_{spread}(t_k)] + u_{spread} \qquad (4)$$

where α is a positive adjustment coefficient representing the speed of adjustment and u_{spread} is a random variable with mean zero. A coefficient of α = .50, for example, would indicate that about half of the difference between the current spread and the normal spread would disappear between times t_k and t_{k+1}. The parameters α and C can be estimated by rewriting equation (4) as:

$$p_{spread}(t_{k+1}) - p_{spread}(t_k) = \gamma + \delta \cdot p_{spread}(t_k) + u_{spread} \qquad (5)$$

where $\gamma = \alpha \cdot C$ and $\delta = -\alpha$. These parameters can then be estimated using ordinary least squares regression and α and C can be identified as:

$$\alpha = -\delta$$

$$C = -\frac{\gamma}{\delta}$$

Empirical Results

Table 2 shows the parameter estimates for the normal spread and the partial adjustment coefficients. The results indicate all of the price spreads follow mean reverting processes, with the speed of adjustment varying considerably.

The speed of adjustment of the different price spreads appears to be related to the demand side substitutability of the commodities. The HRS-HRW spread, pictured in the top panel of Figure 5, is quickest to adjust. Note that the spread shows considerable fluctuation, but always returns to a level quite close to zero. The first line in Table 2 indicates that about 54% of the abnormal spread evaporates in one week, and that the average spread is not significantly different from zero at a 95% confidence level. This is consistent with the fact that HRW and HRS are good substitutes for each other in production, with HRS flour commonly being used to fortify HRW flour in the baking process.

The second quickest adjustment is seen in the HRW SRW spread, shown in the second panel of Figure 5. Here, the adjustment speed is about 7% per week and the average spread about $0.18 per bushel, which is significantly different from zero. Note that the line in Figure 5 does not appear to hover about that $0.18 level but instead moves away from it for long periods of time. This weaker linkage is consistent with the fact that some HRW is used for products with low protein requirements, particularly when the SRW crop is poor in quality.

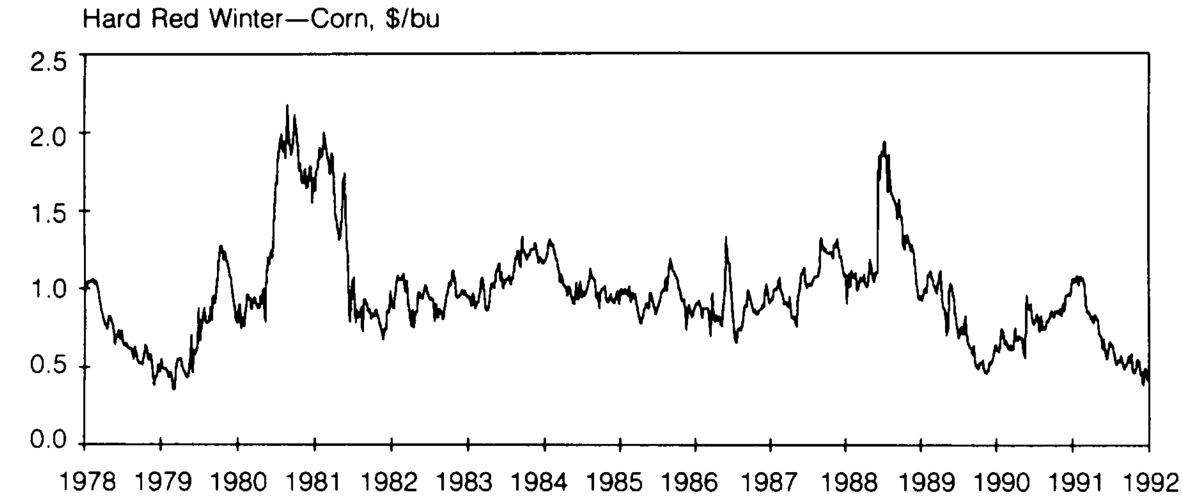
Third in terms of adjustment speed is the spread between HRS and SRW, which is shown in the third panel of Figure 5. Here, the normal spread is about $0.25 per bushel, with an adjustment speed of about 5% per week. Like that of the HRW SRW spread, the plot does not hover around its average. There is little direct substitution between these two wheat types. HRW, however, can be substituted for both. If either HRS or SRW prices become relatively expensive, substitution of HRW will take place. Thus, the link between HRS and SRW prices is indirect.

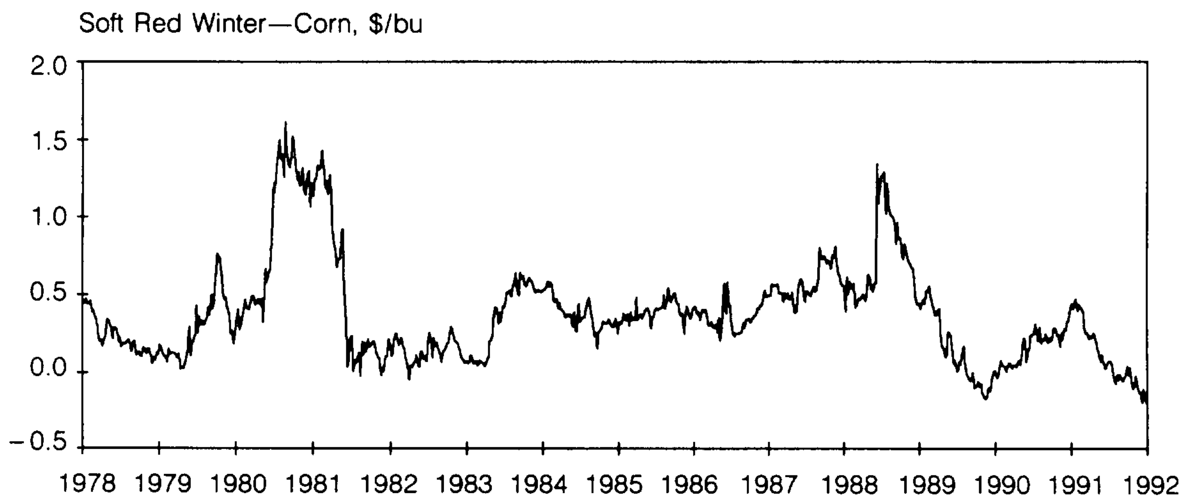
The spreads between the major wheats and corn, shown in Figure 6, have adjustment speeds that are slower still. Here, the adjustment coefficients are between 2% and 4% per week, and the spreads are statistically significant at around one dollar per bushel. The spreads between the major wheats and durum, shown in Figure 7, behave similarly. These adjustment speeds are also in the 2 to 4% range. The average spreads are between $0.70 and $0.90 per bushel compared with other wheats and $1.80 per bushel compared with corn. The limited degree of mean reversion in these spreads may reflect the long-run substitutability on both the supply and demand sides of these commodities.

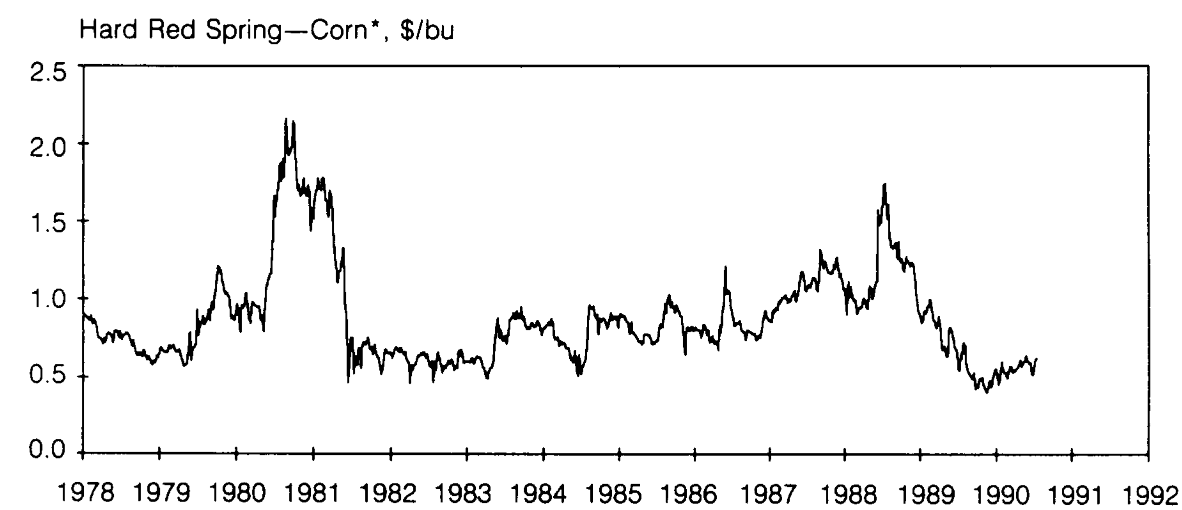
V. CONCLUSIONS

This paper examined several aspects of fluctuations in wheat prices. First, it showed that wheat prices have seasonal components which trough immediately after harvest and peak somewhat before harvest, with wheats grown in the north central U.S. subject to additional seasonal variation due to the effect of weather on wheat flows. Second, it demon-

Figure 6. Deseasonalized Price Spreads of Major Wheats to Corn

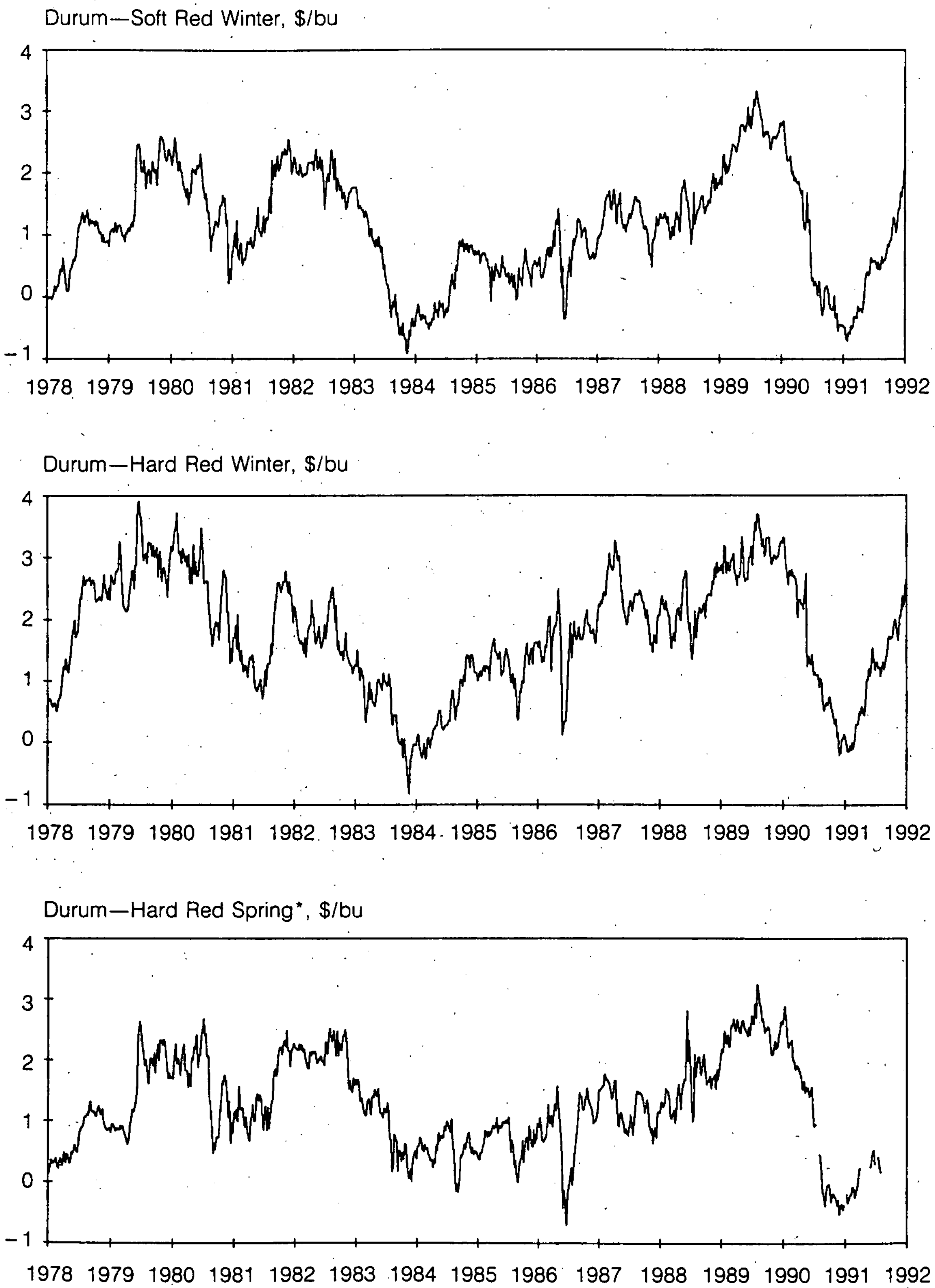






*gap due to missing price observations

Figure 7. Deseasonalized Price Spreads of Durum to Major Wheats



*gaps due to missing price observations

Table 2. Parameter Estimates for Normal Spread and Adjustment Coefficients
(t-statistics on null hypotheses that parameters equal zero beneath estimates)

Price Spread	γ	δ	C	α	Standard Error of Regression	Number of observations	R^2	F
HRS-HRW	0.0064 0.4581	−0.5441 −16.2786	0.0118 $/bu	0.5441	0.3735 $/bu	711	0.5216	264.9932*
HRW-SRW	0.0129 3.0713	−0.0712 −5.1780	0.1812	0.0712	0.0918	729	0.1886	26.8113*
HRS-SRW	0.0129 2.5676	−0.0520 −4.1552	0.2474	0.0520	0.1020	653	0.1607	17.2661*
SRW-CORN	0.0257 2.9882	−0.0278 −3.2219	0.9238	0.0278	0.1101	729	0.1186	10.3805*
HRW-CORN	0.0245 2.8020	−0.0218 −2.8577	1.1219	0.0218	0.0909	729	0.0154	8.1666*
HRS-CORN	0.0484 3.6563	−0.0409 −3.7768	1.1841	0.0409	0.0996	653	0.1464	14.2639*
DURUM-SRW	0.0299 2.6781	−0.0336 −3.0215	0.8921	0.0336	0.1700	729	0.1258	11.6977*
DURUM-HRW	0.0186 2.1033	−0.0268 −3.0215	0.6955	0.0268	0.1549	729	0.1114	9.1295*
DURUM-HRS	0.0197 2.1866	−0.0273 −2.9745	0.7208	0.0273	0.1475	653	0.1158	8.8477*
DURUM-CORN	0.0402 2.6213	−0.0223 −2.8395	1.8026	0.0223	0.1513	729	0.1047	8.0629*

* on null hypothesis that γ and δ are both zero, statistically significant at a confidence level in excess of 99%

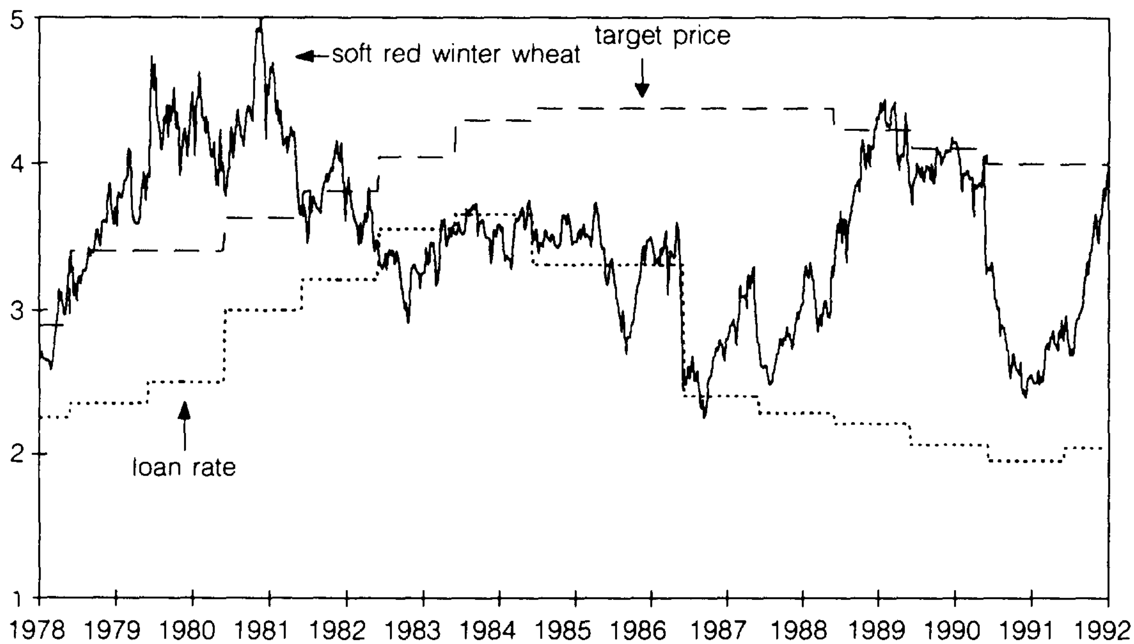
strated that changes in wheat prices do not follow Gaussian random walks with cross-correlated increments. Instead, it suggested that the dynamic evolution of spreads is more appropriately modeled as a mean reverting process. Third, it related the speed of adjustment of that process to the degree of demand substitution between any two wheats, with wheats that are close substitutes having price spreads that revert to their normal levels faster than those that are not.

APPENDIX: THE EFFECT OF GOVERNMENT POLICIES ON WHEAT PRICES

U.S. government agricultural programs and policies have evolved in response to often dramatic price changes attributable to weather conditions, technological advances, changes in domestic and foreign policy, and shifts in the world supply of and demand for wheat. While many policy instruments have been used since the 1930's, the focus of U.S. farm policy has often adjusted to the changing needs of the U.S. farm sector. Current U.S. farm policy is carried out by the U.S. Department of Agriculture through the Agricultural Stabilization and Conservation Service, which administers farm price and income support and conservation programs, and the Commodity Credit Corporation, which functions as the financial institution through which payments to farmers are made.

Most wheat production in the U.S. is carried out within the structure of a domestic wheat program authorized under a series of laws, the most recent being the 1990 Farm Act and the 1990 Budget Reconciliation Act. The aim of the program is to protect farm income so farmers can produce needed crops without fear that excessive production will cause prices to fall drastically. Participation in the program is voluntary and qualifies the farmer to receive price support payments, called deficiency payments. These deficiency payments along with acreage reduction requirements are the primary mechanisms of U.S. farm policy. In deciding whether or not to participate in the program, farmers will estimate their income with and without participation based upon their estimate of market prices. Recent participation in the U.S.D.A. wheat program has been in the 80%–90% range.

Figure 8. Soft Red Winter Prices, the Loan Rate, and the Target Price ($/bu)



To become eligible for farm subsidy payments, farmers must participate in the Acreage Reduction Program. The Acreage Reduction Program serves to limit planted acreage while encouraging protection of land from weeds and from water and wind erosion. In many circumstances, idled land is still eligible for deficiency payments, albeit at a reduced rate. The amount of land to be set aside is determined each year and is a function of the previous year's carryover.

In determining deficiency payments, Congress sets two prices, the target price and the loan rate. The target price is the price which it believes will provide farmers with a "reasonable return" on their investment. The loan rate is the rate per bushel at which the government will provide a secured, non-recourse loan to participating farmers, enabling them to hold their crops for sale at some later date. The non-recourse feature allows a farmer to transfer ownership of the grain to the government rather than repay the loan if the market price is too low. Thus the loan rate serves as a price floor. Figure 8 shows the loan rate and target price for wheat as well as the price of soft red winter wheat. Note the extent to which the market price for SRW falls within these administered prices.

Deficiency payments to farmers are based upon the difference between the target price and the greater of the average market price and the loan rate. This difference is called the deficiency payment rate. The total payment is the payment rate times the farmers' participating acreage times an administratively-determined program yield per acre. Payment may be made in cash or in Commodity Certificates which may be redeemed for grain currently in storage. Grain coming out of storage into the market through this sort of payment-in-kind can affect overall market price and quality premia.