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Risk Management: Hedging Potential for U.S. Breweries

by

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In this paper we investigate the potential to develop hedging strategies for firms in the U.S. brewing sector. The primary ingredients for beer are hops (grown in many different varieties), grain malt (mostly malted barley but also other grains), wheat, yeast, and water. We test for statistical relationships between hop and barley prices and futures prices wheat, and corn to determine whether price relationships are such that cross hedging hops and barley with existing futures contracts appears feasible. If hops and barley can be effectively hedged then most of the primary inputs used by brewers can be hedged. Using standard multivariate time series models, we test for stationarity in prices, test for co-integration relationships between the various brewers' inputs, and report the statistical results. We find the existence of a structural break in the prices associated with beginning of the most recent recession. This created greater instability in commodity prices and a change in their inter-relationships. Insight into these relationships provides relevant information concerning hedging and cross-hedging opportunities for small breweries.

Keywords: vector error correction model, beer, grains, hedging models.

Introduction

There is a substantial literature focused on hedging agricultural commodities (see for example Garcia and Leuthold (2004) and Zapata and Fortenbery (1996)). However, to our knowledge there has been little or no research focused on developing a portfolio hedging model for inputs for the brewing industry: wheat, barley, and hops. This is surprising given the rapid growth of the craft beer sector over the past 20 years (Brewers Association, 2016).

As the craft brewing sector has grown, derived demand for different types of hops and malts has also evolved. Given the price volatility exhibited in most grain markets it might be useful to investigate risk management opportunities in brewery feedstock procurement.

Before constructing a hedge strategy for brewers, however, it is necessary to investigate the price relationships between brewer inputs that have no direct futures pricing contracts (i.e., hops and malting barley) and commodities for which futures contracts do exist.

A necessary condition for an effective hedge is an identifiable and stable relationship between the price of the commodity being purchased in the cash market and a commodity futures price traded on an organized exchange. In the case where the two commodities are identical in form (i.e., the cash commodity purchased and the futures contract traded are for identical commodities) a hedge is relatively straight forward. However, when the cash purchased commodity is not identical to a commodity traded in the futures market the price relationship is less clear. Nonetheless, if it can be determined that the price relationship is stable (the cash and futures prices for dis-similar commodities are found to move together in a predictable way) then basis risk (the difference between the cash and futures price) may still be less than the out-right cash price risk for the purchased input. When these opportunities exist they are referred to as cross-hedges – a cash price for a non-futures traded commodity can be cross-hedged on a futures contract for some other commodity.

To examine whether the necessary condition exists to allow for cross-hedging of brewers' inputs this research empirically tests for price relationships between the primary inputs of brewers and established futures contracts for various grains. We explicitly look at price dynamics between hops, malting barley and cash priced wheat relative to futures prices for corn and wheat (presumed to be the commodities with the closet potential relationships to brewers' inputs).

We initially inspect quarterly cash and futures price data from January 1972 to December 2011 to determine whether empirical investigation is warranted. Futures prices are from the Commodity Research Bureau, and hops and malting barley prices from the United States Department of Agriculture (USDA).

An examination of the data suggests several potential structural changes in price behavior over the entire sampled period (Figure 1). Several of the shifts are likely due to changes in government policy farm level price supports for commodity producers, macro-economic conditions, and possibly changes in agricultural productivity (associated with technological development). As a result, we restrict our empirical analysis to span from 1996 to 2011 (the emergence of non-binding price support programs with increased emphasis on market determined farm level prices). This data period corresponds to the emergence of the craft brewing industry, and the beginning of farm program provisions that were more market focused (i.e., the emergence of non-binding price support programs with increased emphasis on market determined farm level prices as an explicit Federal farm program).

Additionally, we break the 1996-2011 sample period into two sub-periods: before and after fourth quarter 2007. This break coincides with increased emphasis on grain-based bio-fuels production at both state and national levels. (Carter et al., 2016; Motamed et al., 2016) as well as the prelude to the Great Recession. It appears that, in addition to a change in general price levels and volatility, relative price behavior between commodities (for example hops and corn) also changed from being generally negatively correlated to positively correlated following 2007. The second sub-period also represents the period of greatest growth in the craft brewing sector.

Our approach for testing the price dynamics for the commodities of interest is to employ traditional multivariate time-series methods. We test for stationarity in the individual price series, and then, based on the results of unit root tests estimate, test for bi-variate cointegration and estimate a set of Vector Error Correction Models (VECM). In general, the model results suggest that the necessary conditions exist for a risk efficient hedging program to be developed for brewers. A detailed discussion of both the analysis and results follows.

Background and Data

Background

The analysis presented here closely follows the established literature on hedging in both commodities and securities markets (e.g., Howard and D'Antonio, 1984; Gemmil, 1988; Shapiro and Brorsen, 1988; Wolf, 2012). However, unlike much of this literature a large part of our focus is on cross-hedging of non-futures traded commodities not previously studied (i.e., hops and malting barley).

To address hedging potential, we investigate the cross-correlations among the primary inputs in producing beer (wheat, barley, and hops) and corn and wheat futures prices. Both wheat and barley can be substitutes for corn production in some environments and this suggests there could be strong price relationships between them. According to Motamed et al. (2016) there has been a trend toward switching to corn production at the expense of wheat and barley in response to changes in public policy.

We limit our empirical analysis and reporting of empirical results from the second quarter of 1996 to the fourth quarter of 2011.[1] This coincides with the beginning of significant growth in the micro-brewing sector and also the period in which government price supports for commodity markets were generally non-binding (Tremblay et al., 2005; Carroll and Swaminathan, 2000). As noted earlier, we further divide this period into two subsamples that match the general increase in price levels and volatility (Figure 1).

It is important to note that, over the study period, we see higher prices and more volatility in the second sub-period across all commodities evaluated, as presented in Table 1. Based on structural shifts observed during model diagnostics, and highlighted in Figure 2, the two sub-samples are defined by 1) Q2 1996 to Q3 2007 and 2) Q4 2007 to Q4 2011.

Data

Hops prices are taken from the USDA's Foreign Agricultural Service, and represent export prices for hops (this is the closest to farm level prices we could get). These are quarterly data averaged across various hop varieties (see Appendix A1). Barley prices are from USDA's National Agricultural Statistics Service (NASS). Futures prices for corn and wheat for both the Chicago and Kansas City futures exchanges are from the Commodity Research Bureau (CRB). Barley, corn, and wheat prices are aggregated to quarterly averages to be consistent with the hops price time series reported by USDA. Descriptive statistics for all data used are presented in Table 1.

Of all commodities, corn prices are the least volatile over the study period, with a variance of 34% and a range of $3.60 per bushel. Hops and hard-red wheat prices are the most volatile, with variances of 163% and 76%, respectively. The range of hops and hard-red wheat prices are similar in magnitude: around $5.00 per ton for hops and $5.00 per bushel for hard red winter wheat. A visual check (see Figure 2 below) of prices over the study period shows all prices have similar trends, rising and falling with a high degree of correlation.

In terms of average prices, corn and barley appear to remain in the range of $3 to $5 per bushel. However, barley appears to exhibit greater variability over the study period compared to corn. Soft-red winter wheat is initially more volatile than hard-red wheat, but seems to stabilize relative to hard-red towards the end of the sample period. Figure 2 shows that the futures traded commodities (wheat, barley,[2] and corn) move together, indicating a high degree of correlation over this period. While the grains tend to move together through the sample period hops appears to be negatively correlated with grains until about 2005, and then moves in the same direction of grains in the later years. This provides some anecdotal evidence that in the more recent years cross hedging

[1] Quarters: Q1 = January to March; Q2 = April to June; Q3 = July to September; Q4 = October to December.
[2] Feed barley trade at the Winnipeg Futures Exchange. However, we do not explicitly consider futures prices on Canadian exchanges in this analysis due to the need to account for exchange rate variation. There is no futures contract for malting barley.

opportunities may exist for hops using grain futures.

Empirical Approach

A necessary condition for an effective hedge is a strong and predictable relationship between cash prices for the commodity to be hedged and futures prices for the hedge instrument. We test for this using a multivariate time-series regression that jointly estimates own- and cross-price effects.

A standard model in the commodities literature (Fortenbery and Zapata, 2004) is the Vector Autoregressive model (VAR), which controls for own and cross-price effects, as well as measures causality in the price series (Sims, 1980). This is represented by:

$$\mathbf{y}_t = \nu + \mathbf{A}_1\mathbf{y}_{t-1} + \ldots + \mathbf{A}_p\mathbf{y}_{t-p} + \mathbf{u}_t \tag{1}$$

where $\mathbf{y}_t$ is a $K \times 1$ vector of variables, ν is a $K \times 1$ of constant, $\mathbf{A}_1, \ldots, \mathbf{A}_p$ are $K \times K$ matrices of parameters to be estimated, K is the set of commodities, and p represent the number of time lags.

If individual commodity prices behave as non-stationary series, but prices for different commodities and/or different market locations respond to the same fundamental stimuli then the possibility exists that prices from the different markets co-integrated. That is, commodity prices move together and they exhibit a long-run equilibrium. In this case, equation (1) would mis-specify the relationship, as the first difference would be stationary (Engle and Granger, 1987). A VAR in the first difference, although properly specified in terms of a covariance-stationary series, would not capture long-run tendencies (Davidson et al, 1987).[3]

If this is the case, there is a vector of error-correction terms, of length equal to the number of co-integrating relationships, or co-integrating vectors, among the series. Based on unit root tests (available from the authors), it was determined that the commodity prices modeled here do, in fact, behave as non-stationary series. As a result, and consistent with previous literature (Fortenbery and Zapata, 2004), we employ a Vector Error-Correction Model to control for the shared common stochastic trend if it exists:

$$y_t = \nu + \prod \mathbf{y}_{t-1} + \sum_{i=1}^{p-1} \mathbf{\Gamma}_i \Delta\mathbf{y}_{t-i} + \epsilon_t \tag{2}$$

where, $\prod = \sum_{j=1}^{j=p} \mathbf{A}_j - I_k$ and $\mathbf{\Gamma}_i = -\sum_{j=i+1}^{j=p} \mathbf{A}_j$ represent vectors of coefficients for the equilibrium relationships and long-run adjustment parameters, respectively.

Empirical Results

Following the literature, we tested for co-integration using the Johansen trace test (Johansen, 1991). The Johansen test indicated 4 co-integration equations in the first sub-period and 3 co-integration equations in the second sub-period. Order-selection testing shows the optimal lag-length for the first sub-period (Q2:1996-Q3:2007) to be 8, and for the second sub-period (Q4:2007-Q4:2011) to be 2.[4]

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[3] The VAR model only expresses the short-run responses of prices to any innovations in each commodity market.

[4] Four information criteria were used, the Akaike Information Criterion (*AIC*), Final Prediction Error (*FPE*), Hannan and Quinn Information Criterion (*HQIC*), Schwartz Bayesian Information Criterion (*SBIC*), and the Likelihood Ratio test to determine lag length.

In the first sub-period we observe an inverse relationship between prices for hops and corn futures. There is also some weak evidence of an inverse relationship between wheat and corn futures prices. However, this behavior changes after 2007, providing empirical evidence to support the hypothesis of structural change gained from visually examining Figure 2. In light of this, we present and discuss our results separately for the two sub-sample periods. Results of the VECM models by sub-sample period are presented in Appendix Tables A3 and A4.

Sub-period 1 (Q2:1996 to Q3:2007) VECM Results

Overall

Results from testing for co-integrating relationships among all commodities indicates the existence of an equilibrium relationship between soft-red and hard-red wheat, barley, hops and corn. This implies a long-run relationship across the major inputs used in the production of beer and corn and wheat futures prices. We also find evidence of equilibrium relationships between futures prices for hard-red wheat and corn, and soft-red wheat and corn. Barley prices are positively influenced by (respond to changes in) both hops and corn prices. Specific relationships are presented in Table 2.

Soft-Red Wheat

None of the long-run adjustment parameters for soft-red wheat are statistically different from zero, indicating no long-run causality in prices to the other commodities. There is short-run negative feedback at lag 5 in own-prices and positive feedback at lag 2 from hard-red winter wheat. Granger causality tests (see Table A2) for short-run causality for all prices fails to reject the null of no causality; that is no changes in other grains *Granger cause* changes in soft-red wheat. Results from the co-integrating equation do indicate the existence of an equilibrium relationship between soft-red wheat and corn prices.

Hard-Red Wheat

Results from the long-run adjustment parameters indicate that when hard-red wheat prices are shocked soft-red wheat price quickly adjust to the hard-red wheat price level within the same quarter. However, when hard-red wheat prices are shocked they quickly adjust back to corn price levels, suggesting corn price dynamics dominate hard-red wheat prices movement in determining price levels. There is also short-run positive feedback at lag 2 in barley prices.

Similar to soft-red wheat prices, we fail to reject the null hypothesis of no *Granger* causality between hard-red wheat prices and all other grains in the short-run. We find the existence of an equilibrium relationship between hard-red wheat and corn prices, and a positive influence from the equilibrium relationship between both soft-red wheat and corn prices.

Barley

Results from the long-run adjustment parameters indicate that when barley prices are shocked the average hops price quickly adjusts to the barley price level within the same quarter. We find the existence of an equilibrium relationship between barley and corn prices.

There is short-run negative feedback from soft-red wheat prices at lags 5 and 7; positive feedback in the first three lags for hard-red wheat; negative feedback at lag 1 to 3 and lag 7 of hops prices; and positive feedback at lag 7 in corn prices. Barley prices are *Granger caused* by other commodity prices at a 5% level of significance.

Hops
According to the long-run adjustment parameters, when hops prices are shocked they quickly adjust back to soft-red wheat prices. We find a positive influence from the equilibrium relationship between hops and corn prices.

Hops prices exhibit positive feedback from soft-red wheat at lags 1, 5, and 7; as well as negative feedback from hard-red wheat prices at lag 5. Hops prices also exhibit positive short-run feedback at lags 2, 4, and 6. Hops prices are *Granger caused* by other commodity prices at a 1% level of significance. This is somewhat unexpected, but encouraging in terms of developing a potential hedging program for hops.

Corn
The long-run adjustment parameters indicate that when corn prices are shocked hard-red wheat price quickly adjusts to the corn price level. Corn prices do exhibit a long-run equilibrium relationship with respect to all other commodities considered.

There is short-run positive feedback from soft-red wheat prices at lags 1, 2, and 4; negative from hard-red wheat prices at lag 6; positive from barley prices at lag 3; positive from hops at lag 6 and 7; and positive from own-prices at lag 7. As with wheat prices, the other commodities do not *Granger cause* corn prices in the short-run.

Sub-period 2 (Q4:2007 to Q4:2011) VECM Results

Overall
As expected, we find the existence of an equilibrium relationship among the beer input commodities in the second sub-period. We find a positive influence from the equilibrium relationship with respect to hops and a negative relationship with respect to corn. That is, the percent change in soft-red wheat, hard-red wheat, and barley prices are above the equilibrium value for hops and below the value for corn. Specific relationships are presented in Table 3.

Tests reveal short-run causality across all grain markets in the second sub-period. This period reveals stronger relationships compared to the previous period, with only the barley market appearing to not affect other grains.

Soft-Red Wheat
According to the long-run adjustment parameters, when soft-red wheat prices are shocked, the average prices for hops and corn quickly adjust. Barley prices also adjust to changes in soft red wheat prices. However, shocks in oft-red wheat prices result in a soft red wheat price adjustment back towards hard-red wheat price levels. In the short-run, there is negative feedback from own-prices, and positive feedback from hard-red wheat and hops prices. Short-run causality testing suggests that other grain prices *Granger cause* changes in soft-red wheat prices.

Hard-red wheat
The long-run adjustment parameters suggest that as hard-red wheat prices are shocked, soft-red wheat and barley prices will adjust toward the hard-red wheat level. When hard-red wheat prices are shocked they will adjust back towards the hops and corn price levels. There is negative short-

run feedback from soft-red wheat prices, and positive feedback from own prices and hops prices. Furthermore, short-run causality testing suggests that grain prices *Granger cause* changes in hard-red wheat prices.

Barley

The long-run adjustment parameters suggest that as barely prices are shocked, soft-red wheat prices will adjust towards barely price levels. There is a negative short-run feedback from soft-red wheat and corn prices, and positive feedback from hard-red wheat prices. Other grain price changes *Granger cause* changes in barley prices in the short-run.

Hops

The long-run adjustment parameters suggest that when hops prices are shocked, they quickly adjust to hard-red wheat price levels. Barley prices, however, respond to shocks in hops prices. In the short-run, hops prices receive negative feedback from soft-red wheat prices, and positive feedback from hard-red wheat and own prices. Other commodity price changes *Granger cause* changes in hops prices in the short-run.

Corn

As corn prices are adjusted in the long-run, hard-red wheat prices will adjust towards corn price levels. Soft-red wheat and barley prices also respond to changes in corn prices. In the short-run, corn prices receive negative feedback from soft-red wheat prices, and positive feedback from hard-red wheat and hops prices.

Discussion

Despite covering a shorter time horizon (4 years vs. 11 years), findings show 3 long-run equilibrium relationships in the second sub-period, compared to the 4 in the first sub-period. Short-run feedback is more immediate in the second sub-period compared to the first sub-period as prices are still adjusting from feedback sometimes 5 or 6 lags back in the earlier period. Thus, market dynamic impacts have become stronger and more time-concentrated since 2007. One interesting finding is the loss of the effect of barley price changes on other markets and the increased effect of hops price changes in the second sub-period.

Another interesting finding is the feedback effect that corn prices have on barley prices in the second sub-period. Over this period, corn prices do not exhibit any feedback effect from barley in the short-run. According to the co-integration coefficient, there is a negative equilibrium relationship between corn and barley. A possible explanation for this effect is that corn can be considered a substitute food grain, but barley would not be considered a substitute for fuel (Gold and Thompson, 2004). Thus, as farmers opt to shift their production capacity to corn due to more attractive market opportunities, there is a positive impact on barley prices due in part to expected scarcity as resources are shifted from barley to corn production. On the other hand, changes in barley prices have no effect on corn.

This may have important implications for small beer producers that rely on smaller contract or spot prices to maintain their inventories. As more land is devoted to corn production for fuel and other uses, greater pressure is put on prices for the principal grains used in beer production.

Conclusion

We find that correlations exist between prices considered, but they have evolved over time. What is relevant to current craft brewers is the most recent price relationships. A significant concern in the analysis presented here is the inability to use more disaggregated data, and thus understand the actual time it takes market prices for the considered commodities to adjust to each other. In the second period much of the price adjustment happened “instantaneously,” meaning within a single quarter. Because the spot market for hops is relatively thin and prices are not regularly reported it is not possible to tease out the actual price adjustment in less aggregate time, but this would be critical information in designing and implementing an actual hedging program.

Despite the limitations of aggregated data, the fact that there is short-run causality and feedback between commodities markets is a good indicator of “influence” in the barley and hops markets from commodities with active futures contracts. This gives credence that the necessary price relationships exist to warrant the search for a hedging strategy for the craft brewing industry. However, given futures contract sizes and input needs of individual breweries, it is likely that hedging programs would need to be managed by larger buyers’ cooperatives, with the cooperative then providing cash forward contracts, in smaller volumes, to individual breweries.

Since we find evidence that hedging might be feasible, we would like further test the significance of the relationship between hops and the other commodities. This will require finding disaggregated data for hops varieties, and higher frequency price data. As craft brewers continue to evolve using different hops and malts, and as consumer preferences change, these relationships between individual hops varieties and other inputs may also change. Furthermore, we are interested in exploring the potential to hedge malting barley using a cross-hedge with Winnipeg feed barley futures adjusted for exchange rate risk, as opposed to hedging malting barley with U.S. corn futures. Finally, the next step is to begin developing an actual hedge program and evaluate its ability to help manage price risk in the brewing industry.

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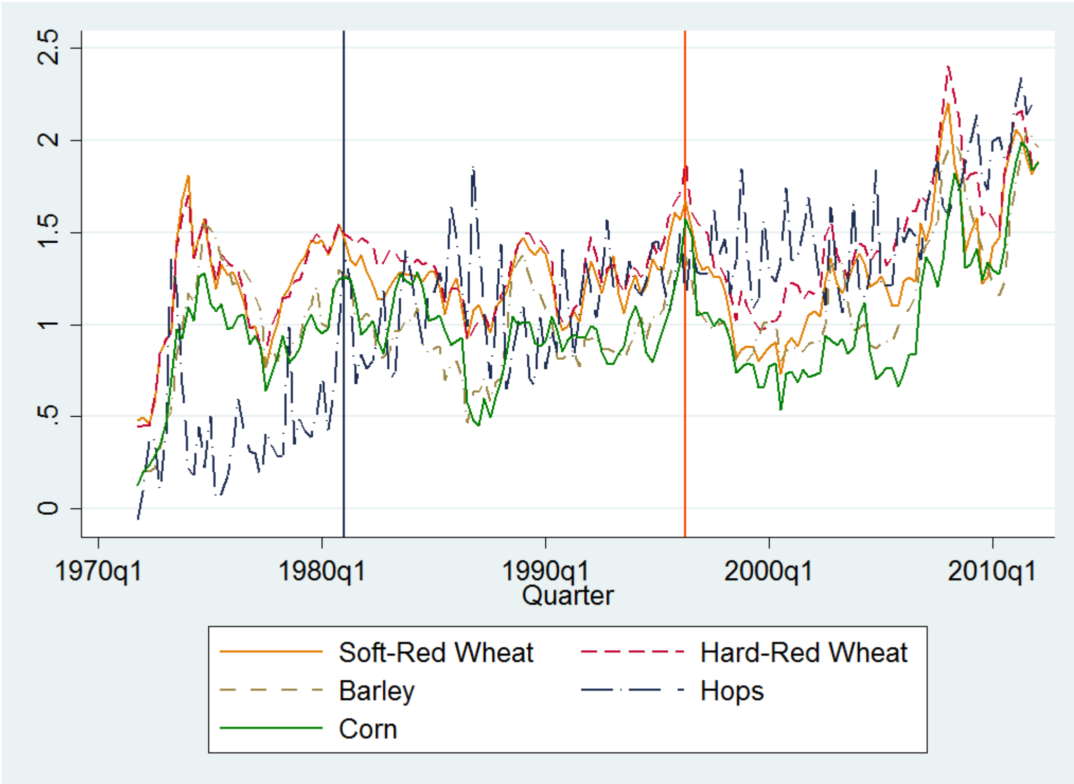

Figure 1. Grain Prices over Analysis Period

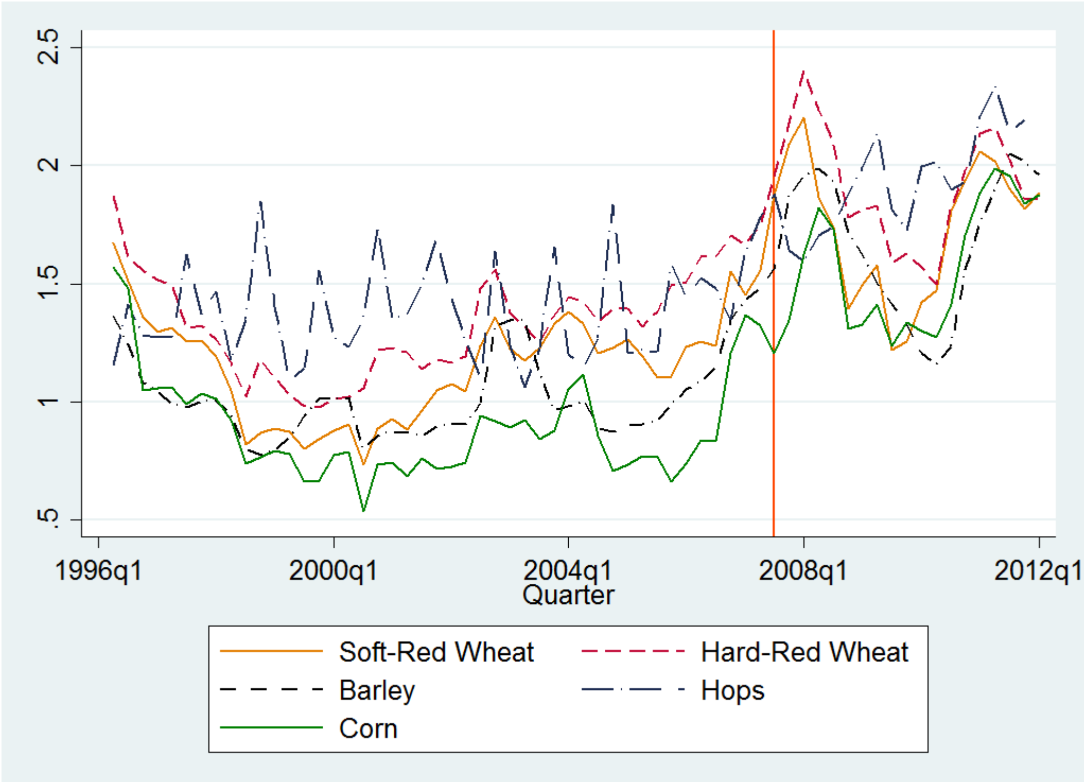

Figure 2. Grain Prices over Study Period

Table 1. Descriptive Statistics

Grain	Study Period (n=63)			Sub-Period 1 (n=46)			Sub-Period 2 (n=17)		
	Mean (Std. Dev.)	Min	Max	Mean (Std. Dev.)	Min	Max	Mean (Std. Dev.)	Min	Max
Soft-Red Wheat	4.01 (1.62)	2.09	9.07	3.33 (0.89)	2.09	6.52	5.85 (1.73)	3.39	9.07
Hard-Red Wheat	4.80 (1.87)	2.65	11.03	3.98 (1.01)	2.65	7.07	7.03 (1.85)	4.47	11.03
Barley	3.57 (1.52)	2.17	7.77	2.87 (0.63)	2.17	4.78	5.49 (1.59)	3.19	7.77
Hops	4.95 (1.75)	2.89	10.39	4.15 (0.97)	2.89	6.57	7.11 (1.56)	4.91	10.39
Corn	3.17 (1.39)	1.71	7.31	2.53 (0.66)	1.71	4.82	4.93 (1.36)	3.45	7.31

Table 2. Sub-period 1 Summary Results (8 lags)

Commodity		Effect on Grain				
		Soft-Red Wheat	Hard-Red Wheat	Barley	Hops	Corn
Commodity	Soft-Red Wheat	–	*NE*	–	+	+
	Hard-Red Wheat	*NE*	*NE*	+	*NE*	*NE*
	Barley	–	+	–	*NE*	+
	Hops	+	–	*NE*	*NE*	+
	Corn	+	–	+	+	+
	Long-run causality	*NE*	✓	✓	✓	✓
	Short-run causality	*NE*	*NE*	✓	✓	*NE*

No effect (NE); Negative Feedback (–); Positive Feedback (+).

✓ denotes effect is present

Table 3. Sub-period 2 Summary Results (2 lags)

Commodity		Effect on Grain				
		Soft-Red Wheat	Hard-Red Wheat	Barley	Hops	Corn
Commodity	Soft-Red Wheat	–	+	*NE*	+	*NE*
	Hard-Red Wheat	–	+	*NE*	+	*NE*
	Barley	–	+	*NE*	*NE*	+
	Hops	–	+	*NE*	+	*NE*
	Corn	–	+	*NE*	+	*NE*
	Long-run causality	✓	✓	✓	✓	✓
	Short-run causality	✓	✓	✓	✓	✓

No effect (NE); Negative Feedback (–); Positive Feedback (+).

✓ denotes effect is present

Appendix A

Table A1. Data Sources

Grain	Source	Price type
Soft-red Winter Wheat (Chicago)	Commodity Research Bureau (CRB)	Futures Contract
Hard-red Winter Wheat (Kansas City)	Commodity Research Bureau (CRB)	Futures Contract
Malted Barley (Export Terminal)	Commodity Research Bureau (CRB)	Cash
Hops (Export Terminal)	USDA Foreign Agricultural Services	Cash
Corn (Chicago)	Commodity Research Bureau (CRB)	Futures Contract

Table A2. Granger Causality Test Results

Commodity	Sub-period 1			Sub-Period 2		
	χ^2	p-value	Result	χ^2	p-value	Result
Soft-red Wheat	4.00	0.406	Accept H_0	16.10	0.003	Reject H_0
Hard-red Wheat	2.89	0.576	Accept H_0	37.80	0.000	Reject H_0
Barley	12.81	0.012	Reject H_0	10.32	0.035	Reject H_0
Hops	14.85	0.005	Reject H_0	15.30	0.004	Reject H_0
Corn	5.81	0.214	Accept H_0	26.01	0.000	Reject H_0

Table A3. VECM Results Sub-period 1

Variable	Soft-red Wheat	Hard-red Wheat	Barley	Hops	Corn
α_1	0.827	2.013**	0.422	-2.514*	-1.109
	(1.038)	(0.944)	(0.510)	(1.425)	(1.140)
α_2	-0.939	-1.652*	-0.401	2.034	2.315**
	(1.050)	(0.954)	(0.516)	(1.441)	(1.153)
α_3	1.145	-1.088	0.591	1.958	-1.351
	(1.559)	(1.418)	(0.767)	(2.140)	(1.713)
α_4	1.617	-0.154	1.603***	-2.102	-1.020
	(1.162)	(1.057)	(0.571)	(1.595)	(1.277)
Δ Soft-red Wheat$_{t-1}$	-0.314	-0.042	-0.339	3.176**	2.444**
	(0.997)	(0.906)	(0.490)	(1.368)	(1.095)
Δ Soft-red Wheat$_{t-2}$	-1.147	-1.684	-0.508	-1.124	3.699***
	(1.202)	(1.094)	(0.591)	(1.651)	(1.321)
Δ Soft-red Wheat$_{t-3}$	-1.025	-1.355	-0.467	0.404	0.841
	(0.934)	(0.850)	(0.459)	(1.283)	(1.027)
Δ Soft-red Wheat$_{t-4}$	-0.718	-0.670	-0.555	-0.356	1.484*
	(0.723)	(0.658)	(0.356)	(0.993)	(0.795)
Δ Soft-red Wheat$_{t-5}$	-1.251*	-0.547	-0.942**	1.952*	-1.112
	(0.744)	(0.676)	(0.366)	(1.021)	(0.817)
Δ Soft-red Wheat$_{t-6}$	-0.527	0.032	-0.397	-1.346	1.379
	(0.956)	(0.869)	(0.470)	(1.312)	(1.050)
Δ Soft-red Wheat$_{t-7}$	-0.853	-0.642	-0.985**	2.365*	-0.324
	(0.987)	(0.898)	(0.485)	(1.355)	(1.085)
Δ Hard-Red Wheat$_{t-1}$	1.369	0.770	1.286**	-1.346	-2.581*
	(1.218)	(1.107)	(0.599)	(1.672)	(1.338)
Δ Hard-Red Wheat$_{t-2}$	1.987*	1.578	1.188**	-1.241	-1.739
	(1.140)	(1.036)	(0.560)	(1.565)	(1.252)
Δ Hard-Red Wheat$_{t-3}$	0.460	-0.101	0.817*	-2.114	-1.368
	(0.936)	(0.851)	(0.460)	(1.285)	(1.028)
Δ Hard-Red Wheat$_{t-4}$	0.749	0.291	0.486	-0.845	-1.218
	(0.767)	(0.697)	(0.377)	(1.053)	(0.843)
Δ Hard-Red Wheat$_{t-5}$	0.084	-0.949	0.069	-3.520***	-0.248
	(0.748)	(0.680)	(0.368)	(1.027)	(0.822)

Variable	Soft-Red Wheat	Hard-Red Wheat	Barley	Hops	Corn
Δ Hard-Red Wheat$_{t-6}$	0.277	-0.176	0.410	0.908	-3.425***
	(1.193)	(1.085)	(0.587)	(1.638)	(1.311)
Δ Hard-Red Wheat$_{t-7}$	1.014	1.253	0.507	-0.078	-0.754
	(0.907)	(0.825)	(0.446)	(1.245)	(0.997)
Δ Barley$_{t-1}$	-2.161	-0.315	-0.988	-2.625	-0.839
	(1.334)	(1.214)	(0.656)	(1.832)	(1.466)
Δ Barley$_{t-2}$	0.019	2.873*	-0.071	1.407	-0.509
	(1.635)	(1.487)	(0.804)	(2.244)	(1.796)
Δ Barley$_{t-3}$	0.698	2.371	-0.438	-2.002	3.261*
	(1.677)	(1.525)	(0.824)	(2.302)	(1.842)
Δ Barley$_{t-4}$	-1.273	-0.280	-0.522	-0.764	-0.289
	(1.155)	(1.050)	(0.568)	(1.586)	(1.269)
Δ Barley$_{t-5}$	0.210	1.363	0.003	-0.739	1.213
	(0.921)	(0.837)	(0.453)	(1.264)	(1.011)
Δ Barley$_{t-6}$	-0.532	0.234	-0.496	-1.453	1.207
	(0.900)	(0.818)	(0.442)	(1.235)	(0.989)
Δ Barley$_{t-7}$	0.163	0.724	-0.108	-0.890	-0.415
	(0.858)	(0.780)	(0.422)	(1.177)	(0.942)
Δ Hops$_{t-1}$	-1.442	0.490	-1.558***	1.472	0.370
	(1.170)	(1.064)	(0.575)	(1.606)	(1.285)
Δ Hops$_{t-2}$	-1.069	0.868	-1.373**	1.148	0.497
	(1.150)	(1.046)	(0.565)	(1.579)	(1.263)
Δ Hops$_{t-3}$	-0.796	1.069	-1.156**	1.405	0.205
	(1.108)	(1.008)	(0.545)	(1.522)	(1.218)
Δ Hops$_{t-4}$	-0.326	1.348	-0.781	1.533	0.449
	(0.972)	(0.884)	(0.478)	(1.334)	(1.068)
Δ Hops$_{t-5}$	-0.084	1.098	-0.489	1.127	1.011
	(0.742)	(0.675)	(0.365)	(1.019)	(0.815)
Δ Hops$_{t-6}$	0.021	0.611	-0.343	0.811	1.020*
	(0.551)	(0.501)	(0.271)	(0.756)	(0.605)
Δ Hops$_{t-7}$	-0.121	0.054	-0.248*	0.214	0.509*
	(0.257)	(0.234)	(0.126)	(0.353)	(0.283)
Δ Corn$_{t-1}$	0.060	-0.049	-0.039	0.365	-0.257
	(0.702)	(0.639)	(0.345)	(0.964)	(0.772)

Variable	Soft-Red Wheat	Hard-Red Wheat	Barley	Hops	Corn
Δ Corn_{t-2}	0.110	0.142	-0.307	2.195**	-0.717
	(0.629)	(0.572)	(0.309)	(0.864)	(0.691)
Δ Corn_{t-3}	0.097	0.147	-0.126	1.402	-0.247
	(0.695)	(0.632)	(0.342)	(0.955)	(0.764)
Δ Corn_{t-4}	0.426	0.672	0.150	2.061***	-0.798
	(0.554)	(0.504)	(0.272)	(0.761)	(0.609)
Δ Corn_{t-5}	0.643	0.649	0.416	-0.070	0.994*
	(0.550)	(0.500)	(0.270)	(0.755)	(0.604)
Δ Corn_{t-6}	0.124	0.101	0.026	1.451**	-0.095
	(0.443)	(0.403)	(0.218)	(0.609)	(0.487)
Δ Corn_{t-7}	0.560	0.468	0.526***	-0.495	0.829*
	(0.407)	(0.371)	(0.200)	(0.559)	(0.448)
Constant	-0.003	0.001	0.004	0.001	0.000
	(0.018)	(0.016)	(0.009)	(0.025)	(0.020)
AIC	-864.43				
HQIC	-15.58				
SBIC	-10.51				
Log Likelihood	632.21				
Observations	46				

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$ Standard errors in parenthesis.

Table A4. VECM Results Sub-period 2

Variable	Soft-Red Wheat	Hard-Red Wheat	Barley	Hops	Corn
α_1	1.843***	1.804***	0.906***	0.007	1.530***
	(0.398)	(0.229)	(0.251)	(0.431)	(0.303)
α_2	-5.065***	-3.766***	-0.761	-2.987***	-2.777***
	(0.908)	(0.524)	(0.574)	(0.983)	(0.692)
α_3	1.967***	1.324***	-0.215	1.498***	0.936***
	(0.431)	(0.249)	(0.273)	(0.467)	(0.329)
Δ Soft-Red Wheat_{t-1}	-2.135***	-2.020***	-0.843**	-1.227*	-2.155***
	(0.616)	(0.355)	(0.389)	(0.667)	(0.469)
Δ Hard-Red Wheat_{t-1}	3.322***	2.660***	1.191**	2.973***	2.804***
	(0.898)	(0.518)	(0.568)	(0.973)	(0.685)
$\Delta\ \text{Barley}_{t-1}$	0.148	0.146	0.117	0.213	-0.152
	(0.305)	(0.176)	(0.193)	(0.331)	(0.233)
$\Delta\ \text{Hops}_{t-1}$	1.163***	0.791***	0.204	0.965***	0.492**
	(0.317)	(0.183)	(0.200)	(0.343)	(0.241)
$\Delta\ \text{Corn}_{t-1}$	-0.147	-0.016	-0.461**	-0.211	0.199
	(0.326)	(0.188)	(0.206)	(0.353)	(0.248)
Constant	-0.011	-0.016	0.002	0.009	0.031
	(0.029)	(0.017)	(0.018)	(0.031)	(0.022)
AIC	-242.64				
HQIC	-13.32				
SBIC	-11.07				
Log Likelihood	166.32				
Observations	17				

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$ Standard errors in parenthesis.

Table A5. Sub-Period 1 Co-integrating Equations

Cointegrating Equation	Soft-Red Wheat	Hard-Red Wheat	Barley	Hops	Corn
CE 1	1	0	0	0	-1.720
					(0.484)
CE 2	0	1	0	0	-1.301
					(0.379)
CE 3	0	0	1	0	-0.919
					(0.183)
CE 4	0	0	0	1	0.411
					(0.067)

Johansen normalization restrictions imposed. Standard errors in parenthesis.

Table A6. Sub-Period 2 Co-integrating Equations

Cointegrating Equation	Soft-Red Wheat	Hard-Red Wheat	Barley	Hops	Corn
CE 1	1	0	0	0.850	-1.551
				(0.088)	(0.095)
CE 2	0	1	0	0.852	-1.298
				(0.119)	(0.129)
CE 3	0	0	1	0.901	-1.934
				(0.236)	(0.256)

Johansen normalization restrictions imposed. Standard errors in parenthesis.