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## Is Storage at a Loss Merely an Illusion of Spatial Aggregation?

Jason R. V. Franken, Philip Garcia, and Scott H. Irwin

The storage-at-a-loss paradox—stocks despite inadequate price growth to cover storage costs—is an unresolved issue of long-standing interest to economists. Alternative explanations include risk premiums for futures market speculators, convenience yields from holding stocks, and mismeasurement/aggregation of data. Statistical analyses of regional and elevator corn and soybean price growth in Illinois suggest limited aggregation effects and reveal a pattern of regional- and elevator-level backwardations in the presence of Illinois corn stocks that is inconsistent with aggregation explanations for storage at a loss. Interviews with elevator managers support the existence of convenience yields.

**Key Words:** aggregation, convenience yield, corn, intertemporal arbitrage, regional and elevator data, soybeans, storage at a loss

Seasonal production and geographically dispersed agricultural commodity markets imply temporal and spatial dimensions to storage decisions. When and where to store are chief concerns to those involved in the production, processing, and marketing of storable commodities, and to policy makers overseeing market performance. Empirical anomalies of stocks despite inadequate price growth to cover storage costs (i.e., warehousing plus interest opportunity costs) appear to violate intertemporal arbitrage conditions. What causes this *storage-at-a-loss paradox* is an unresolved issue of long-standing interest to economists.

As an alternative to conventional explanations, i.e., risk premiums (Keynes, 1930) and convenience yields (Kaldor, 1939; Working, 1948, 1949), researchers (Wright and Williams, 1989; Benirschka and Binkley, 1995; Brennan, Williams, and Wright, 1997) suggest that empirical anomalies are merely artifacts of data aggregation, curable by precise definition of stocks and prices.<sup>1</sup> The logic is that

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<sup>1</sup> Risk premiums, compensation for futures market speculators bearing risk, can downwardly bias futures prices as estimates of expected spot prices, making storage appear unprofitable. A convenience yield is a stock's inherent replacement value, a consequence of costly short-run inflexibilities in transporting, processing, and trading commodities, which may offset apparent losses from storage.

similar yet economically distinct commodities often are reported in the same data category, though they differ by time-varying costs of transformation (e.g., transportation, processing, and merchandising). If no stocks exist at a location with negative price growth and stocks exist at another with positive price growth, their aggregate may yield negative average returns on stocks held.

Notably, Benirschka and Binkley (1995, p. 523) dismiss other explanations, asserting that all empirical deviations from the theory of storage can be remedied by using disaggregated data. In their model, spot price growth exactly covers interest opportunity costs of storage at stockholding locations, and hence is greater where stocks exist than at locations closer to the Gulf of Mexico export market. However, similar to other researchers examining storage at a loss, their analysis is hampered by a paucity of quality data. Further, their variable of primary interest (producer price received) is often insignificant, leading to only indirect evidence in support of their theory. Carter and Giha's (2007) review of Working's (1933) early 20th century wheat market data, and Klump, Brorsen, and Anderson's (2007) study of present-day wheat markets, suggest that aggregation effects do not explain all inferences of storage at a loss. To date, no study has examined present-day corn and soybean markets.

This research employs a unique data set to investigate the existence of *price growth-interest rate relationships* that, in conjunction with transportation costs, drive Benirschka and Binkley's (1995) optimal storage model. Thirty years of Illinois regional and elevator corn and soybean prices and three-month Treasury bill interest rates enable direct examination of the validity of their model and aggregation effects. More generally, we address whether the returns from holding commodities and financial assets are in fact equal. Distances between elevators of up to 400 miles adequately capture the spatial dimension of price-growth relationships. Whereas previous studies approximate returns to storage as simple price spreads between nearby and distant futures, reliable commercial storage cost schedules for central Illinois permit precise computation of net price growth rates corresponding to the percentage changes in spot prices specified in Benirschka and Binkley's model.

Our 2006 survey of 23 Illinois elevator managers provides insights on the reasons for storage that complement our empirical findings. Reported 2006 storage cost schedules at these locations also inform a sensitivity analysis, which leads to spatial price behavior consistent with theory by allowing storage costs to vary across the state. Viewed in concert, empirical results and survey responses offer a more comprehensive understanding of the storage mechanisms operating in these markets.

Two implications of Benirschka and Binkley's (1995) model are tested directly for marketing years 1975 through 2004. First, since Illinois corn and soybean quarterly stocks for our sample period have never fallen below 31.7 million and 16.5 million bushels, respectively (USDA/National Agricultural Statistics Service,

2005), spot price growth should consistently equal the interest rate.<sup>2</sup> This intertemporal arbitrage condition is assessed using matched sample pairwise *t*-tests of mean differences between interest rates and price growth net of physical storage costs. Second, Benirschka and Binkley's claim that spot prices grow faster farther from the central market (the Gulf of Mexico) is assessed using matched sample pairwise *t*-tests of north-south mean differences in price growth net of physical storage costs. Their argument is that higher transportation costs reduce commodity prices, and hence the interest opportunity costs of storage, at distant locations. Consequently, nearby locations deliver the commodity to the central market earlier than distant locations.<sup>3</sup> Significantly faster (slower) relative price growth at northern locations would support (contradict) Benirschka and Binkley's notion that interest opportunity costs explain spatial price growth differences.

A common procedure for investigating whether price growth exactly covers storage costs, including interest charges, is to test for a one-to-one relationship between interest rates and (net) price growth computed using nearby and distant futures prices (e.g., Fama and French, 1987; Kitchen and Denbaly, 1987). Though differences in current and expected prices govern storage behavior, futures prices cannot be adjusted to reflect expected prices at a particular location without a time series of transportation costs. Thus, we use spot prices to investigate price growth behavior across space. As Benirschka and Binkley (1995) also utilized spot prices, our work is directly comparable to theirs.

## Literature Review

Researchers posit several explanations for the existence of stocks when markets appear to be in backwardation.<sup>4</sup> Evidence is limited by the scarcity of quality data, especially on stocks and prices at individual locations, which led to use of aggregated data or proxies. Keynes' (1930) risk premiums only account for instances when observed loss from storage is small (Wright and Williams, 1989), and evidence on their existence is mixed (Williams, 2001). The weight of the literature leans on convenience yields (Kaldor, 1939; Working, 1948, 1949) as the primary explanation for apparent storage at a loss (Wright and Williams), with the marginal convenience yield approaching zero as stocks increase. Though convenience yields are plausible, empirical support is modest (Wright and Williams), and their existence in the presence of large carryovers is perplexing (Benirschka and Binkley, 1995).

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<sup>2</sup> In frictionless (i.e., zero transaction cost) markets, returns on commodity stocks (i.e., price growth net of physical storage costs) equal those on financial assets (Benirschka and Binkley, 1995). Departures from this are arbitrage opportunities, exploitation of which continues until rates of return are equalized.

<sup>3</sup> Northern locations in U.S. corn and soybean markets also receive lower harvest prices because harvest occurs later than in more southern locations. Producers at southern locations sell before prices hit harvest lows, while producers in northern locations store a portion of the crop, anticipating price to appreciate.

<sup>4</sup> Backwardation (contango) is a term for spot-futures price spreads indicating negative (positive) returns to storage (Garcia and Leuthold, 2004).

Wright and Williams (1989) suggest that storage at a loss is inferred from aggregated prices and stocks if one commodity is profitably stored, while a related yet economically distinct commodity is not stored. As evidenced by comparison of total U.S. coffee stocks and stocks certified for futures contract delivery plotted against coffee futures price spreads, they find fewer stocks held under backwardation using the more precise measurement of storage curves with certified stocks. Yet, this evidence is unconvincing, since the opposite result is logically impossible, given that certified stocks are a subset of total stocks.<sup>5</sup>

In Brennan, Williams, and Wright's (1997) optimization model, Australian port prices imply storage at a loss even though first-order conditions preclude storage anywhere backwardations exist in local prices. This support for aggregation effects reflects optimal marketing given available loading and storage costs and local harvest and transportation data, but is not based on actual stocks and does not invalidate the possibility of alternative explanations.

Benirschka and Binkley's (1995) theoretical model also supports aggregation explanations. In their model, prices, and hence interest opportunity costs of storage, decrease with increasing transportation costs to locations farther from the central market, prompting sequential delivery with remote production areas holding long-term stocks and delivering later than those nearby.<sup>6</sup> Due to data limitations, they offer only indirect evidence that storage capacity, especially on-farm, increases with distance to the Gulf export market, and that U.S. grain prices grow faster farther from this central market and at a decreasing rate as the end of the marketing year nears. They conclude (too strongly) that storage at a loss is only an illusion, curable by precise measurement of prices where stocks are held. Yet, Carter and Giha (2007) reproduce the Working Curve after disaggregating Working's (1933) wheat stock data, and Klump, Brorsen, and Anderson (2007) find no significant difference in backwardations computed using recent aggregate and disaggregate wheat price series.

Frechette and Fackler (1999, p. 764) caution that additive storage costs impose faster price growth at locations farther from the central market if transportation bases are constant, meaning "... the relative rate of change is lower in the higher-priced demand center, even if no backwardation occurs." Their finding that location effects are substantially smaller than the negative effect of aggregate stocks on far-near corn futures spreads contradicts Benirschka and Binkley's (1995) claim that the location of stocks explains backwardations.<sup>7</sup> The negative effect may reflect risk premiums (Gorton, Hayashi, and Rouwenhorst, 2007). For a different sample period, Yoon and Brorsen (2002) find a significantly positive influence of stocks on far-near corn, soybean, and wheat futures spreads, which

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<sup>5</sup> We thank an anonymous reviewer for pointing out this impossibility.

<sup>6</sup> Transport costs decrease the price received, and hence the interest income from immediate sale.

<sup>7</sup> Statistical significance of the location effects varied substantially across models and its economic significance was typically much smaller than that of the stock effects which were statistically significant at the 5% level (Frechette and Fackler, 1999).



**Figure 1. Illinois Price Reporting Districts or Regions**

they attributed to convenience yields; as stocks decrease, price growth may fall into backwardation. Peterson and Tomek (2005) explicitly modeled convenience yields in the U.S. corn market using a rational expectations model that allows backwardations to be independent of stock-outs. Their relatively straightforward model successfully simulated spot and futures price behavior throughout the 1990s.

### **Data and Variable Construction**

Weekly corn and soybean prices reported on Thursdays for 19 grain elevators and seven Illinois Price Reporting Districts, or regions (figure 1), over the 1975–2004 marketing years were obtained from the USDA’s Illinois Agricultural Marketing Service (2005). The publicly available regional prices are midpoint averages of prices at surveyed elevators, subjectively altered to eliminate the effect of specific elevators bidding up price to attract grain. Elevators opened and closed at several locations during the sample period, giving rise to 129 elevators from these regions in the database, with only 50 to 60 operating at any point in time. We work with 19 elevator-level series as the most disaggregate data. Seventeen of these operated

**Table 1. Commercial Physical Storage Cost Schedules, 1975–2004 Marketing Years**

Marketing Years	Corn Storage Costs (\$/bu.)					Soybean Storage Costs (\$/bu.)	
	Warehousing					Warehousing	
	Harvest → Jan 31	Monthly (after Jan 31)	Drying	Shrinkage		Harvest → Jan 31	Monthly (after Jan 31)
1975–1979 <sup>a</sup>	0.100	0.015	0.010	1.30%		0.100	0.015
1980–1988 <sup>b</sup>	Harvest → Jan 31	Monthly (after Jan 31)	Drying	Shrinkage		Harvest → Jan 31	Monthly (after Jan 31)
	0.129	0.021	0.023	1.30%		0.142	0.024
1989–2004 <sup>c</sup>	Harvest → Dec 31	Monthly (after Dec 31)	Drying	Shrinkage		Harvest → Dec 31	Monthly (after Dec 31)
	0.130	0.020	0.020	1.30%		0.130	0.020

*Sources:*<sup>a</sup> Good (2004).<sup>b</sup> Hill, Kunda, and Rehtmeyer (1983).<sup>c</sup> Irwin et al. (2006).

for the entire period. The Marion and Browns elevator series were constructed by appending prices at Marion and Browns to prices at two elevators within 35 miles that closed in 2003.

Unreported mean, maximum, and minimum prices decrease from south to north, supporting the notion of the Gulf of Mexico as the demand center. All price series are correlated at 0.98 or greater. The three-month Treasury bill annual interest rate (Commodity Research Bureau, Inc., 2003) for the same period averaged 6.62% with a standard deviation of 3.12%. It reached a maximum of 16.76% on December 12, 1980, and a minimum of 0.81% on June 19, 2003.

Commercial physical storage costs for corn and soybeans were compiled from personal communication with Dr. Darrel Good (2004) of the University of Illinois for 1975–1979, Hill, Kunda, and Rehtmeyer (1983) for 1980–1988, and Irwin et al. (2006) for 1989–2004 (table 1).<sup>8</sup> These figures most closely reflect costs at elevators in the North Central and South Central regions, as the majority of elevators reported by Hill, Kunda, and Rehtmeyer, and Irwin et al. are located in the Central Illinois Crop Reporting District. Because our storage costs primarily reflect Central Illinois and surrounding areas, we surveyed 23 elevators across the state in 2006 to develop a better understanding of the degree of heterogeneity in storage costs. Knowledge of this variation later informed a sensitivity analysis of spatial price growth and interest rate-price growth relationships.

<sup>8</sup> Irwin et al. (2006) remark that physical storage charges in central Illinois have not changed from 1995 through 2003, and cite similar rates in Hill, Kunda, and Rehtmeyer (1983). Irwin et al. note little difference between elevator and producer storage (variable plus fixed) costs in the long term.

Net price growth at market  $i$  is a geometric return computed from prices at the start and close of the storage horizon,  $p_i^t$  and  $p_i^\tau$ , respectively, and physical storage costs  $s$ :

$$\% \Delta p_{i,t} = \left[ \ln(p_i^\tau - s) - \ln(p_i^t) \right],$$

where  $\tau > t$ . Monthly storage costs, accruing after the upfront fixed costs, are prorated to the number of days in storage for calculations of price growth rates. Price growth rates are also adjusted by dividing by the fraction of days stored in a year  $(\tau - t)/365$  to allow equitable comparisons with annual interest rates. Annual series of price growth rates are computed, yielding 30 observations for each storage horizon. Several storage horizons start at the approximate completion of harvest in November and span successively longer time periods: Nov  $\rightarrow$  Apr, Nov  $\rightarrow$  Jun, and Nov  $\rightarrow$  Jul. For instance, the price growth rate denoted by Nov  $\rightarrow$  Apr is the April 1–November 1 logarithmic price difference net of physical storage costs. Storage horizons are also examined for other portions of the marketing year, e.g., Apr  $\rightarrow$  Jun and Apr  $\rightarrow$  Jul. The storage horizons span the historical storage period in Illinois from the completion of harvest in early November through the beginning of July, during which an average of 71% and 64% of Illinois producer sales of annual corn and soybean crops, respectively, are made (USDA/National Agricultural Statistics Service, 2005). Monthly sales statistics also imply storage throughout the period investigated, since on average 13% of corn sales and 11% of soybean sales occur from July through August. Price growth rates are compared to the close-of-day three-month Treasury bill annual interest rate at the start of a horizon.

### Methods, Results, and 2006 Survey Findings

Two-tailed pairwise  $t$ -tests provide insight on the validity of the intertemporal arbitrage condition and the proposed positive north-south price growth differences. Tables 2 and 3 report the mean differences between price growth (net of physical storage costs) and interest rates for corn and soybeans, respectively, with asterisks indicating statistical significance. Net price growth and interest rates are computed as percentages, and hence, so are their mean differences. The null hypothesis is that price growth and interest rates are equal—i.e., their mean difference is not statistically different from zero. Consistent with intertemporal arbitrage conditions, price growth generally is not significantly different from the interest rate for either commodity, with one exception—storing corn for the Nov  $\rightarrow$  Jul horizon—possibly implying a convenience yield. Notably, aggregation does not change the inference of storage at a loss, as results are generally consistent across regional and elevator series except for the Jamaica and Carlinville elevators.

Many statistically insignificant differences appear economically large for both commodities. The largest of these is corn price growth at Erie for the Jun  $\rightarrow$  Jul



**Table 2. Pairwise *t*-Tests Between Net Corn Price Growth and Interest Rates, 1975–2004 Marketing Years (n = 30 annual observations)**

Reporting Districts / Elevators	Storage Horizons: Mean Difference (%)					
	Nov→Apr	Nov→Jun	Nov→Jul	Jan→Apr	Apr→Jun	Jun→Jul
Northern	-4.66	-5.47	-10.54*	-6.59	-7.43	-36.49
Belvidere	-7.05	-6.07	-10.58*	-7.97	-3.56	-33.48
Erie	-4.02	-5.01	-10.37*	-4.14	-7.45	-37.82
Western	-5.77	-6.00	-10.80*	-8.78	-6.58	-35.19
Galesburg	-7.02	-7.08	-11.20**	-9.38	-7.16	-31.96
Stronghurst	-4.52	-5.00	-9.81*	-4.79	-6.23	-34.49
Avon	-6.60	-6.85	-11.68**	-8.89	-7.39	-36.11
North Central	-6.77	-6.60	-10.88*	-10.28	-6.11	-32.52
Manteno	-6.71	-5.76	-10.23*	-8.50	-3.40	-32.97
Ashkum	-7.13	-6.61	-10.37*	-9.71	-5.24	-29.36
Gridley	-8.50	-7.85*	-11.45**	-10.22	-6.09	-29.35
South Central	-7.38	-6.83	-10.64*	-10.79	-5.37	-29.85
Chestnut	-8.69	-7.95	-11.39**	-9.25	-5.88	-28.51
Maroa	-8.81	-7.38	-11.04*	-8.53	-3.65	-29.43
Stonington	-8.62	-7.59	-11.01*	-9.24	-4.84	-28.09
Jamaica	-4.78	-5.24	-8.90	-8.15	-6.39	-27.51
Mason City	-6.21	-6.79	-10.91**	-9.38	-8.13	-31.73
Elkhart	-8.51	-7.93	-11.38*	-9.66	-6.21	-28.60
West Southwest	-3.86	-4.22	-7.86	-12.35	-5.27	-26.60
Carlinville	-5.85	-5.85	-9.36*	-11.68	-5.87	-27.12
Altamont	-3.30	-4.20	-7.89	-9.68	-6.55	-26.80
Nashville	-2.13	-5.85	-6.44	-9.64	-6.00	-23.48
Wabash	-1.57	-1.87	-5.11	-10.85	-3.01	-22.15
Browns	-2.93	-3.46	-6.53	-12.71	-5.01	-22.42
Little Egypt	-1.97	-1.72	-5.23	-10.86	-1.46	-23.67
Marion	-2.28	-2.80	-6.64	-10.82	-4.35	-26.70

Notes: Single, double, and triple asterisks (\*, \*\*, \*\*\*) denote statistically different than zero at the 10%, 5%, and 1% levels of confidence, respectively.  $H_0$ : The mean difference = 0;  $H_a$ : The mean difference  $\neq$  0.

horizon, which is 37.82% lower than the interest rate, but not statistically different. Failure to reject the null of equality stems from low correlations between price growth and interest rates, which yield few systematic differences and large variances.

Pairwise *t*-tests of mean differences in price growth between paired elevators are reported for corn and soybeans, respectively, in tables 4 and 5. Again, the null hypothesis is that mean differences are not statistically different from zero. Benirschka and Binkley's (1995) and Frechette and Fackler's (1999) claims of faster price growth farther from the central market actually suggest a one-tailed test.

**Table 3. Pairwise *t*-Tests Between Net Soybean Price Growth and Interest Rates, 1975–2004 Marketing Years (n = 30 annual observations)**

Reporting Districts / Elevators	Storage Horizons: Mean Difference (%)					
	Nov→Apr	Nov→Jun	Nov→Jul	Feb→Apr	Apr→Jun	Jun→Jul
Northern	2.26	4.36	2.21	7.79	9.56	−12.05
Belvidere	1.97	4.38	2.18	6.57	10.03	−11.75
Erie	2.40	4.71	2.29	10.37	10.44	−13.53
Western	1.45	3.85	1.79	6.95	9.82	−11.57
Galesburg	0.47	3.33	1.58	6.76	10.59	−9.99
Stronghurst	2.21	4.46	2.70	9.39	10.05	−9.39
Avon	0.60	3.15	1.25	7.03	9.57	−11.02
North Central	0.80	3.41	1.45	6.97	9.97	−11.28
Manteno	0.53	3.57	1.08	8.28	11.30	−14.48
Ashkum	0.62	3.68	1.87	7.05	11.47	−9.54
Gridley	−0.28	2.73	0.95	7.41	10.42	−10.38
South Central	0.27	3.41	1.57	6.05	11.43	−10.00
Chestnut	0.09	3.11	1.51	7.63	10.78	−8.37
Maroa	1.14	4.23	2.32	7.42	12.06	−9.41
Stonington	0.15	3.32	1.77	6.95	11.37	−7.77
Jamaica	0.06	2.80	0.96	8.22	9.76	−10.90
Mason City	0.46	3.63	2.00	3.80	11.70	−9.13
Elkhart	0.28	3.56	1.87	6.50	11.91	−8.57
West Southwest	1.46	3.88	2.14	3.70	9.91	−8.93
Carlinville	0.06	3.22	1.73	3.21	11.25	−7.58
Altamont	1.58	4.27	2.40	5.54	11.03	−9.85
Nashville	2.11	4.69	2.91	3.32	11.14	−7.85
Wabash	3.66	5.67	3.32	5.77	10.60	−11.82
Browns	2.75	4.49	2.77	4.06	8.72	−8.94
Little Egypt	3.68	5.37	2.82	5.49	9.42	−13.77
Marion	3.53	5.20	2.99	3.40	9.22	−11.38

Notes: Single, double, and triple asterisks (\*, \*\*, \*\*\*) denote statistically different than zero at the 10%, 5%, and 1% levels of confidence, respectively.  $H_0$ : The mean difference = 0;  $H_a$ : The mean difference  $\neq$  0.

However, given the geographical distance between locations, we employ a more conservative two-tailed test, as mean differences not significantly different from zero may be interpreted as indicating that the sites in question are two price centers in essentially the same location. Alternatively, such findings may be interpreted as weak evidence against both studies' claims.

Consistent with the findings of Benirschka and Binkley (1995), several of the spatial differences in price growth for corn and soybeans are significantly positive at the 10% level or better, particularly for soybean differences between elevators in Northern and North Central or South Central regions during Nov → Apr and

**Table 4. Pairwise *t*-Tests of Spatial Difference in Net Corn Price Growth, 1975–2004 Marketing Years (n = 30 annual observations)**

Reporting Districts / Elevators	Storage Horizons: Mean Difference (%)					
	Nov→Apr	Nov→Jun	Nov→Jul	Jan→Apr	Apr→Jun	Jun→Jul
Northern						
Belvidere–Erie	–3.03**	–1.07	–0.20	–3.83***	3.89**	4.34
Northern–Western	1.11	0.53	0.26	2.19**	–0.85	–1.30
Belvidere–Galesburg	–0.03	1.01	0.63	1.42	3.60*	–1.53
Belvidere–Stronghurst	–2.53**	–1.08	–0.76	–3.18***	2.67	1.01
Belvidere–Avon	–0.45	0.77	–5.56	0.92	3.83*	2.63
Northern–North Central	2.11***	1.13	0.30	3.68***	–1.32	–3.97*
Belvidere–Manteno	–0.34	–0.31	–0.34	0.53	–0.16	–0.52
Belvidere–Ashkum	0.09	0.54	–0.20	1.74	1.68	–4.13
Belvidere–Gridley	1.45	1.78**	0.88	2.25*	2.53*	–4.14
Northern–South Central	2.72***	1.36	0.09	4.19***	–2.06	–6.64***
Belvidere–Chestnut	1.64	1.88*	0.81	1.28	2.31	–4.97*
Belvidere–Maroa	1.76	1.31	0.47	0.56	0.08	–4.05
Belvidere–Stonington	1.57	1.52	0.43	1.28	1.27	–5.39
Belvidere–Jamaica	–2.27	–0.83	–1.67	0.18	2.82	–5.97
Belvidere–Mason City	–0.84	0.71	0.34	1.41	4.57***	–1.75
Belvidere–Elkhart	1.46	1.85*	0.80	1.70	2.64	–4.88
Northern–West Southwest	–0.80	–1.25	–2.69***	5.76***	–2.16	–9.89***
Belvidere–Carlinville	–1.20	–0.22	–1.21	3.71***	2.31	–6.37***
Belvidere–Altamont	–3.74***	–1.88*	–2.68***	1.71	2.99	–6.69**
Belvidere–Nashville	–4.92***	–2.89**	–4.13***	1.67	2.44	–10.00**
Northern–Wabash	–3.09**	–3.60***	–5.44***	4.26**	–4.42	–14.34***
Belvidere–Browns	–4.12***	–2.61**	–4.05***	4.74**	1.45	–11.06***
Northern–Little Egypt	–2.69**	–3.75***	–5.32***	4.27**	–5.97**	–12.82***
Belvidere–Marion	–4.77***	–3.27**	–3.93***	2.85	0.79	–6.78**

Notes: Single, double, and triple asterisks (\*, \*\*, \*\*\*) denote statistically different than zero at the 10%, 5%, and 1% levels of confidence, respectively.  $H_0$ : The mean difference = 0;  $H_a$ : The mean difference  $\neq$  0.

Nov → Jun storage horizons.<sup>9</sup> These findings also are consistent with Frechette and Fackler's (1999) point that additive (physical) storage costs impose faster relative price growth farther from the central market. For instance, over Nov → Jun, the statistically significant difference indicates that the annually adjusted return to storage at Belvidere is 1.14% more than that at Avon.

<sup>9</sup> The two-tailed test implies much fewer elevators with statistically significantly slower price growth than at Belvidere for corn than for soybeans. Using the less stringent and more theoretically appealing one-tailed test for corn, positive spatial differences between Belvidere and Gridley, Chestnut, Maroa, and Elkhart, as well as between their encompassing regions, during Nov → Apr and Nov → Jun horizons are statistically significant at the 10% level or better. Positive spatial differences for elevators in these horizons are consistently statistically significant for both commodities when Belvidere is replaced in the calculations by Erie, the other elevator in the Northern region.

**Table 5. Pairwise *t*-Tests of Spatial Difference in Net Soybean Price Growth, 1975–2004 Marketing Years (n = 30 annual observations)**

Reporting Districts / Elevators	Storage Horizons: Mean Difference (%)					
	Nov→Apr	Nov→Jun	Nov→Jul	Feb→Apr	Apr→Jun	Jun→Jul
Northern						
Belvidere–Erie	–0.43	–0.42	–0.12	–3.80***	–0.41	1.77
Northern–Western	0.81**	0.52*	0.41	0.84	–0.27	–0.48
Belvidere–Galesburg	1.50***	0.95***	0.59*	–0.19	–0.56	–1.76
Belvidere–Stronghurst	–0.24	–0.18	–0.52	–2.82**	–0.02	–2.36
Belvidere–Avon	1.37**	1.14***	0.93**	–0.47	0.46	–0.73
Northern–North Central	1.45***	0.95*	0.75*	0.08	–0.41	–0.77
Belvidere–Manteno	1.45**	0.71	1.10*	–1.71*	–1.27	2.72
Belvidere–Ashkum	1.35**	0.60	0.31	–0.48	–1.44	–2.21
Belvidere–Gridley	2.25***	1.55***	1.23***	–0.84	–0.39	–1.38
Northern–South Central	1.99***	0.95*	0.63	1.73*	–1.87*	–2.05
Belvidere–Chestnut	1.88***	1.17**	0.66	–1.06	–0.75	–3.38
Belvidere–Maroa	0.83	0.06	–0.15	–0.85	–2.03	–2.34
Belvidere–Stonington	1.82***	0.97**	0.41	–0.39	–1.34	–3.98*
Belvidere–Jamaica	1.91***	1.48**	1.21**	–1.66	0.27	–0.86
Belvidere–Mason City	1.51**	0.65*	0.18	2.77***	–1.67	–2.62
Belvidere–Elkhart	1.69***	0.73*	0.30	0.07	–1.88	–3.19*
Northern–West Southwest	0.80*	0.49	0.07	4.09***	–0.36	–3.12*
Belvidere–Carlinville	1.91***	1.07**	0.45	3.36***	–1.22	–4.18**
Belvidere–Altamont	0.39	0.02	–0.22	1.03	–0.99	–1.91
Belvidere–Nashville	–0.13	–0.41	–0.73	3.25***	–1.11	–3.90
Northern–Wabash	–1.40***	–1.31**	–1.11*	2.01	–1.04	–0.24
Belvidere–Browns	–0.78	–0.20	–0.59	2.51**	1.31	–2.81
Northern–Little Egypt	–1.42***	–1.00**	–0.61	2.29**	0.14	1.72
Belvidere–Marion	–1.55**	–0.91	–0.81	3.17**	0.81	–0.37

Notes: Single, double, and triple asterisks (\*, \*\*, \*\*\*) denote statistically different than zero at the 10%, 5%, and 1% levels of confidence, respectively.  $H_0$ : The mean difference = 0;  $H_a$ : The mean difference  $\neq$  0.

Aggregation effects appear prevalent, whereas they were essentially non-existent in tests of the intertemporal arbitrage condition. Over the Nov → Jun storage horizon, the spatial difference in soybean price growth for the Northern–Wabash and Northern–Little Egypt regional pairs was statistically significantly negative, while it was not different from zero for the underlying Belvidere–Browns and Belvidere–Marion elevator pairs. Significantly positive differences for corn at the regional level (i.e., Northern–North Central and Northern–South Central for Nov → Apr) which do not emerge at the elevator level reveal that aggregation also *generates* misleadingly intuitive results. The varying statistical significance of spatial differences across regional pairs and their underlying elevator pairs suggests that averaging across elevators contributes to aggregation

**Table 6. Average Storage Costs from Harvest, Using 2006 Marketing Year Storage Cost Schedules at Illinois Elevators**

Reporting District	Corn Storage Costs (\$/bu.)					
	3/1/2006	4/1/2006	5/1/2006	6/1/2006	7/1/2006	8/1/2006
Northern	0.232	0.257	0.282	0.307	0.332	0.357
Western	0.226	0.242	0.259	0.275	0.291	0.308
North Central	0.231	0.253	0.276	0.298	0.321	0.343
South Central	0.232	0.254	0.276	0.297	0.319	0.340
<b>Central Illinois Average</b>	0.230	0.250	0.271	0.291	0.311	0.331
West Southwest	0.345	0.373	0.402	0.430	0.458	0.487
Wabash	0.248	0.271	0.293	0.316	0.338	0.361
Little Egypt	0.234	0.249	0.264	0.279	0.294	0.309
<b>Southern Illinois Average</b>	0.286	0.309	0.332	0.354	0.377	0.400

*Notes:* Storage costs from harvest are computed in \$/bu. using 2006 marketing year schedules at 23 elevators across Illinois, obtained by a phone survey in November 2006. Storage costs reflect a minimum charge that covers storage to some pre-specified date (generally January 1) with a variable charge (daily or monthly) thereafter. Drying and shrinkage is charged on corn, which is assumed to be delivered at 1% above the acceptable 15% moisture content. No moisture dock is assumed on soybeans, which are usually delivered at or below the acceptable 13% moisture content.

( extended ... → )

effects at the regional level. Differences in regional- and elevator-level results may also reflect the previously mentioned adjustment of average prices to purge the effects of specific elevators bidding up price to attract grain.

Unexpectedly, other findings reported in tables 4 and 5 indicate statistically significantly negative spatial differences in price growth across elevators (e.g., the Belvidere–Marion spatial differences over various storage horizons for corn and soybeans). These findings are less frequent and less significant for soybean than corn markets. Three explanations may contribute to these negative differentials. First, corn but not soybean stocks incur a multiplicative shrink charge in addition to an additive component. Thus, Frechette and Fackler's (1999) contention that additive storage costs impose faster relative price growth farther from the central market may be less applicable for corn. Second, the assumption of a central market may be somewhat inappropriate for the regions analyzed. Northern and central Illinois historically ship to the Gulf of Mexico, while southern Illinois also serves local livestock and poultry markets, primarily with corn. Third, while our storage cost schedules enable computation of reliable net price growth rates for central Illinois elevators, they may overestimate the returns to storage at more southern locations where storage costs may have been higher historically.

Based on elevator managers' responses to our 2006 survey which pointed to a storage costs explanation, we systematically increase storage costs of the southern elevators that registered larger statistically significant price growth rates than Belvidere. Current 2006 marketing year storage costs from harvest (table 6) are more than 20% higher in the south for corn ( $0.332/0.271 = 1.23$  for storing until

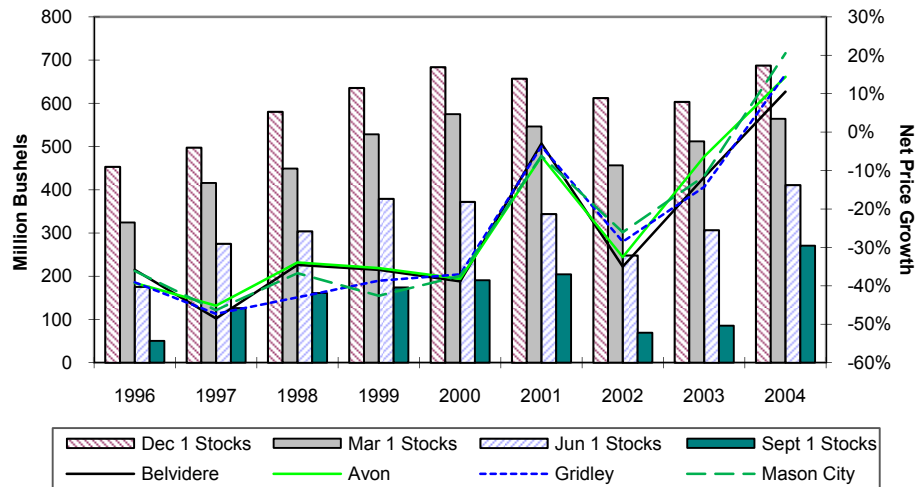
**Table 6. Extended**

Reporting District	Soybean Storage Costs (\$/bu.)					
	3/1/2006	4/1/2006	5/1/2006	6/1/2006	7/1/2006	8/1/2006
Northern	0.178	0.206	0.233	0.261	0.288	0.316
Western	0.171	0.192	0.213	0.234	0.254	0.275
North Central	0.173	0.195	0.218	0.240	0.263	0.285
South Central	0.172	0.195	0.218	0.241	0.263	0.286
<b>Central Illinois Average</b>	0.172	0.194	0.216	0.239	0.261	0.283
West Southwest	0.207	0.237	0.267	0.297	0.327	0.357
Wabash	0.200	0.228	0.255	0.283	0.310	0.338
Little Egypt	0.195	0.225	0.255	0.285	0.315	0.345
<b>Southern Illinois Average</b>	0.168	0.192	0.215	0.238	0.262	0.285

May), but little difference exists for soybeans, which partly reflects higher shrinkage and drying costs in the south that pertain to corn but not soybeans. Further, most surveyed elevator managers identified southern elevators as having historically higher storage costs. Differences in storage costs for soybeans are unnecessary for price growth at Belvidere to equal or exceed that at southern elevators, excluding Marion where storage costs would need to be 18% higher. Hence, we focus on the more interesting sensitivity results for corn markets.

Price growth at Belvidere does not differ statistically from that at elevators in the West Southwest, Wabash, and Little Egypt regions if corn storage costs in these regions are 14% higher, which is less than our reported 2006 survey results. Interestingly, as we increase storage costs, these elevators exhibit statistically significant backwardations for the Nov → Jul horizon. This is consistent with more northerly elevators, but was not evident previously (table 2). Thus, allowing for higher storage costs for corn in southern locations provides results more consistent with Benirschka and Binkley (1995) in a spatial sense, but less consistent intertemporally.

The statewide backwardations in corn prices for the Nov → Jul horizon appear to be driven by negative returns to storage for the 1996–2003 marketing years, as illustrated in figure 2. Quarterly off-farm Illinois stocks are graphed alongside price growth net of physical storage costs at representative elevators for the period. The backwardations are even stronger than they appear, since interest opportunity costs are not included in the net price growth calculations. Still, Illinois corn stocks on September 1 are never below 50 million bushels for the period. Furthermore, on average, 14% of Illinois producer sales of annual corn crops for the period are made in July and August, implying storage at a loss (USDA/National Agricultural Statistics Service, 2005).



**Figure 2. Illinois quarterly off-farm stocks and corn price growth net of warehousing costs from harvest through July 1**

Surveyed elevator managers were asked questions regarding their storage practices in addition to storage costs.<sup>10</sup> While Illinois elevators tend to liquidate stocks as the new harvest nears, managers report that July stocks generally range from 10% to 50% of capacity. All managers avoid holding unnecessary stocks when the carry is negative, but indicated that farmer-owned stocks are often held at the elevator in this circumstance for various reasons, including taxes and speculation. Also, elevators with only trucking load-out capabilities may experience transportation bottlenecks which can limit their ability to immediately liquidate stocks. A manager in central Illinois and another in southern Illinois retain stocks for elevator-owned processing and milling businesses during negative carry. Another southern elevator manager adds that producers withdraw stored grain from the elevator for delivery to local feed mills, making good on previous commitments.

These managers' comments, along with the reported backwardations for corn stored from harvest until July, suggest that Benirschka and Binkley's (1995) focus on spatial aggregation effects is too narrow. Using the most disaggregated data available, we find significant backwardations for corn at almost every elevator in a market that never experiences stock-outs. In general, spatial aggregation effects do not explain the result, as backwardations were found using regional and elevator prices. Given the representative and broad geographic scope of our data set, the reported Illinois stocks are unlikely to be held profitably through July 1 at an elevator for which price data are unavailable. More likely, this behavior reflects flows of value from stockholding in excess of expected price appreciation, which

<sup>10</sup> For brevity, we simply summarize relevant survey findings. Complete results are available from the authors upon request.

are also unobservable. Indeed, if such convenience yields could be measured and explicitly accounted for, then we may have found storage to be profitable.

Benirschka and Binkley's (1995) model with one central market also may be inadequate to capture the complexities of Illinois stockholding and stock flows. Their model with a central export market is better suited for terminal elevators located north to south along the Mississippi River, as studied by Frechette and Fackler (1999). Here, we note that local markets served by interior elevators can complicate interpretation of spatial price growth differences when assuming a central market. As one manager stressed, southern Illinois primarily serves poultry and livestock markets, whereas northern and central Illinois historically ship to the Gulf export markets and may be transforming into ethanol markets. Most elevator managers suggest that larger stocks are usually held farther north, where production is larger and facilities were built for government-owned stocks in the 1980s. These additional reasons for the northern location of stocks may complement rather than exclude Benirschka and Binkley's interest opportunity cost explanation.

### **Further Discussion and Conclusions**

Using a unique set of weekly regional and elevator corn and soybean prices in Illinois for the 1975–2004 marketing years, we investigate the spatial aggregation explanation for the storage-at-a-loss paradox. In particular, two implications of Benirschka and Binkley's (1995) model supporting the illusion of aggregation explanation are examined using pairwise *t*-tests. Specifically, we test for price growth and interest rate equivalence where stocks are held and whether prices grow faster farther from the Gulf of Mexico. All empirical analyses employ price growth rates net of physical storage costs. A 2006 survey of Illinois elevator managers provides additional insight into our empirical results.

In general, the results do not vary over the level of data aggregation (i.e., regional vs. elevator series) for pairwise *t*-tests of the differences between price growth and interest rates, but do for pairwise *t*-tests of spatial differences in price growth. Similarly, Klump, Brorsen, and Anderson (2007) also find a lack of aggregation effects in wheat markets, noting that their absence undermines aggregation explanations for storage at a loss.

Initial analyses suggest that price growth does not necessarily increase with distance from the Gulf of Mexico, nor must price growth exactly encompass interest rates. While price growth is often statistically significantly faster in the north for corn and soybeans, the result may reflect predominantly additive physical storage costs (Frechette and Fackler, 1999) instead of a comparative advantage in interest opportunity costs in the north. The few findings of significantly faster price growth at southern elevators, which are more pronounced for corn than for soybeans, may reflect the multiplicative shrinkage component of corn storage costs, a cost considered negligible for soybeans. Southern Illinois livestock and poultry markets drawing mostly corn away from stock flows toward the assumed



central market at the Gulf of Mexico may also contribute to this result. More likely, representative storage costs for central Illinois underestimate actual costs in more southern regions. Sensitivity analysis shows that when allowing for higher storage costs in the south, as found by our 2006 statewide elevator survey, most spatial anomalies disappear.

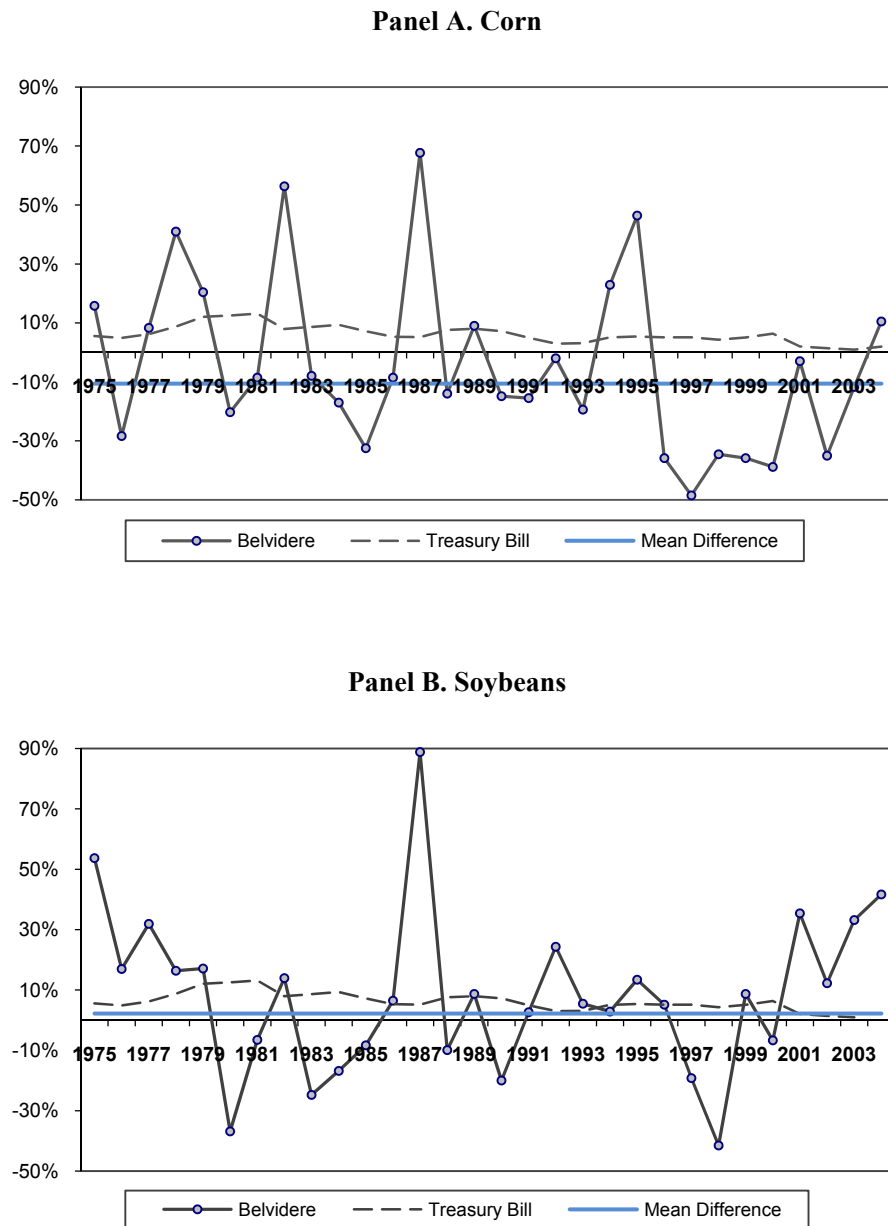
Overall, support is found for intertemporal arbitrage conditions in both markets, with the exception of the Nov → Jul storage horizon for corn. The results corroborate Fama and French's (1987) finding that soybean (but not corn) price growth generally tracks interest rates, implying relatively stronger support in soybean markets for intertemporal arbitrage conditions. While their conclusion follows from the "well-known implication of the theory of storage ... that (far-near futures) basis for any stored commodity should vary one-for-one with the ... interest rate" (Fama and French, p. 56), ours follows from direct tests finding mean equivalence between price growth and interest rates.

Clearly, the intertemporal findings are influenced by the conservative three-month Treasury bill interest rate that we chose for the analysis. The three-month rate was selected because of its use in the literature and because it reflects well the decision framework used by Benirschka and Binkley (1995)—the choice between investment in storage or in a risk-free instrument. The three-month rate averaged about 6% for our sample. If a higher interest rate is more appropriate, then we may have underestimated the backwardation, and hence the inferred convenience yields in both markets. Alternative interest rates are unlikely to change soybean results qualitatively, though. A 17% interest rate is necessary to introduce statistically significant backwardations at the 10% level in the Nov → Jul storage horizon.

Despite the conservative interest rate, corn results for the Nov → Jul storage horizon support the hypothesis that other factors besides interest rates drive price growth. These results are consistent with Peterson and Tomek's (2005) strong evidence for convenience yields in that market, where the presence of higher fuel ethanol production in recent years may also be a contributing factor. Another potential explanation for the willingness to store when price growth is less than interest rates, and even when it is less than zero, is the prevalence of government programs for corn, particularly during the early part of the sample period. In this case, spot prices may be less relevant to storage decisions in the presence of additional government assistance. For soybeans, one might suspect that the convenience yield has disappeared with increasing year-round availability from Brazilian production. In a somewhat similar vein, Chavas, Despins, and Fortenbery (2000) argue that Brazil's increasing soybean production decreased storage incentives for the spring and summer in the United States because of changing transaction costs.<sup>11</sup> However, the pattern of backwardations over time is not supportive of any of these explanations (figure 3).

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<sup>11</sup> Convenience yields typically are realized by agents who use the stock as an input, whereas transaction costs are relevant to all would-be participants in stock management. In contrast to convenience yields, which are generally thought to depend on stock levels, Chavas, Despins, and Fortenbery (2000) find that marginal transaction costs depend on expected changes in stock.



**Figure 3. Net price growth, interest rates, and mean difference for the Nov → Jul storage horizon, 1975–2004 marketing years**

Yet, the convenience yield concept seems to be an intuitive explanation. Two of the elevator managers we surveyed have held stocks for operation of elevator-owned processing plants and feed mills despite a negative carry, and another manager notes that producers store in such circumstances to meet previous commitments to feed mills. Relative to soybeans, the end uses of corn traditionally have been more diverse with different production functions, and thus cost and profit structures that may dampen the sensitivity of corn stockholding to price signals. In comparison, the soybean industry is dominated by a few large firms, which may facilitate information transfer and stock flow response to price signals. Future research may be useful in explaining the sources of these differences between corn and soybean markets.

While aggregation effects are apparent, our results are not supportive of spatial disaggregation as a cure-all for inferences of storage at a loss. Contrary to Wright and Williams (1989) and Benirschka and Binkley (1995), aggregation appears to be only part of the explanation. The importance of this issue goes beyond apparent violations of intertemporal arbitrage conditions or desires to understand the operation of markets—though both points provide sufficient motivation for continued investigation. As Frechette and Fackler (1999) note, valuation of commodity-based assets by derivative pricing theory relies on the convenience yield interpretation, as backwardations must be viewed as dividend flows. Similarly, Peterson and Tomek's (2005) simulations of corn prices require convenience yields, and Hranaiova and Tomek's (2002) basis forecasts improve with inclusion of convenience yields. Future research aimed at quantifying convenience yields could serve to substantiate or invalidate the conceptual underpinnings of such models. The pursuit of a greater understanding of the relationships between stocks, prices, and basis should continue to occupy the interests of applied economists.

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