Analysis of Agricultural Commodity Storage Using Futures and Options Market

Dissertation

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Abstract

This dissertation focuses on agricultural commodity storage utilizing concepts and data from futures and options market. The first essay investigates the measurement of expected net return to private storage. The second essay examines the crowding out of private stocks by public stocks. The third essay analyzes the forecasting of returns to private storage.

The measurement of expected return to storage is of interest because expected storage return impacts the optimal inter-temporal allocation of storable commodities between harvests. Beginning with Working's seminal articles on the theory of storage, the conventional measure of the incentive to store has been a market-determined inter-temporal price spread involving the cash price or nearby futures contract price and the price for a futures contract that matures at a later date. The first essay proposes a new measure of expected return to storage using the concept of European options. Specifically, the conventional futures price spread measure is shown to be mathematically equivalent to the value of a European call option minus the value of a European put option. Both options mature at the end of a storage period and have a strike price equal to the initial storage period price plus the cost of storage until the end of the storage period. The mathematical derivation is empirically confirmed using data from Chicago corn and soybean futures and options traded between 1989 and 2014. This two-option measure allows the expected storage return

to be decomposed into an expected profit from storage, which equals the call option value, and an expected loss from the same storage, which equals the put option value. Compared with using the conventional futures price spread, using the two option values as separate explanatory variables improved the explanatory power of the supply of storage for both crops over the analysis period. Moreover, absolute value of the estimated negative coefficient for the put option is higher than the estimated positive coefficient for the call option. This implies that private stocks have a larger response to a one unit change in expected loss from storage (the put value) than from a one unit change in expected profit from storage (the call value). This asymmetric response is consistent with the behavior of risk-averse private storage agents and raises the long-standing policy question of whether the private sector holds sufficient stocks if the risk preferences for stocks differ between society at large and private storage agents.

The second essay investigates the crowding out effect of public stocks on privately-held stocks. The farm commodity price run up since 2006 has renewed interest in public stocks, spurring several studies of optimal food reserve policy. These studies have not included the potential crowding out of private stocks by public stocks. Empirical studies of this crowding out exist, but the reported magnitude varies widely and no conceptual model has been developed. Using the concept of options, a conceptual model is developed of the crowding out that occurs when accumulated public stocks are released. The model and results from an empirical analysis find the private stock crowding out decreases as public stocks increase. Previous studies reported a constant crowding out effect for a given commodity and storage policy. The model and empirical investigation also reveal that crowding out depends on the characteristics of the commodity's demand function and thus can vary by commodity. In particular, the crowding out effect is likely to be highest for commodities with the most inelastic demand. These commodities include wheat, rice, and other food staples that countries often hold as public stocks. For example, in this study, the first unit of wheat public stocks crowded out one unit of private stocks. These findings suggest crowding out of private stocks is substantial, especially for staple crops. The finding of sizable crowding out cost is consistent with the eventual decision of the U.S. to eliminate most public stock programs and raises the possibility that less developed countries with public stock programs today may eventually repeat the U.S. decision.

Forecasting net returns to private storage is a subject of interest because commodities that have a harvest must be stored to meet demand until the next harvest. In a seminal 1953 article, Working proposed that return to storage could be predicted using expected changes in the cash-futures basis. However, empirical studies of the effectiveness of the so-called basis strategy are inconclusive, especially for unhedged storage. Using data for the 1989-2012 crops of Illinois corn and soybeans, this study finds that both the rate of harvest progress and the ratio of demand to supply for storage bin space significantly add explanatory power to the basis strategy's forecast of observed net return to storage, especially for unhedged storage. Moreover, while the basis strategy in combination with hedged storage generates the lowest risk of net return to storage, unhedged storage using either a strategy of storing routinely each year or a strategy of storing based on harvest progress rate and storage bin space can generate higher net returns to storage. This finding implies that the choice of hedged and unhedged storage depends on the risk-return preference of the storage agent. In particular, if farmers prefer higher net return over lower risk, this finding helps explain the available evidence that farmers infrequently use hedging with futures contracts. In short, forecasting net returns to private storage is a richer area of study than just the basis strategy.

Dedicated to my wife, Juhee,

my three little angels, Yeyin Winnie (3), Yerang Esther (2), and Yehahn Paul (1),

and my parents

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Fields of Study

Major Field: Agricultural, Environmental, and Development Economics

Specialization: Agricultural Policy, Futures and Options Market, Microeconometrics

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1.1 Introduction

Measurement of expected return to storage is a subject of interest to economists because expected storage return impacts the optimal inter-temporal allocation of storable commodities. Since Working's seminal articles on the theory of storage (1948, 1949), the conventional measure of this storage incentive has been a market-determined inter-temporal price spread involving the cash price or nearby futures contract price and the price for a futures contract that matures at a later date. Among the commodities for which the associated supply of storage curve has been confirmed are corn (Joseph, Irwin, and Garcia, 2015) and soybeans (Miranda and Glauber, 1993; Gardner and Lopez, 1996; Joseph, Irwin, and Garcia, 2015).

This study contributes to the storage literature by showing that the conventional futures price spread measure of net return to storage is mathematically equivalent to the value of a European call option minus the value of a European put option. Both options mature at the end of a storage period and have a strike price equal to the initial storage period price plus the cost of storage until the end of the storage period.

The mathematical derivation is empirically confirmed using data from Chicago corn and soybean futures and options traded between 1989 and 2015.

This two-option measure of expected net return to storage allows the expected return to be decomposed into an expected profit from storage, which equals the call option value, and an expected loss from the same storage, which equals the put option value. This decomposition allows a test of whether private storage responds differently to expected storage profit and expected storage loss. Asymmetric response to price is well-established in economics. Recent examples include an asymmetric impact of agricultural commodity price shocks on economic growth in Sub-Saharan Africa (Addison and Ghoshray, 2014), an asymmetric production response to price change for Zambian coffee (Mofya-Mukuka and Abdulai, 2012), and an asymmetric response of sugar cane supply to price change in Bangladesh (Jaforullah, 1993).

Investigation of the two-option measure of expected net storage return for U.S. corn and soybean markets during the 1989 through 2014 crop years finds the response to expected storage profit and loss is asymmetric. Moreover, using the two-option measure increases explanatory power of the corn and soybean supply of storage curve.

The chapter is structured as follows. Studies of the supply of storage are reviewed. Next, the option-based alternative to the price spread as a measure of expected net return to storage is derived. The two-option measure is then used to estimate the supply of storage curve for U.S. corn and soybeans. The paper ends with a summary, conclusions, and implications section.

1.2 Literature Review

In his seminal articles, Working (1948, 1949) posited that the difference between a nearby and distant price for a commodity was a market-determined return to storing the commodity over the time interval. This interpretation was applied whether price was expected to increase (distant price exceeds nearby price) or decrease (distant price is less than nearby price). Based on earlier empirical work (Hoos and Working, 1940; Working, 1933 and 1934), Working presented a stylized supply of storage curve. Subsequent research has confirmed this stylized storage curve (Telser, 1958; Brennan, 1958; Gray and Peck, 1981; Thompson, 1986; Brennan, 1991; Milonas and Henker, 2001; Milonas and Thomadakis, 1997a; Sorensen, 2002)[1].

There were two features of Working's supply of storage curve.[2] First, level of stocks was positively correlated with distant minus nearby futures price. Second, stocks existed even when price was expected to decline[3], more broadly, when net returns to storage are expected to be negative. The latter is generally thought to be an economically irrational behavior because of the cost of storage. Among the many lines of inquiry to explain this empirical phenomenon, a recent line[4] of inquiry

[1]Consistent with the supply of storage theory, Heaney (1998) found only one cointegrating vector existed among a constant term, interest rate, three month futures price of lead at the London Metals Exchange (LME), cash LME price of lead, and stocks of lead held in LME-approved warehouses.

[2]Figure 1.1 depicts the replicated supply of storage curves using data of this analysis. Their appearance is consistent with the two features of the original Working's supply of storage curve.

[3]An expected decline in price is also referred to as backwardation. Backwardation occurs when, for the same commodity, a futures price is lower than the cash price, or the price of a more deferred futures contract is lower than the price of a more nearby futures contract.

[4]Other lines of inquiry include, according to Zulauf, Zhou, and Roberts, 2006, "(1) convenience yield as the benefit that accrues from having immediate access to stocks (Working, 1949); (2) nonlinear cost of production (Williams, 1987; Wright and Williams, 1989); (3) nonlinear cost of merchandising stocks, including transportation cost (Bobenrieth H., Bobenreith H., and Wright, 2004); (4) transportation cost resulting from geographically dispersed producers (Benirschka and Bindley, 1995; Brennan, Williams, and Wright, 1997; and Frechette and Fackler, 1999); (5) transaction costs

concerning convenience yield has conceptualized it as the value of a call option held by the holder of the stocks. Bresnahan and Spiller (1986), followed by Milonas and Thomadakis (1997a and 1997b), argued this call option will have value if a non-zero probability exists that a stock-out (*i.e.*, zero stocks) can occur before the end of the expected storage period. Their argument is an update of Keynes' (1930) "liquid stocks" theory. Heinkel, Howe, and Hughes (1990) broaden this interpretation by showing that the call option will have value whenever demand shocks create a non-zero probability that current stocks may be sold at a higher price during the storage period. Both Heinkel, Howe, and Hughes (1990) and Milonas and Thomadakis (1997a and 1997b) find value of the call option is negatively related to the level of stocks.

From the theory of options, if convenience yield is a call option on current stock holdings, value of the call option should be positively related to variability of the relevant cash price and to exercise price of the option (Milonas and Thomadakis, 1997a). Empirical support has been found for the hypothesized relationship with exercise price (Milonas and Thomadakis, 1997a) but not price variability (Milonas and Thomadakis, 1997a; Sorensen, 2002).

Heaney (2002) notes the call option will have its highest value when the storage agent has perfect foresight to sell at the highest price that occurs over the storage period. He estimates the value of this call by drawing on Longstaff's (1995) model for estimating the value of marketability (liquidity) of securities. Heaney's derivation finds value of this call option is related to the difference between the variance of the cash market price and the variance of the price of the futures contract at the end of the

of holding and handling stocks (Chavas, Despins, and Fortenbery, 2000); (6) sufficiently risk averse competitive storage firms (Chavas, 1988); (7) asymmetric information (Khoury and Martel, 1989; Frechette, 1999 and 2001); and (8) a positive call option value to defer production (Litzenberger and Rabinowitz, 1995)."

storage period, as well as the time to futures contract maturity. In essence, the higher the variability of cash price to futures price, the higher the value of the call option to sell stock before the end of the storage period. Zulauf, Zhou, and Roberts finds Heaney's (2002) metric for valuing the call explained approximately 60 percent of the variation in the storage cost-adjusted old crop-new crop futures price spread in the U.S. soybean market between 1988 and 2004. While a 60 percent explanation share is large for a single variable, this finding also suggests other variables are needed to explain the storage cost-adjusted spread or Heaney's estimate of the call value associated with stocks can be improved.

1.3 Model

For the sake of simplicity, assume a risk neutral storage agent in a two period world with uncertainty. The agent has two alternatives: (1) sell now at time t for the certain cash price, or (2) store to sell at future time $t+1$ for an uncertain price. Also assume a futures market exists for time $t+1$. Net return expected from storage until time $t+1$ as of time t, designated $ERS_{t,t+1}$, is conventionally stated:

$$ERS_{t,t+1} = F_{t+1,t} - (P_t + C_{t,t+1}) \tag{1.1}$$

where $F_{t+1,t}$ is the time-t-price of the futures contract that expires at time $t+1$, P_t is the cash price at time t, and $C_{t,t+1}$ is storage cost from time t to time $t+1$. Storage cost is composed of physical storage cost, interest opportunity cost, and insurance cost.

If the futures market is assumed to be efficient and thus provides an unbiased forecast for future cash price, then:

$$F_{t+1,t} = E_t\left(P_{t+1}|\Omega_t\right) \tag{1.2}$$

where $E_t\left(P_{t+1}|\Omega_t\right)$ is the cash price expected for time $t+1$, or the expected value of the distribution of future cash price for time $t+1$, as of time t based on the set of all information known at time t (Ω_t). Substituting equation (1.2) into equation (1.1) and denoting the storage cost-adjusted cash price at time t in equation (1.1), $(P_t + C_{t,t+1})$, as P_t^*, equation (1.1) is re-expressed as follows:

$$ERS_{t,t+1} = E_t\left(P_{t+1}|\Omega_t\right) - P_t^* \tag{1.3}$$

Using the rules of integration, equation (1.3) can be restated:

$$\begin{aligned}
E_t\left(P_{t+1}|\Omega_t\right) - P_t^* &= \int_0^\infty (P) f_{P_{t+1}}\left(P|\Omega_t\right) dP - P_t^* \\
&= \int_0^{P_t^*} (P) f_{P_{t+1}}\left(P|\Omega_t\right) dP + \int_{P_t^*}^\infty (P) f_{P_{t+1}}\left(P|\Omega_t\right) dP - P_t^* \\
&= \int_0^{P_t^*} \left(P - P_t^*\right) f_{P_{t+1}}\left(P|\Omega_t\right) dP + \int_{P_t^*}^\infty \left(P - P_t^*\right) f_{P_{t+1}}\left(P|\Omega_t\right) dP \\
&= \int_{P_t^*}^\infty \left(P - P_t^*\right) f_{P_{t+1}}\left(P|\Omega_t\right) dP - \int_0^{P_t^*} \left(P_t^* - P\right) f_{P_{t+1}}\left(P|\Omega_t\right) dP
\end{aligned} \tag{1.4}$$

where $f_{P_{t+1}}\left(\cdot|\Omega_t\right)$ is a probability distribution of the unknown cash price for time $t+1$ (P_{t+1}) generated by the market using all available information at time t, Ω_t.

The first term on the right side of the last equality in equation (1.4) is the value of a call with a strike price of P_t^* expiring at time $t+1$. The second term on the right hand side is the value of a put with a strike price of P_t^* expiring at time $t+1$. Value of the call option is the net storage profit expected at time t when price increases by more than the cost of storage between time t and time $t+1$. Value of the put option is the net storage loss expected at time t when price increases by less than the storage cost between time t and time $t+1$ or when price decreases. As derived in equation (1.4), the difference between these two options is equivalent to the conventional spread measure of the net return to storage expected at time t from storing stocks between time t and time $t+1$ as follows:

$$ERS_{t,t+1} = E_t\left(P_{t+1}|\Omega_t\right) - P_t^* = CV_{t,t+1}\left(P_t^*\right) - PV_{t,t+1}\left(P_t^*\right) \qquad (1.5)$$

where $CV_{t,t+1}\left(P_t^*\right)$ is the time-t-value of a call option with strike price P_t^* expiring at time $t+1$, and $PV_{t,t+1}\left(P_t^*\right)$ is the time-t-value of a put option with strike price P_t^* expiring at time $t+1$.

In summary, the two-option measure of expected net return to storage allows the expected net return to be separated into two components, an expected storage profit and an expected storage loss, which is a distinctive feature compared with the conventional measure of expected net storage return as a temporal price spread. Moreover, the two-option measure is highly flexible as it requires no specific functional form for the price distribution except for the usual assumption that price is non-negative.

1.4 Empirical Analysis

The first empirical analysis examines whether equation (1.5) holds, that is the conventional measure of expected net return to storage, the temporal price spread, equals the difference between the call and put option values. The second empirical analysis updates the supply of storage estimation by using the two options as separate explanatory variables. This analysis permits an examination of whether the response of stocks is asymmetric between expected storage profit and expect storage loss, as well as whether the two option model ehnhances the supply of storage estimation compared with the conventional inter-temporal price spread measure.

1.4.1 Data and Variable Measurement

The U.S. corn and soybean markets are chosen for analysis. Corn and soybeans are the largest acreage field crops in the U.S. They also have relatively liquid futures and options markets. Thus, contemporaneous data of futures and option prices as well as corn and soybean stocks, and storage costs can be collected. Contemporaneous data minimizes measurement error by aligning prices with the information set the market used to determine them.

Trading of options began in 1984 and 1985 for soybeans and corn, respectively (Board of Trade of the City of Chicago (CBOT), 1989). Due to low trading volume during the early years of option trading for corn and soybeans, this study begins with the 1989-1990 crop year. It ends with the 2014-2015 crop year, the latest crop year. Moreover, public stocks can displace privately held stocks, thus affecting private supply of storage relationships (Peck, 1977-78; Sharples and Holland, 1981). The 1986-1987 crop year was the last year that public stocks of soybeans existed and the 1989 -1990 crop year was the last year public stocks of corn[5] exceeded 10 percent of annual use (*World Agricultural Supply and Demand Estimates* reports, 1985-2013). Hence, starting the analysis with the 1989-1990 crop year also avoids the need to consider for U.S. corn and soybeans the impact of public stocks on private stocks.

The call and put option values in equations (1.4) and (1.5) are European options because the values are based on the price distribution at contract maturity. These

[5]Even since 1991-92 crop year, public stocks of corn were less than 2.1 percent of annual use, with less than 0.2 percent for a majority of crop years afterward (*World Agricultural Supply and Demand Estimates* reports, 1985-2013).

option values are graphically depicted in Figure 1.2, which presents a stylized probability density function of an unknown future cash price for time $t+1$ as of time t.

The options traded for corn and soybeans in Chicago are American options. American options can be exercised prior to contract maturity while European options can be exercised only at contract maturity. In other words, an American option can have an early exercise premium. However, for options on futures contracts subject to daily mark-to-the-market of contract value, it is more profitable to trade rather than exercise the option (Black, 1976). Hence, the Chicago options traded on corn and soybeans are priced as if they are European options.

Options for corn and soybeans at Chicago are traded at discrete strike prices. The interval between strike prices was 25 cents per bushel for soybeans until 2000 and then became 20 cents[6]. For corn, the strike price has been 10 cents per bushel over the analysis period. It is unlikely that the strike prices[7] identified by the option valuation of storage will match one of the discretely traded strike prices. Therefore, the value of option with a strike price associated with the option valuation of storage is calculated using linear interpolation[8] of the two adjacent option premiums with

[6]In 2000 when the interval between strike prices were changed from 25 cents to 20 cents per bushel for soybeans, 10 cent intervals were also observed but very barely. The linear interpolation was not affected by the rare case.

[7]The strike price associated with the option valuation of storage is initial cash price plus the cost of storage over the storage interval.

[8]More sophisticated procedures can be used. For example, traded option premiums can be used to estimate curvature of the price distribution. However, because the strike prices are adjacent, linear interpolation should provide a relatively accurate approximation of the option premiums associated with storage.

the two traded discrete strike prices that bracket the strike price associated with the option valuation of storage[9].

To avoid statistical problems associated with overlapping samples as well as the potential for seasonal effects of stocks for a crop with a harvest, carryout stocks are chosen for analysis. Carryout stocks have been commonly evaluated in the storage literature. Moreover, each month the U.S Department of Agriculture (USDA) issues an estimate of stocks carried out of the current crop year, as well as other supply and demand information, for corn and soybeans in its *World Agricultural Supply and Demand Estimates* (*WASDE*) report. These reports are widely-followed key market events. Carryout stocks are reported as of September 1.

Carryout stocks care measured as a stocks-use ratio. This ratio is commonly used because, *ceteris paribus*, stocks need to increase as use increases since stocks allow an annual harvest to satisfy continuous consumption (Routledge, Seppi, and Spatt, 2000). Use is total annual use estimated and reported in *WASDE* report, a common measure.

The spread between old crop and new crop prices is measured using the September and November futures and options for soybeans and the September and December futures and options for corn. September is chosen as the nearby contract while November soybeans and December corn are the first futures contracts traded after the September contract.

[9]To illustrate the linear interpolation, consider soybeans for April 2000. The September 2000 futures price plus storage cost equals \$5.55 per bushel. The two November 2000 option strike prices that bracket \$5.55 are \$5.50 and \$5.75. Premiums for the \$5.50 and \$5.75 November 2000 call are \$0.45 and \$0.365 per bushel, respectively, on April 11, 2000, the first non-limit close after release of the April 2000 *WASDE* report. A \$0.433 premium is finally calculated for the \$5.55 strike price as follows:

$$\$0.365 \times \frac{(\$5.55 - \$5.50)}{\$0.25} + \$0.45 \times \frac{(\$5.75 - \$5.55)}{\$0.25} = \$0.433 \tag{1.6}$$

The storage cost-adjusted September futures price as of a *WASDE* release date w, $F^*_{t,w}$, is calculated as:

$$F^*_{t,w} = F_{t,w} + I_{t,t+1,w}\left(F_{t,w}, r_w\right) + PSC_{t,t+1,w} \tag{1.7}$$

where t represents the beginning date of the storage period, September, and w is the *WASDE* release date, $F_{t,w}$ is September futures price as of time w, $I_{t,t+1,w}\left(F_{t,w}, r_w\right)$ is the expected interest opportunity cost of storing stocks from time t to time $t+1$ as of time w, and $PSC_{t,t+1,w}$ is physical storage cost from time t to time $t+1$ calculated as of time w. Interest opportunity cost and physical storage cost are calculated, respectively, as:

$$I_{t,t+1,w}\left(F_{t,w}, r_w\right) = F_{t,w} \times r_w \times \lambda \tag{1.8}$$

$$PSC_{t,t+1,w} = sr_w \times \lambda \tag{1.9}$$

where λ is the proportion of a crop year between time t and $t+1$, thus 1/6 for soybeans and 1/4 for corn, r_w is the three-month U.S. Treasury Bill rate as of time w, and sr_w is annual physical storage rate as of time w. Both interest opportunity cost and physical storage cost are estimated using discrete rather than continuous time method because physical storage cost is reported in discrete time intervals, either per month or per year.

The contemporaneous data on futures and option prices, stocks and annual use, and storage costs are collected as of the first non-limit close of corn and soybean futures prices after the release of a *WASDE* report. This procedure allows the market time to incorporate new supply and demand information contained in the *WASDE* report into futures and option prices.

The *WASDE* reporting dates used in this study are for April, May, June, and July. Trading of September options ends around the 20th of August and option premiums can become erratic as expiration approaches. Hence, the decision was made that the last *WASDE* would be July. The decision to start with the April *WASDE* was based on trading volume of options, which was limited prior to April for the September options.

Futures and option prices are for Chicago contracts and from Barchart.com. Corn and soybean stocks carried out of a crop year are the estimates reported in *WASDE* reports. The three-month U.S. Treasury Bill rates are from the Federal Reserve Economic Data maintained by the Federal Reserve Bank of St. Louis. Physical storage costs are from USDA, Commodity Credit Corporation (CCC) through the 2008 crop year. CCC changed its method used to report storage rates by commodity, substantially changing storage rates. Thus, beginning with the 2009-10 crop year, physical storage rates were collected from an Ohio country elevator and cross checked with another Ohio elevator. This storage rate is more consistent with the rates CCC reported prior to 2009.

1.4.2 Empirical Equivalence of the Spread Measure and Two-Option Measure

Figure 1.3 is a graph of the individual observation values of the conventional spread measure and the two-option measure of expected net storage return across all four *WASDE* release dates. For both corn and soybeans, R^2 of a linear regression rounds to 1.0, and the mean, standard deviation, minimum, and maximum differ by no more than one cent per bushel across the two measures. In conclusion, the two-option measure of expected net storage return is found to be empirically equivalent to the conventional spread measure of expected net return to storage for both corn and soybeans, consistent with the mathematical derivation of equations (1.1) through (1.5).

1.4.3 Updating Supply of Storage Estimation

The supply of storage curve is estimated using the two-option measure of expected net return to storage to assess whether it improves the explanation of variations in the supply of storage relative to the conventional price spread measure of expected net return to storage and to examine whether an asymmetric relationship between stockholding and expected profit and loss from storage. Given that *WASDE*-predicted carryout stocks differ only slightly over the April through July report months (see Table 1.1), it is reasonable to expect the unobserved heterogeneity that determines carryout stocks is correlated across the four *WASDE* report months. Thus, a potential estimation issue is cross-equation correlations in disturbances between any two *WASDE* release dates, or among more than two *WASDE* release dates for a crop. This correlation[10] averaged 0.86 for corn and 0.76 for soybeans across the four report months in the conventional supply of storage estimation. The Breusch-Pagan test for no contemporaneous cross-equation correlations in disturbances rejects the null hypothesis at the one percent significance level. Following Kahl and Tomek's (1986) suggestion, Seemingly Unrelated Regressions (SUR; Zellner, 1962) is chosen over both separate equation-by-equation ordinary least squares (OLS) and pooled OLS estimations since SUR estimation provides more efficient estimates by capturing the cross-equation correlations in disturbances.

[10]Cross-equation correlations in disturbances are calculated using the residuals of separate equation-by-equation ordinary least squares estimations.

Furthermore, given that corn and soybean carryout stocks are influenced by the same contemporaneous demand and supply of storage factors including weather and storage capacity, it is also possible that the disturbances in corn's supply of storage equation are correlated with those in soybean's equation. As the Breusch-Pagan test for no contemporaneous cross-equation correlations in disturbances between corn and soybean equations rejects the null hypothesis at the one percent significance level, this analysis estimates 8-equation SUR model, four equations for the four *WASDE* report months for corn and four equations for the four *WASDE* report months for soybeans.

Given the times series nature of the data, it is essential to check whether the individual time series variables are stationary[11] before conducting a regression analysis. Both the Augmented Dickey-Fuller test and the Phillips-Perron test reject the null hypothesis of non-stationarity (*i.e.* unit root) for all variables at least at the 10 percent significance level.

Table 1.1 contains summary statistics for the variables used in this analysis as of the earliest and latest[12] *WASDE* release dates (April and July). The average futures price spread was negative as expected, reflecting that losses are expected from storing corn and soybeans from September to December or November. A few observations had positive price spreads; thus, expected a profit from storing. For corn, the per bushel call option premium measure of expected profit from storage averaged $0.26

[11]As a sensitivity test, the ratio of each return measure (price spread, put, and call) to the September futures price is used as explanatory variables in the regression analysis. The regression results remained the same in terms of statistical significance of the coefficients and the coefficients had similar magnitudes.

[12]Summary statistics for the variables used in this analysis are reported only as of the earliest (April) and latest (July) *WASDE* release dates in order to reserve space. The summary statistics were highly consistent for the May and June *WASDE* release dates.

for the April *WASDE* and \$0.20 for the July *WASDE*, while the per bushel put option measure of expected loss from storage averaged \$0.39 and \$0.28 for the April and July *WASDE*, respectively. For soybeans, the call option measure (put option measure) averaged \$0.47 (\$0.68) and \$0.38 (\$0.57) as of the April and July *WASDE* release dates, respectively.

All SUR estimated coefficients have their expected signs, negative for the put value and positive for the spread measure and call value (see Table 1.2). Each coefficient is statistically significant mostly at the one percent test level. This implies as expected that 1) the expected profit from storage is significantly positively correlated with carryout stocks-use ratio while the expected loss from storage is significantly negatively correlated with carryout stocks-use ratio, and 2) the conventional price spread measure has a significant positive impact on the level of carryout stocks-use ratio, consistently for both crops for each *WASDE* release date. Figure 1.4. depicts these bivariate relationships between carryout stocks-use ratio and call value, put value, and futures price spread, respectively.

The two-option measure of expected net return to storage has a higher explanatory power than the conventional price spread measure for both crops and every *WASDE* release date. The increase in adjusted R^2 (see Table 1.3[13]) is smallest for soybeans at the April *WASDE* (+0.04) and largest for soybeans at the June *WASDE* (+0.14). On average, adjusted R^2 increased by 15.3 percent for corn and 12.8 percent for soybeans. Adjusted R^2 is used instead of R^2 because the number of explanatory variable differs.

[13]As the concept of R^2 is not appropriately defined for SUR estimations that utilize Feasible Generalized Least Squares technique, R^2s in separate OLS estimations need to be compared.

Estimated coefficients for the call and put option values differ significantly at the one percent test level at all *WASDE* release dates and both crops. Furthermore, absolute value of the coefficients differ statistically from one another. Level of significance is one percent for five of the eight tests, five percent for two tests, and ten percent for corn at the April *WASDE* release date. In each case, absolute value of the coefficient is higher for the put option than for the call option. This empirical finding suggests that the supply of storage asymmetrically responses to the expected profit and loss from storage statistically significantly.

As a sensitivity test, the supply of storage relationship is estimated using equation-by-equation OLS and pooled OLS regression (see Tables 1.3 and Appendix Table A.1, respectively). These results are consistent with the SUR estimation results.

1.5 Summary, Conclusions, and Implications

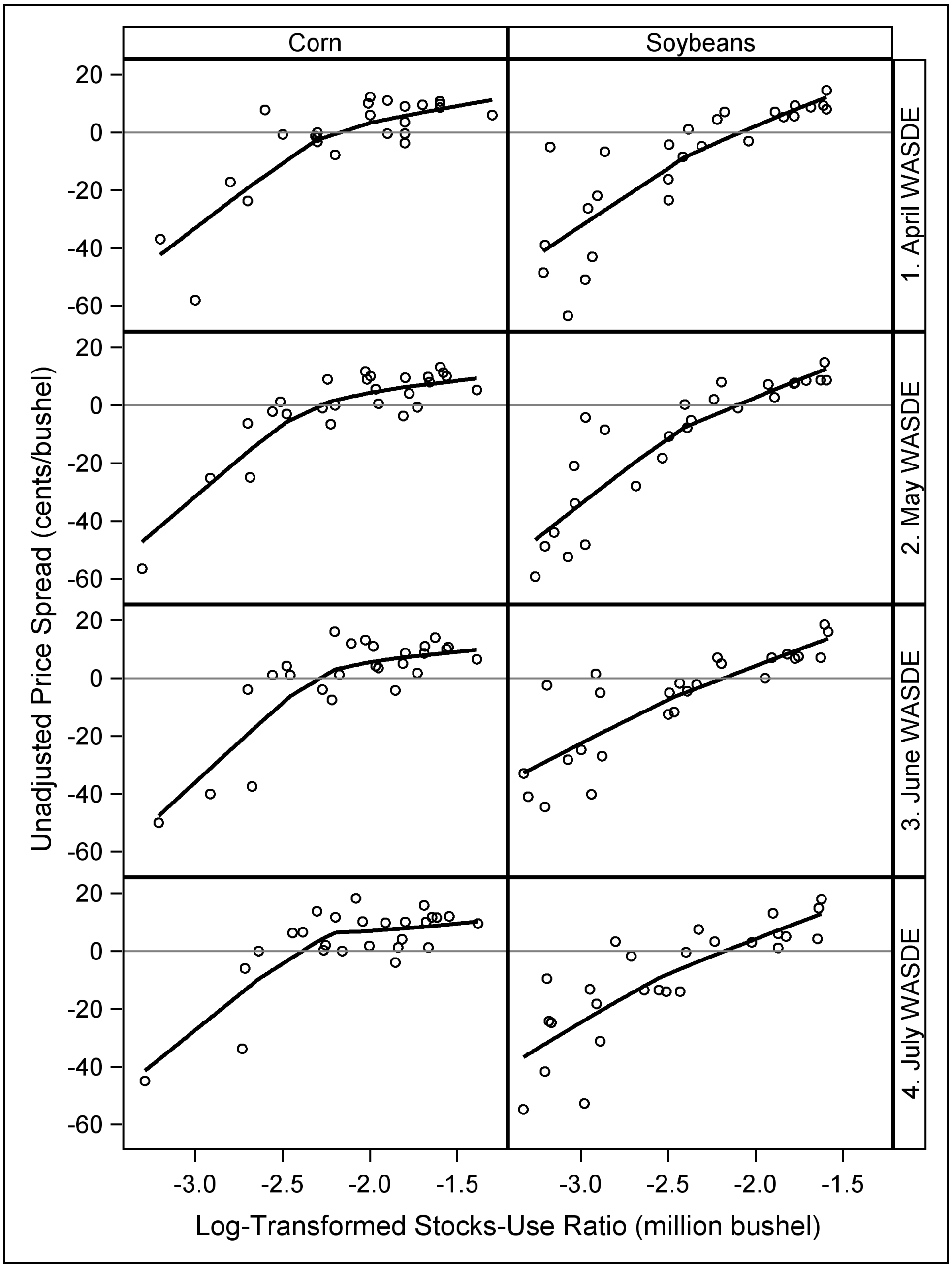
This article has shown that the traditional futures price spread measure of expected net return to storage is mathematically equivalent to the difference obtained by subtracting a put option premium from a call option premium when each option has the same strike price equal to the nearby futures price plus the cost of storage. Value of the call option is the storage profit expected if price increases by more than the cost of storage while value of the put option is the loss expected if price increases by less than the storage cost or declines. The conceptual derivation of equivalency is confirmed empirically using data from the trading of corn and soybean futures and options in Chicago over the 1989 through 2014 crop years.

Given this confirmed equivalence, estimation of the supply of storage curve is updated. Compared with using the conventional futures price spread, using the two option values as separate explanatory variables improved the supply of storage curve's explanatory power for both crops over the analysis period. Moreover, absolute value of the estimated negative coefficient for the put option is higher than the estimated positive coefficient for the call option. Private stocks thus had a larger response to a one unit change in expected loss from storage (the put value) than from a one unit change in expected profit from storage (the call value).

The asymmetric response is consistent with the behavior of risk-averse private storage agents and raises the long-standing policy question of whether the private sector holds sufficient stocks if the risk preferences for stocks differ between society at large and private storage agents. By providing a measure of the different responses to expected profit and loss from storage, the two-option measure of expected net return to storage may allow a more precise estimate of the benefit and cost of public stocks when the risk preferences for stocks differ. Future research will explore this policy question.

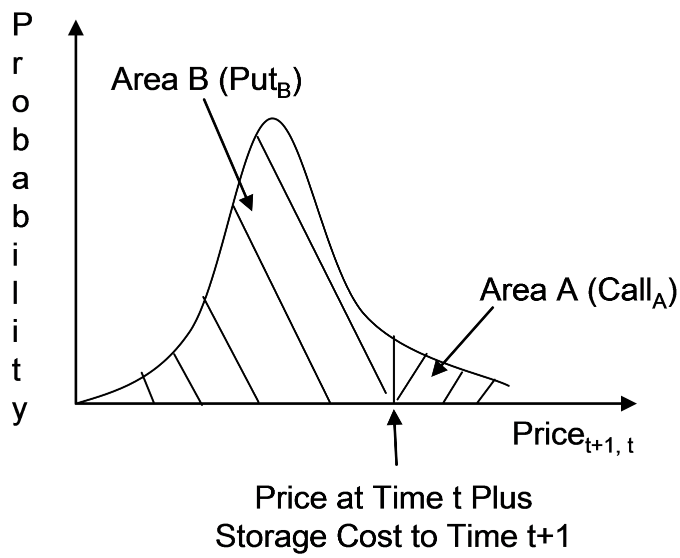
Ever since Working published his seminal articles on the supply of storage (1948, 1949), debate has swirled around the apparently economically irrational empirical observation that stocks exceed zero even when price is expected to decline. Many explanations have been put forward, but none has been accepted including Milonas and Thomadakis' (1997a and 1997b) proposal of an option value based on the probability of a stock out of zero stocks at the end of a storage period. The findings of this study that expected net return to storage can be expressed using option premiums and that the option approach better fits the supply of storage curve underscore the fundamental question raised by Milonas and Thomadakis, does the current understanding of storage include all the possible options associated with storage? Future research will explore this question.

Finally, the two-option analysis of net storage returns can be extended to other agricultural commodities including wheat and cotton as well as to non-agricultural commodities such as oil and copper.



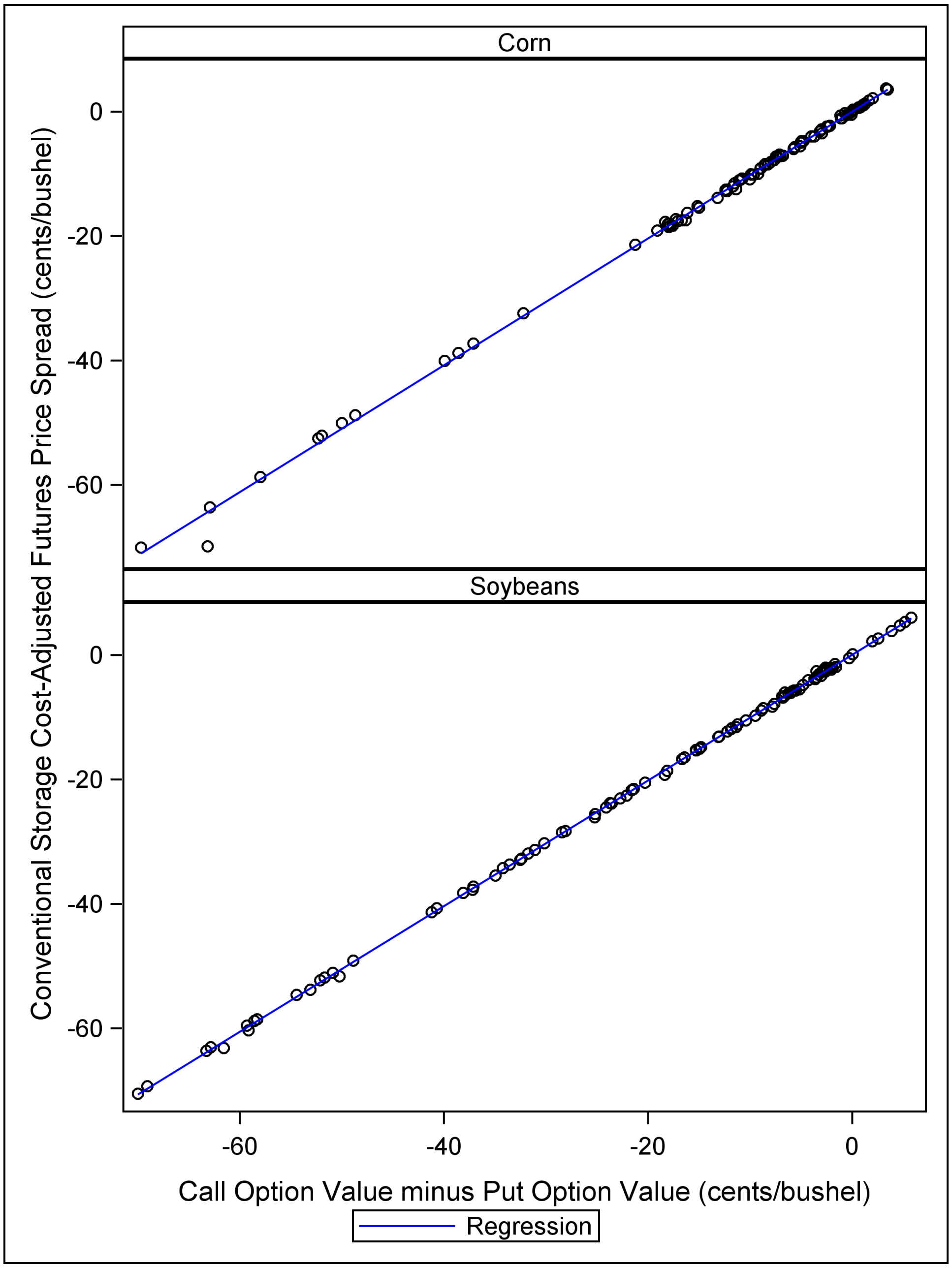
Source: Original Calculation

Figure 1.1: Replication of Working's Stylized Supply of Storage Curve, September and December CBOT Corn, September and November CBOT Soybeans, April, May, June, and July *World Agricultural Supply and Demand Estimates* Release Dates, 1989-2014 Crop Years



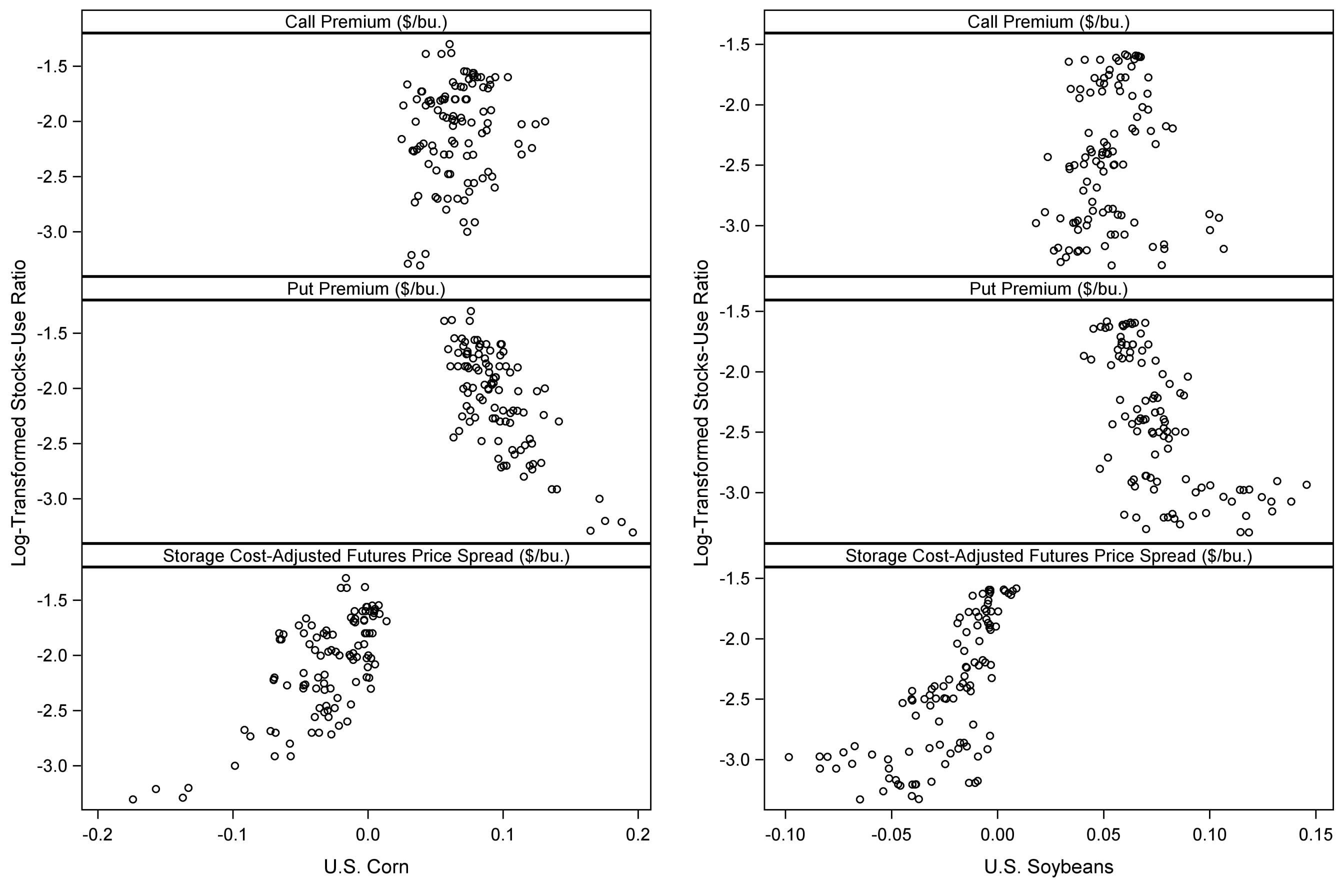
Note: Areas A and B are the values of a European call and a European put, respectively; both maturing at time $t+1$ with a strike price equal to the cash price at time t plus storage cost from time t to time $t+1$.

Figure 1.2: Options Associated with Calculating Expected Net Return to Storage



Source: Original Calculation

Figure 1.3: Empirical Relationship between Traditional Storage Cost-Adjusted Futures Price Spread Measure of Expected Net Storage Return and Difference equal to Option Call Premium Minus Option Put Premium, September and December CBOT Corn, September and November CBOT Soybeans, April, May, June, and July *World Agricultural Supply and Demand Estimates* Release Dates, 1989-2014 Crop Years



Source: Original Calculation

Figure 1.4: Relationship between Log Stocks-Use Ratio and (1) Call Premium, (2) Put Premium, and (3) Storage Cost-Adjusted Futures Price Spread, September and December CBOT Corn, September and November CBOT Soybeans, April, May, June, and July *World Agricultural Supply and Demand Estimates* Release Dates, 1989-2014 Crop Years

Variable	*WASDE* Release	# of Obs.	Mean	S.D.	Min.	Max.
Stocks-Use Ratio (%)						
Corn	April	26	14%	6%	4%	26%
	July	26	14%	5%	4%	25%
Soybeans	April	26	11%	6%	4%	20%
	July	26	10%	5%	4%	20%
Futures Price ($/bu.)						
September Corn	April	26	3.45	1.40	2.12	7.11
	July	26	3.33	1.58	1.86	7.04
December Corn	April	26	3.44	1.29	2.21	6.53
	July	26	3.36	1.54	1.97	7.09
September Soybeans	April	26	7.91	3.02	4.31	14.01
	July	26	8.07	3.38	4.18	16.06
November Soybeans	April	26	7.80	2.90	4.35	13.96
	July	26	7.98	3.33	4.19	15.96
Option Price ($/bu.)						
December Corn, Call	April	26	0.26	0.15	0.10	0.71
	July	26	0.20	0.14	0.06	0.61
December Corn, Put	April	26	0.39	0.25	0.16	1.22
	July	26	0.28	0.20	0.11	0.71
November Soybeans, Call	April	26	0.47	0.26	0.21	1.34
	July	26	0.38	0.25	0.12	1.26
November Soybeans, Put	April	26	0.68	0.39	0.30	1.87
	July	26	0.57	0.31	0.23	1.48
Futures Price Spread ($/bu.)						
Corn	April	26	-0.14	0.17	-0.70	0.00
	July	26	-0.09	0.15	-0.59	0.04
Soybeans	April	26	-0.21	0.22	-0.71	0.02
	July	26	-0.19	0.19	-0.64	0.05
Two-Option Measure ($/bu.)						
Corn	April	26	-0.13	0.17	-0.70	0.00
	July	26	-0.09	0.15	-0.58	0.03
Soybeans	April	26	-0.21	0.22	-0.70	0.02
	July	26	-0.19	0.19	-0.63	0.05
Interest Rate (%/year)						
	April	26	2.99	2.41	0.03	8.03
	July	26	2.99	2.36	0.02	7.68
Physical Storage Cost (¢/bu./year)		26	39.83	10.23	33.00	60.00

Source: original calculation using data from USDA *WASDE* reports, Barchart.com, Federal Reserve Bank at St. Louis, USDA CCC, and Ohio country elevator

Table 1.1: Descriptive Statistics, Supply of Storage Variables, U.S. Corn and Soybeans, April and July *World Agricultural Supply and Demand Estimates* (*WASDE*) Release Dates, 1989-2014 Crop Years

	Log (Stocks-Use Ratio) − U.S. Corn							
	April *WASDE*		May *WASDE*		June *WASDE*		July *WASDE*	
Futures Spread	0.014*** (0.002)		0.016*** (0.002)		0.013*** (0.002)		0.015*** (0.002)	
Call Value		0.007** (0.004)		0.011*** (0.003)		0.007*** (0.003)		0.010*** (0.003)
Put Value		-0.012*** (0.002)		-0.017*** (0.002)		-0.013*** (0.002)		-0.015*** (0.002)
Intercept	-1.906*** (0.061)	-1.812*** (0.082)	-1.904*** (0.056)	-1.758*** (0.066)	-1.942*** (0.058)	-1.821*** (0.067)	-1.945*** (0.061)	-1.834*** (0.069)
	Test for Asymmetric Supply Response to Expected Price Change − χ^2_1-Statistics							
$\lvert\text{Call}\rvert^A = \lvert\text{Put}\rvert$	*n/a*^{B}	3.52*	*n/a*	10.24***	*n/a*	7.98***	*n/a*	6.25**
Call = Put	*n/a*	13.60***	*n/a*	43.97***	*n/a*	27.67***	*n/a*	29.01***
Observations	26	26	26	26	26	26	26	26
R^2	0.557	0.577	0.589	0.672	0.534	0.621	0.482	0.580

	Log (Stocks-Use Ratio) − U.S. Soybeans							
	April *WASDE*		May *WASDE*		June *WASDE*		July *WASDE*	
Futures Spread	0.013*** (0.002)		0.013*** (0.002)		0.014*** (0.002)		0.014*** (0.002)	
Call Value		0.008*** (0.003)		0.008*** (0.002)		0.010*** (0.002)		0.009*** (0.002)
Put Value		-0.012*** (0.002)		-0.014*** (0.001)		-0.017*** (0.002)		-0.015*** (0.002)
Intercept	-2.110*** (0.077)	-1.934*** (0.108)	-2.123*** (0.065)	-1.864*** (0.086)	-2.198*** (0.073)	-1.860*** (0.078)	-2.217*** (0.079)	-1.941*** (0.095)
	Test for Asymmetric Supply Response to Expected Price Change − χ^2_1-Statistics							
$\lvert\text{Call}\rvert^A = \lvert\text{Put}\rvert$	*n/a*^{B}	5.86**	*n/a*	16.76***	*n/a*	37.35***	*n/a*	18.85***
Call = Put	*n/a*	19.44***	*n/a*	46.46***	*n/a*	57.64***	*n/a*	32.01***
Observations	26	26	26	26	26	26	26	26
R^2	0.572	0.612	0.635	0.722	0.536	0.733	0.530	0.656

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ for one-tailed test. Standard errors reported in parentheses
A. Test for equivalence in magnitude between estimate of call value and estimate of put value
B. Test not applicable because the test requires two explanatory variables
Source: original calculation using data from USDA *WASDE* reports, Barchart.com, Federal Reserve Bank at St. Louis, USDA CCC, and Ohio country elevator

Table 1.2: Estimated Supply of Storage, Conventional Storage Cost-Adjusted Futures Price Spread vs. Two Option Components of Expected Net Storage Return, 8-Equation Seemingly Unrelated Regressions of U.S. Corn and Soybeans, April, May, June, and July *World Agricultural Supply and Demand Estimates* (*WASDE*) Release Dates, 1989-2014 Crop Years

	Log (Stocks-Use Ratio) − U.S. Corn							
	April *WASDE*		May *WASDE*		June *WASDE*		July *WASDE*	
Futures Spread	0.022***		0.025***		0.021***		0.022***	
	(0.004)		(0.003)		(0.002)		(0.003)	
Call Value		0.015**		0.018***		0.011***		0.013***
		(0.005)		(0.003)		(0.003)		(0.004)
Put Value		-0.021***		-0.027***		-0.021***		-0.024***
		(0.004)		(0.002)		(0.003)		(0.003)
Intercept	-1.790***	-1.655***	-1.789***	-1.562***	-1.847***	-1.635***	-1.876***	-1.651***
	(0.073)	(0.105)	(0.064)	(0.084)	(0.068)	(0.088)	(0.068)	(0.094)
	Test for Asymmetric Supply Response to Expected Price Change − χ^2_1-Statistics							
$\lvert\text{Call}\rvert^{A} = \lvert\text{Put}\rvert$	n/a^{B}	3.79*	*n/a*	16.02***	*n/a*	13.65***	*n/a*	17.99***
Call = Put	*n/a*	14.97***	*n/a*	119.76***	*n/a*	39.74***	*n/a*	31.77***
Observations	26	26	26	26	26	26	26	26
Adjusted R^2	0.653	0.691	0.683	0.778	0.622	0.729	0.547	0.680

	Log (Stocks-Use Ratio) − U.S. Soybeans							
	April *WASDE*		May *WASDE*		June *WASDE*		July *WASDE*	
Futures Spread	0.021***		0.022***		0.027***		0.023***	
	(0.003)		(0.002)		(0.003)		(0.004)	
Call Value		0.015**		0.015***		0.018***		0.016***
		(0.006)		(0.003)		(0.003)		(0.004)
Put Value		-0.020***		-0.021***		-0.026***		-0.024***
		(0.003)		(0.002)		(0.003)		(0.003)
Intercept	-1.958***	-1.796***	-1.937***	-1.715***	-1.986***	-1.667***	-2.039***	-1.754***
	(0.094)	(0.157)	(0.086)	(0.104)	(0.096)	(0.090)	(0.102)	(0.095)
	Test for Asymmetric Supply Response to Expected Price Change − χ^2_1-Statistics							
$\lvert\text{Call}\rvert^{A} = \lvert\text{Put}\rvert$	n/a^{B}	1.13	*n/a*	6.80**	*n/a*	32.37***	*n/a*	23.26***
Call = Put	*n/a*	18.27***	*n/a*	48.70***	*n/a*	57.12***	*n/a*	30.57***
Observations	26	26	26	26	26	26	26	26
Adjusted R^2	0.653	0.689	0.745	0.800	0.675	0.815	0.626	0.737

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ for one-tailed test. Standard errors reported in parentheses
A. Test for equivalence in magnitude between estimate of call value and estimate of put value
B. Test not applicable because the test requires two explanatory variables

Source: original calculation using data from USDA *WASDE* reports, Barchart.com, Federal Reserve Bank at St. Louis, USDA CCC, and Ohio country elevator

Table 1.3: Estimated Supply of Storage, Conventional Storage Cost-Adjusted Futures Price Spread vs. Two Option Components of Expected Net Storage Return, Separate Equation-by-Equation OLS Regressions of U.S. Corn and Soybeans, April, May, June, and July *World Agricultural Supply and Demand Estimates* (*WASDE*) Release Dates, 1989-2014 Crop Years

1.6 Addendum

1.6.1 Additional Regression Results

	Log (Stocks-Use Ratio)			
	U.S. Corn		U.S. Soybeans	
Futures Spread ($= SP$)	0.0223***		0.0232***	
	(0.0030)		(0.0037)	
Call Value ($= CV$)		0.0126***		0.0165***
		(0.0038)		(0.0041)
Put Value ($= PV$)		-0.0236***		-0.0238***
		(0.0031)		(0.0034)
April *WASDE* ($=$ *April*)	0.0868	-0.0037	0.0838	-0.0369
	(0.1000)	(0.1410)	(0.1370)	(0.1830)
May *WASDE* ($=$ *May*)	0.0876	0.0891	0.1040	0.0448
	(0.0930)	(0.1270)	(0.1310)	(0.1400)
June *WASDE* ($=$ *June*)	0.0294	0.0161	0.0554	0.0920
	(0.0958)	(0.1290)	(0.1380)	(0.1290)
$SP \times April$	0.0001		-0.0025	
	(0.0047)		(0.0045)	
$SP \times May$	0.0026		-0.0014	
	(0.0041)		(0.0042)	
$SP \times June$	-0.0016		0.0033	
	(0.0036)		(0.0049)	
$CV \times April$		0.0024		-0.0011
		(0.0066)		(0.0070)
$CV \times May$		0.0051		-0.0013
		(0.0047)		(0.0053)
$CV \times June$		-0.0013		0.0018
		(0.0048)		(0.0052)
$PV \times April$		0.0025		0.0043
		(0.0054)		(0.0044)
$PV \times May$		-0.0030		0.0029
		(0.0036)		(0.0039)
$PV \times June$		0.0030		-0.0021
		(0.0041)		(0.0043)
Intercept	-1.876***	-1.651***	-2.041***	-1.759***
	(0.0679)	(0.0944)	(0.0996)	(0.0931)
Observations	104	104	104	104
R^2	0.629	0.721	0.680	0.765

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ for one-tailed test.
Standard errors reported in parentheses

Source: original calculation using data from USDA *WASDE* reports, Barchart.com, Federal Reserve Bank at St. Louis, and USDA CCC

Table 1.4: Estimated Supply of Storage, Conventional Storage Cost-Adjusted Futures Price Spread vs. Two Option Components of Expected Net Storage Return, Pooled OLS Regressions of U.S. Corn and Soybeans, April, May, June, and July *World Agricultural Supply and Demand Estimates* (*WASDE*) Release Dates, 1989-2014 Crop Years

Chapter 2: Reexamining the Crowding Out of Private Stocks by Public Stocks

2.1 Introduction

Similar to past price run-ups, the increase in farm commodity prices since 2006 has sparked increased interest in the issue of public stocks. Several recent studies of optimal (or strategic) food reserve policy have been conducted (Murphy, 2009; von Braun and Torero, 2009; von Braun, Lin, and Torero, 2009; Mckee, 2012; Rashid and Lemma, 2011; Actionaid International, 2011; Gouel and Jean, 2012; Gouel, 2013; and Romero-Aguilar and Miranda, 2014). Moreover, a survey of 71 less developed countries by the United Nations Food and Agriculture Organization (Demeke et al., 2014) found that during the 2007-12 calendar years approximately 70 percent of the surveyed countries had a national food reserve system and that the size of public food stocks had expanded in many Asian and African countries[14].

[14]Considerable discussion also has occurred regarding the market implications of China's large public stocks of cotton (for example, Meyer and MacDonald, 2014; and Adams, Boyd, and Huffman, 2015).

None of the studies cited in the previous paragraph considered the crowding out[15] of private stocks by public stocks. The greater this crowding out, the less public stocks augment private stocks and thus reduce the occurrence of high prices. Crowding out of private by public stocks was investigated primarily in the late 1970s and early 1980s (Peck, 1977-78; Gardner, 1981; Just, 1981; and Sharples and Holland, 1981). However, the magnitude of crowding out differs widely among these studies, even for the same commodity and public storage program.

To explore why existing estimates vary so much, a conceptual model utilizing a call option associated with the release of public stocks is developed. It suggests omitted variables may explain the wide variation in existing estimates. In particular, crowding out is found to decrease as public stocks increase, in contrast to a constant marginal crowding out reported by previous studies. In addition, crowding out is a function of the slope parameter of a commodity's demand function and thus price elasticity of the demand function, implying crowding out can vary by commodity. These and other contributions of the conceptual model are confirmed in an empirical analysis of private and public stocks of U.S. corn, soybeans, and wheat carried out of the 1952 through 1971 crop years, a period of extensive U.S. public stocks held under a consistent policy design and with a measure of the private market incentive to carry stocks.

[15] Crowding out of private market activity by public policy has long been of interest to economists. Recent studies include the crowding out of farm bank loans by government subsidies (Ciaian, Pokrivcak, and Szegenyova, 2012), of private risk management tools by government-sponsored margin insurance (Wolf, Bozic, Newton, and Thraen, 2013), and of commercial supply of fertilizer by government supplied fertilizer (Ricker-Gilbert, Jayne, and Chirwa, 2011; and Mason and Jayne, 2013).

Studies of the crowding out of private stocks by public stocks are reviewed in the next section. The conceptual model is then presented, followed by the empirical analysis. The paper closes with a summary, conclusions, and implications section.

2.2 Studies of the Crowding out of Private Stocks by Public Stocks

Peck (1977-78) was the first to empirically estimate the crowding out of private stocks of agricultural commodities. Each bushel of wheat owned by the U.S. Department of Agriculture (USDA), Commodity Credit Corporation (CCC) was found to crowd out 0.12 bushel of private wheat stocks over the 1950-74 period. Using a somewhat longer 1950-1978 period, Gardner (1981), in a report to Congress for the U.S. General Accounting Office (GAO), found a statistically significant crowding out effect of 0.42 for CCC wheat but a crowding out for CCC corn that was not significantly different from zero at the 10 percent test level. In a companion report, Just (1981), using quarterly data from 1969 through the second quarter of 1978, found a crowding out effect for CCC wheat that did not differ from zero at the 10 percent test level.

Gardner and Just also examined the crowding out of private stocks by Farmer-Owned Reserve[16] (FOR) grain. Gardner found a statistically significant crowding out effect of 0.61 for FOR corn at the 10 percent test level. In contrast, Just found the crowding out effect of FOR corn did not differ significantly from zero at the 10 percent level. For FOR wheat, Gardner found a crowding out effect that did not differ from one at the 10 percent level; Just found it to be 0.81 and significant at the 1 percent

[16]The Farmer-Owned Reserve (FOR) was authorized in the 1976 farm bill. Under FOR, U.S. farmers had the option to receive a public storage subsidy for storing grain they had placed in the nonrecourse loan program. FOR grain could be stored for up to an additional 3 crop years. The grain could not be sold until market price exceeded a pre-specified release price.

level. In contrast, Sharples and Holland (1981) found a 0.14 crowding out effect for FOR wheat using data from the 1972-1978 crop years.

Thus, widely varying estimates of the crowding out of private by public stocks was found in these studies, even for the same commodity and type of public stock program. Moreover, in a study of public stock policy using a stylized model that included private storage, Wright and Williams (1991) found crowding out ranged from 36 to 56 percent, depending on the type of public storage program and and whether or not price controls distorted transportation.

2.3 Model of the Crowding Out of Private Stocks by Public Stocks

The investigations discussed in the previous section did not develop a conceptual model of the crowding out of private by public stocks. Such a model is developed using the concept of options and given that the public stock policy has an operational rule to release public stocks when market price exceeds a public stock release price that is known by the private market. Options are used because the release of public stocks introduces a discontinuity in the private market's price discovery process. Specifically, public stocks augment private market supply only when market price exceeds the public stock release price. This discontinuity can be modeled as follows:

$$C_{t,t+n} = \int_{P_{release}}^{\infty} (P - P_{release}) f_{P_{t,t+n}}(P; \mu, \sigma) dP \tag{2.1}$$

where $C_{t,t+n}$ = value of a call option written at time t for expiration date, $t+n$, with a strike price of $P_{release}$, the public stock release price, $P_{t,t+n}$ = unknown price at time $t+n$ as of time t with a probability distribution function, $f_{P_{t,t+n}}(\cdot; \mu, \sigma)$, which is conventionally assumed to be log-normally distributed, and μ and σ are the location and scale parameter of the distribution function of $P_{t,t+n}$. Value of this call option is the incentive, based on information the market knows at time t, to carry private stocks from time t to $t+n$ to sell at prices higher than $P_{release}$ at time $t+n$.

If public stocks exist and if the market at time t expects price to exceed the public stock release price at time $t+n$ with a non-zero probability, the market must rationally expect the release of public stocks at time $t+n$ with the same non-zero probability equal to $1 - F_{P_{t,t+n}}(P_{release}; \mu, \sigma)$, where $F_{P_{t,t+n}}(P_{release}; \mu, \sigma) < 1$. The resulting expected increase in market supply will cause the market to reduce its expectation that price at time $t+n$ will exceed $P_{release}$, reducing the value of the call option and hence the incentive to carry private stocks to sell at prices greater than $P_{release}$. Crowding out thus begins once the market assigns a positive probability to the release of public stocks. This usually will occur before public stocks are released.

The preceding discussion implies the following extension. If the market expects $F_{P_{t,t+n}}(P_{release}; \mu, \sigma) = 1$, where $F_{P_{t,t+n}}(\cdot; \mu, \sigma)$ is the cumulative distribution function of $P_{t,t+n}$, the call option has no value since the market at time t does not expect price at time $t+n$ to exceed $P_{release}$. Hence, when the market does not expect public stocks to be released, public stocks accumulated for release at a public stock release price will not crowd out private stocks.

Because public stocks are released via a government program and not a response of private firms to a higher price, it can be conceptualized as a rightward shift of a supply curve along a stationary demand curve. Thus, to examine the impact of an expected release of public stocks on private stocks, assume the following inverse demand function:

$$P = (\alpha/\beta) - (1/\beta)Q + (\epsilon/\beta) \tag{2.2}$$

where P is price, Q is quantity of demand, α and β are the intercept and slope of the demand function, and ϵ is a random variable with mean, 0, and variance, σ^2. The inverse demand function $P(\cdot) : [0, \infty) \longrightarrow [0, \infty)$ is, without loss of generality, assumed to be differentiable, and negatively sloped throughout, implying each price-quantity combination is unique. Having $Q_{t,t+n}$ and $Q_{release}$ defined as the quantity of demand associated with $P_{t,t+n}$ and $P_{release}$, the call option in equation (2.1) is transformed with respect to quantities:

$$C_{t,t+n} = \int_0^{Q_{release}} (\frac{1}{\beta^2})(Q_{release} - Q) f_{Q_{t,t+n}}(Q; \mu_1, \sigma) dQ \tag{2.3}$$

Whereas the call option of equation (2.1) has value when price is greater than $P_{release}$, the call option of equation (2.3) has value when the quantity of private market demand is less than the quantity of private market demand associated with $P_{release}$. The derivation of equation (2.3) and several equations that follow are described in the appendix.

Assuming public stocks are managed so their release does not drive market price below $P_{release}$, release of public stocks of size G adds G to private market supply Q, impacting the value of the call option in equation (2.4) as follows:

$$C_{t,t+n} = \int_0^{Q_{release-G}} (\frac{1}{\beta^2})[Q_{release} - (Q + G)] f_{Q_{t,t+n}}(Q; \mu_1, \sigma) dQ \tag{2.4}$$

Using the *Leibniz integration rule*, the first derivative of equation (2.4) with respect to G is:

$$\frac{\partial C_{t,t+n}}{\partial G} = -\frac{1}{\beta^2} \int_0^{Q_{release-G}} f_{Q_{t,t+n}}(Q; \mu_1, \sigma) dQ < 0 \tag{2.5}$$

The value of this call is lower the higher are public stocks, assuming the release of public stocks is anticipated. More public stocks reduce the probability that demand will be less than the demand associated with $P_{release}$ as well as the size of this demand shortfall, *i.e.*, $Q_{release} - Q$. As the call declines in value, incentive to carry private stocks to sell at prices above $P_{release}$ declines. In short, private stocks are crowded out as public stocks reduce the potential to profit from price increases. Equation (2.5) adds new insights to this observation investigated by previous studies. *Ceteris paribus*, the marginal crowding out effect is inversely related to the slope parameter of the demand function. Thus, crowding out can vary by commodity. Second, *ceteris paribus*, the marginal crowding out effect is positively related to the probability that market demand is less than demand at the public stock release price (*i.e.*, probability market price exceeds $P_{release}$). Thus, crowding out increases as market price approaches $P_{release}$.

Using the *Leibniz integration rule* to take the derivative of equation (2.5) with respect to G (*i.e.*, the second derivative of equation (2.4) with respect to G) adds other insights as follows:

$$\frac{\partial^2 C_{t,t+n}}{\partial G^2} = (\frac{1}{\beta^2}) f_{Q_{t,t+n}}(Q_{release} - G; \mu_1, \sigma) > 0 \tag{2.6}$$

Ceteris paribus, the rate at which public stocks crowd out private stocks decreases as public stocks increase. The rate of decrease is a function of the probability distribution and slope parameter of the demand function. Thus, the marginal crowding out of private stocks by public stocks is not constant as reported by previous empirical studies. Last, if public stocks are large enough to cover all demand shortfalls at $P_{release}$, the call option has no value. Thus, marginal crowding out is zero, implying that adding one unit to public stocks also increases total stocks by one unit.

To summarize the conceptual model, crowding out of private stocks by public stocks accumulated for release at a public stock release price begins when the market assigns a positive probability to the release of public stocks, not when public stocks are released. Crowding out is highest for the first unit of public stock, then declines with each additional unit. Crowding out reaches zero when public stocks are large enough to cover all shortfalls the market expects in demand at the public stock release price. Last, the size of crowding out depends on how close expected market price is to the public stock release price and can vary by commodity.

2.4 Empirical Analysis

2.4.1 Selection of Observation Period and Crops

The conceptual model of the crowding out of private by public stocks is examined empirically using U.S. stocks carried out of the 1952 through 1971 crop years for the staple commodities of corn, soybeans, and wheat. An extensive effort was made to find a more contemporary data set but all recent data sets are deficient in one or more of the data parameters needed to conduct an appropriate empirical analysis. Most commonly, a measure of the private market incentive to carry stocks is not available. The private market incentive requires information on future expected prices, preferably determined by the market. This measure was first proposed by Working (1948 and 1949), who specifically proposed the use of nearby and more distant market-traded futures contract prices to measure the price spread or expected change in price at a given point in time. Working's proposed measure has been widely used to examine private stockholding behavior. In addition, an analysis period is needed over which the design of the public stocks program was consistent. As noted above, Wright and William (1993) found that different public stock policies had different impacts on private storage. Also, for statistical estimation reasons, a period is needed when public stocks varied widely from relative small to relatively large levels and prices were stationary from a time series perspective. Kenyon, Jones, and McGuirk (1993) demonstrated the importance of this statistical attribute in the context of assessing the forecasting performance of futures prices.

The observation period and crops examined in this empirical analysis satisfies all of the above attributes. The incentive to store private stocks can be measured as the spread between futures contracts traded for corn, soybeans, and wheat on the Chicago Board of Trade and Kansas City Board of Trade during this period. U.S. public stocks program had a consistent design during the observation period centered on the acquisition and release of public stocks by CCC as part of U.S. public policy to support farm income. In addition, the release of public stocks was based on a release price announced by CCC and thus consistent with the conceptual model. Public stocks varied widely and existed in all years for corn and wheat and all but 3 years for soybeans (see descriptive statistics in Tables 2.1-2.3). Last, all variables used this in analysis were found to be stationary by panel unit root tests such as Im, Pesaran, and Shin (2003) and Fisher-type (Choi, 2001) at the 10 (mostly 5) percent test level.

The initial observation crop year of 1952 was determined by the removal in early 1953 of price controls imposed on farm commodities during the Korean War (U.S. General Services Administration). Thus, price controls, which negatively impact private stocks (Wright and William, 1993), ended before the 1952[17] crop year ended. The last observation crop year of 1971 was determined by the increase in level and volatility of crop prices that began during the 1972 crop year as a result of several factors,

[17] As a sensitivity test regarding the decision to start the analysis period with the 1952 crop year instead of the 1953 crop year, an analysis was conducted starting with the 1953 crop year. The findings of the empirical analysis were not affected.

including the Russian grain deal, general price inflation, and production difficulties in several countries including the U.S. (Kenyon, Jones, and McGuirk, 1993).

2.4.2 Data and Variable Measurement

Carryout stocks were chosen for several reasons. They are closely tracked by market participants as a measure of supply-demand balance. USDA surveys stocks on farms and at commercial storage facilities four times a year, including the end of the crop year. These surveys are the most comprehensive accounting of U.S. stocks of these crops. Using carryout stocks avoids both statistical problems associated with overlapping samples and potential seasonality effects associated with harvest since they are annual data. Last, carryout stocks have been examined by previous empirical studies of the crowding out of private stocks (Peck, 1977-78; Gardner, 1981; and Sharples and Holland, 1981) and, starting with Working (February 1934), have often been used in academic studies of stock holding.

Carryout stocks are measured as a stocks-use ratio. This ratio is commonly used because, *ceteris paribus*, stocks need to increase as use increases since stocks allow an annual harvest to satisfy continuous consumption (Routledge, Seppi, and Spatt, 2000). Use is commonly measured as annual disappearance, but in this study use is measured as the annualized difference between stocks reported in USDA's last two surveys of stocks for a crop year. This difference is more contemporary with the demand being placed on stocks at the end of a crop year. Stocks carried out of a crop year are surveyed as of the first day of the new crop year. Over the analysis period, the new crop year started on October 1 for corn, July 1 for wheat, and October 1 for soybeans for crop years prior to 1965 and September 1 thereafter. The prior survey of stocks was as of July 1 for corn and soybeans and April 1 for wheat. The disappearance between the two surveys is annualized in keeping with the common use of annual disappearance.

A stocks-use ratio is calculated for both CCC public stocks and private stocks. The latter is the difference between total carryout stocks and CCC stocks. CCC carryout stocks-use averaged 22 percent, 4 percent, and 64 percent of annualized disappearance for U.S. corn, soybeans, and wheat, respectively, over the analysis period (see Table 2.1-2.3). Private carryout stocks-use averaged 20 percent, 6 percent, and 20 percent for corn, soybeans and wheat, respectively. CCC stocks-use ranged, with the crop year in parentheses, from 3 percent (1970) to 44 percent (1957) for corn, 0 percent (1960, 1965, and 1971) to 22 percent (1968) for soybeans, and 9 percent (1967) to 121 percent (1959) for wheat. Private stocks-use ranged from 14 percent (1958) to 29 percent (1953) for corn, 1 percent (1953) to 20 percent (1968) for soybeans, and 5 percent (1957) to 56 percent (1968) for wheat. The data on stocks is from USDA's *Agricultural Statistics*.

The private incentive to store carryout stocks is measured as the storage cost-adjusted spread between prices of the futures contracts expiring latest in the old crop year and earliest in the upcoming new crop year. Specifically,

$$SPREAD_{t,t+n,T} = \ln\left(FP_{t+n,T+1}\right) - \ln\left(FP_{t,T} + \{USTB_T \times FP_{t,T} \times \lambda\} + \{PSC_T \times \lambda\}\right) \tag{2.7}$$

where $FP_{t+n,T+1}$ is futures price for delivery month $t+n$ in new crop year $T+1$, $FP_{t,T}$ is futures price for delivery month t in old crop year T, $USTB_T$ is 3-month U.S.

Treasury Bill rate[18] expressed as an annual rate, PSC_T is annual physical storage charge paid by CCC for publicly stored grain in crop year T, and λ is the proportion of a year between t and $t+n$. Delivery month t is September for corn and soybeans and May for wheat. Delivery month $t+n$ is December for corn, November for soybeans, and July for wheat. Accordingly, λ is 1/4 for corn and 1/6 for soybeans and wheat. A log transformed spread reflects the common assumption that futures prices as well as changes in futures prices follow a log normal distribution.

Futures prices are from annual reports of the Chicago Board of Trade (CBOT) for corn and soybeans and the Kansas City Board of Trade (KCBOT) for wheat. U.S. three month Treasury Bill rates are from the St. Louis Federal Reserve Bank while physical storage costs are from the *Federal Register* (U.S. General Services Administration). KCBOT trades hard red winter wheat[19], the largest class of wheat grown in the U.S. To avoid problems that can arise with using prices from a contract's delivery month, futures prices are collected as of August 15 for corn and soybeans and April 15 for wheat. Closing futures prices are used for corn and soybeans. However, KCBOT only reported low and high prices for trading days prior to the 1966 calendar year. To create consistent data for wheat, the average of low and high prices is used for all crop years[20].

[18]Among the available interest rates, the 3-month U.S. Treasury bill rate is chosen because it is closest in length to the old crop-new crop spreads being used in this analysis.

[19]Soft red winter and hard red spring are the wheat types primarily traded on the Chicago and Minneapolis exchanges, respectively.

[20]For the 1966-1971 crop years, closing price of the May and July KCBOT wheat futures contract was 100.0 percent and 100.1 percent, respectively, of the average of the day's low and high for the May and July futures contract. Thus, for these years, little difference existed between these two measures.

For all three crops, the log-transformed spread was always negative as the old crop nearby futures price plus storage cost exceeded the new crop distant futures price (see Table 2.1-2.3). The spread was closest to zero or full carry in the 1960 crop year for corn, 1958 crop year for soybeans, and 1961 crop year for wheat.

The conceptual model reveals that the crowding out of private stocks is a function of the relationship between the market price expected at time $t+n$ and the public stock release price. The price at which private market agents could buy CCC grain during the upcoming month was posted in the CCC monthly sales list released at the end of a month. The release price was usually reported as a markup of the loan rate. A release price could not always be located. Thus, to create a consistent variable across the three crops the U.S. loan rate[21] was used to proxy the price at which CCC stocks were available to the private market. Based upon the markups found for corn in the U.S. and wheat at Kansas City, the U.S. loan rate appears to be a reasonable proxy as it is highly correlated with the CCC sales price: +0.96 for corn and +0.99 for wheat. Thus, the relationship between the market price expected at time $t+n$ and the public stock release price ($PRATIO_{t,t+n,T}$) is calculated as:

$$PRATIO_{t,t+n,T} = \frac{FP_{t+n,T+1}}{NLR_{t,T}} \tag{2.8}$$

where $FP_{t+n,T+1}$ is new crop futures price expected at time t and $NLR_{t,T}$ is the U.S. loan rate for crop year T. U.S. loan rates are from USDA's *Agricultural Statistics*.

[21]The grade quality specified as par for the loan rate was changed for both corn and soybeans over the analysis period. To generate loan rates at the same grade quality, the U.S. corn loan rate for the 1952-1966 crop years was increased 1 cent per bushel to reflect the shift from a grade 3 to a grade 2 par value in the 1967 crop year. The U.S. soybean loan rate was increased 5 cents per bushel for the 1952-1968 crop years to reflect the shift from a grade 2 to grade 1 par value in the 1969 crop year. The adjustments are from the CCC schedule of discounts and premiums (U.S. General Services Administration).

2.4.3 Estimation Framework

Given the conceptual model and variable specifications, this equation is estimated:

$$\begin{aligned} PRI_{i,T} &= \alpha + \beta PUB_{i,T} + \gamma PUB_{i,T}^2 + \delta SPREAD_{i,T} + \theta PRATIO_{i,T} \\ &+ \omega CYS_{i,T} + \eta_c + \eta_s + \phi_c PUB_{i,T} \times CORN_i + \phi_s PUB_{i,T} \times SOY_i + \varepsilon_{i,T} \end{aligned} \tag{2.9}$$

where i = U.S. corn, soybeans, and wheat, T = 1952, 1953, $\cdots$, 1971 crop year, PRI is the ratio of private carryout stocks to annualized disappearance, PUB is the ratio of CCC carryout stocks to annualized disappearance, $SPREAD$ and $PRATIO$ are defined as above, $CORN$ and SOY are dummy variables for corn and soybeans, CYS is a dummy variable that bisects the analysis period at the 1965 crop year due to the change in the soybean crop year, (α, β, γ, δ, θ, ω, η_c, η_s, ϕ_c, ϕ_s) are parameters to estimate among which η_c and η_s are coefficients that represent crop-specific intercepts, and ε is an idiosyncratic disturbance with its $iT \times iT$ variance-covariance matrix denoted by Ω with its typical element of $E\left(\varepsilon_{iT}\varepsilon_{jS}\right)$.

The pooled time-series-cross-section (PTSCS) method[22] is used because number of observations is relatively small (20 per crop) and because it can incorporate crop-specific heterogeneity (fixed effect). Crop-specific intercepts are added to capture crop-specific unobserved heterogeneity. Crop-specific slopes are used to examine, if as the conceptual model suggests, crowding out of private stocks by public stocks

[22]An alternative method is Seemingly Unrelated Regression (SUR), but PTSCS is chosen for 3 reasons: (1) correlation among residuals of the separate equations for corn, soybeans, and wheat is small (0.18 on average over all pairs of crops) and statistically insignificant (p-value of Breusch-Pagan test = 0.48); thus, the efficiency gain from using SUR is minimal but the reduction in degrees of freedom is nontrivial; (2) variables for the cross sections are not highly correlated (0.36 on average), implying biased estimators, a potential risk of using PTSCS, is unlikely; and (3) SUR cannot incorporate crop-specific heterogeneity (fixed effects).

varies by crop. To concentrate on examining the conceptual model, the study assumes that the slope coefficient of the other variables is homogeneous[23] across crops.

As discussed above, all variables in equation (2.9) are confirmed to be stationary by panel unit root tests such as Im, Pesaran, and Shin (2003) and Fisher-type (Choi, 2001) at the 10 (mostly 5) percent test level. However, the variance-covariance matrix of error terms, Ω with its typical element of $E(\varepsilon_{iT}\varepsilon_{jS})$, may still violate the Gauss-Markov assumptions due to serial correlation within a cross section ($E(\varepsilon_{iT}\varepsilon_{iS}) \neq 0$ for a given i and for $T \neq S$), contemporaneous correlation between cross sections ($E(\varepsilon_{iT}\varepsilon_{jT}) \neq 0$ for a given T and for $i \neq j$), and/or panel heteroskedasticity of error terms ($E(\varepsilon_{iT}\varepsilon_{iT}) \neq E(\varepsilon_{jT}\varepsilon_{jT})$ for a given T and for $i \neq j$). The traditional remedy, the Parks-Kmenta estimation method (Parks, 1967; and Kmenta 1986), is used to produce consistent and efficient estimates by utilizing the Feasible Generalized Least Squares (FGLS) technique.

The analysis focuses on the crowding out of private stocks when existing public stocks are released. Accumulation of public stocks may also crowd out private stocks. During the analysis period, CCC corn, soybean, and wheat stocks largely were accumulated via a nonrecourse loan program, with a small amount accumulated

[23] Also of empirical interest is whether the PUB^2 coefficient is heterogeneous by crop. Serious multicollinearity was detected when crop-specific effects were estimated for PUB and PUB^2 terms in our pooled regression model (average variance inflation factor = 22.49). Moreover, R^2 increased minimally (less than 0.01, from OLS estimations) when crop-specific coefficients on PUB^2 were added to the regression equation. Serious multicollinearity substantively inflates standard errors of estimates especially if the sample is small, as in this study. In contrast, no serious multicollinearity was detected when crop-specific effects were estimated only for PUB (average variance inflation factor = 13.91) while R^2 increased from 0.73 to 0.78 when the crop specific coefficients on PUB were added. The authors concluded investigation of crop-specific coefficients on PUB^2 is beyond the capability of the data.

via purchase agreements[24] (U.S. General Services Administration). Under the nonrecourse loan program, an eligible farmer could obtain a loan until a specified date, using the crop placed under loan as collateral. By a latter specified maturity date, the farmer had to decide whether to repay the loan, keep the loan and deliver the grain used as collateral to CCC[25], or, if available, place the grain in an extended loan (reseal) program[26]. The loan maturity date for corn was July 31 for all crop years, for soybeans May 31 for 1952-1963, July 31 for 1963-1968, and June 30 thereafter; and for wheat March 31 for 1952-1965 and April 30 thereafter. Thus, except for wheat during the 1966-1971 crop years, the accumulation period for public stocks had ended by the date on which the crowding out effect was estimated. While the number of years is small, a statistical analysis found no evidence that the crowding out effect differed for wheat during 1966-1971. Therefore, potential impact of accumulation on the crowding out of private stocks was not pursed further in this study.

Wright and Williams demonstrate in their analysis of public storage policy that the location of public stocks impacts the crowding out of private stocks. Wright and

[24]Relatively few public stocks were acquired via purchase agreements, especially after the early 1960s (USDA, CCC, August 1979). Purchase agreements accounted for at most 18 percent of corn (1954) and eight percent of wheat (1955 and 1957) delivered to CCC. No data could be found for soybeans but indications are that no more than roughly 1 percent were acquired via purchase agreements.

[25]The name, nonrecourse loan, reflects that CCC had no recourse but to accept the grain used as collateral if the farmer decided to keep the loan.

[26]Any carryout stocks that were loan reseal grain were included in private stocks in this analysis. Reseal carryout grain could have been harvested in the recently completed crop year or in prior crop years. Farmers could reacquire loan reseal grain by repaying the original loan minus physical storage charges deducted by CCC plus interest accumulated since the loan was made (U.S. General Services Administration). In most situations during the analysis period, reseal grain could be acquired at lower prices than CCC stocks and thus would be part of private stocks when CCC stocks were released. While not the usual situation, the reseal repayment rate could exceed the CCC sales price if the loan rate had been reduced enough since the year in which the reseal grain was harvested. A sensitivity test was conducted for wheat in which private stocks were reduced and public stocks increased by any reseal wheat for which the reseal loan repayment rate exceeded the CCC sales price. Statistical significance and signs of the independent variables did not change.

Williams (1991, page 444-445) note that the location of public stocks is less important when transportation is costly but undistorted by price ceilings. This situation characterized the analysis period. However, we do not have information on the location of public stocks of corn, soybeans, and wheat[27]. This missing variable may impact our estimates and thus should be kept in mind when assessing our empirical results.

2.5 Results

Table 2.4 contains Ordinary Least Squares (OLS) and FGLS estimates for two crowding out models. One model is composed of the independent variables used in previous analyses. The second model adds two variables suggested by the conceptual model, public stocks squared and the ratio of the new crop futures price to the U.S. loan rate. OLS estimates are reported to allow R^2 to be used to assess if adding the new variables suggested by the conceptual model improves the empirical model's performance as well as to allow indirect assessment of the three potential threats that arise when the Gauss-Markov assumptions are violated.

Based on the coefficients estimated when neither the squared public stocks term nor the ratio of expected market price to U.S. loan rate is in the model, the crowding out of private stocks by public stocks is estimated to be -0.08, $+0.21$, and -0.21 for U.S. corn, soybeans, and wheat, respectively (see FGLS I, column 3, Table 2.4). These crowding out effects, which are statistically different from zero at the 10 percent test level, are small in magnitude and the sign for soybeans is unexpected.

[27]It seems reasonable that the location of public stocks would have its greatest impact on crowding out the smaller are public stocks. As discussed in the text, the average ratio of public stocks-use was 22 percent for corn, 4 percent for soybeans, and 64 percent for wheat. Thus, location considerations are likely to have the largest impact on the crowding out of soybean private stocks.

Adding the two variables as suggested by the conceptual model dramatically changes the estimated crowding out effects. The coefficients for public stocks and public stocks squared have their expected negative and positive signs and are statistically significant at the 1 percent test level (see FGLS II, column 4, Table 2.4). Thus, *ceteris paribus*, as public stocks increase, private stocks are crowded out at a declining rate. R^2 in the OLS estimation increases by 0.10. The resulting 30 percent reduction in unexplained variation is consistent with an empirical model that is more completely identified. Since previous empirical studies did not include PUB^2 or $PRATIO$, an omitted variable bias may exist regarding their estimates of the crowding out effect.

The marginal crowding out effects by crop are:

$$\left.\frac{\partial\left(PRI\right)}{\partial\left(PUB\right)}\right|_{\text{corn}} = \left(\hat{\beta} + \hat{\phi}_c\right) + 2\hat{\gamma} \times PUB|_{\text{corn}} = -0.49 + \left(1.09 \times PUB|_{\text{corn}}\right)$$

$$\left.\frac{\partial\left(PRI\right)}{\partial\left(PUB\right)}\right|_{\text{soybeans}} = \left(\hat{\beta} + \hat{\phi}_s\right) + 2\hat{\gamma} \times PUB|_{\text{soybeans}} = -0.16 + \left(1.09 \times PUB|_{\text{soybeans}}\right)$$

$$\left.\frac{\partial\left(PRI\right)}{\partial\left(PUB\right)}\right|_{\text{wheat}} = \hat{\beta} + 2\hat{\gamma} \times PUB|_{\text{wheat}} = -0.97 + \left(1.09 \times PUB|_{\text{wheat}}\right) \tag{2.10}$$

The first unit of CCC stocks for wheat had a crowding out effect of -0.97, which does not differ significantly from -1 at the 1 percent test level. Crowding out effects of the first unit of CCC stocks of corn (-0.49) and soybeans (-0.16) are significantly lower than for wheat at the 1 percent test level. The initial crowding out effect for soybeans is significantly lower than for corn at the 1 percent level. The initial crowding out effect differs significantly from zero at the 1 percent level for corn and wheat, and at the 10 percent test level for soybeans.

The statistically different crowding out effects by crop is consistent with the first derivative of private stocks with respect to public stocks in the conceptual model being dependent on the slope parameter of the demand equation, with a factor of $1/\beta^2$. This factor implies a higher absolute value of the slope parameter of the demand function is associated with less crowding out. Since the slope and elasticity of a demand function are related, this relationship further implies that, *ceteris paribus*, crowding out of private by public stocks is higher the more inelastic is demand.

A review of the literature did not find an estimate of the elasticity of demand for the 3 crops during the analysis period. However, a 2013 article by Roberts and Schlenker used data from 1961 through 2010 to estimate world demand elasticities[28] in order to assess the U.S. ethanol mandate. Their estimated demand elasticity for wheat (-0.109) was more inelastic than for corn (-0.244) than for soybeans (-0.329). These demand elasticities are consistent with the empirical findings of this analysis and the implications of the conceptual model.

The estimated coefficient of $PRATIO$ has its expected sign from the conceptual model, negative, and is statistically significant at the 1 percent test level. Thus, *ceteris paribus*, the crowding out of private stocks increases as market price approaches the public stock release price.

The statistically significant (1 percent test level) positive coefficient for $SPREAD$ is consistent with the expectation that private storage agents will carry more stocks as expected net return to storage increases. Also as expected, the dummy variable for change in soybean crop year is positive and statistically significant (1 percent

[28]Roberts and Schlenker estimated a 4×4 system of equations for corn, rice, soybeans, and wheat since interdependencies are likely among the demand for these crops.

test level). More old crop carryout stocks should be needed on September 1 than on October 1 to meet demand before the new crop harvest begins.

All standard errors of the coefficients in the FGLS II column are lower than in the OLS II column, with the difference being as high as 50 percent (see Table 2.4). This finding confirms that concerns over serial correlation, cross-sectional correlation, and panel heteroskedasticity deserve consideration and thus that FGLS is preferred over OLS.

Several sensitivity checks were conducted to assess robustness of the empirical findings. They were 1) using futures prices for the last trading day of the month proceeding delivery month of the old crop futures contract (see Table 2.5 for a representative robustness check), 2) using either annual disappearance or production, not annualized disappearance, for the crop year to calculate carryout stock-to-use ratios, 3) using bootstrapped standard errors to assess statistical significance of the variables, 4) using the Beck and Katz method[29] (Beck and Katz, 1995; Beck, 2001) to estimate equation (2.9), and 5) measuring the futures price spread in cents per bushel and measuring the ratio of new crop futures price to U.S. loan rate as a log-transformed variable. These sensitivity checks consistently supported the estimation results reported in Table 2.4.

2.6 Summary, Conclusions, and Implications

This study reexamines the crowding out of private stocks given the renewed interest in public stocks and the potential importance of the crowding out effect given the wide variation in existing estimates of its magnitude. A conceptual model utilizing

[29]The Beck and Katz method retains the OLS coefficients but replaces the OLS standard errors with panel-corrected standard errors.

options is developed, then empirically tested against data for carryout stocks of U.S. corn, soybeans, and wheat during the 1952-1971 crop years.

The empirical results are consistent with the conceptual model. The marginal crowding out of private stocks by public stocks accumulated for release at a public stock release price declines with each addition to public stocks. Thus, crowding out of private stocks is highest for the first unit of public stocks accumulated. Crowding out varies by crop, with the conceptual model implying it should be higher for commodities with the most inelastic demand, *ceteris paribus.* These commodities include the staple crops of rice and wheat, which countries often hold as public stocks. Crowding out also depends on the relationship between the expected market price and public stock release price. This finding is consistent with two implications of the conceptual model: (1) crowding out begins not when public stocks are released but when the market assigns a positive probability to their release and (2) crowding out increases as the market price approaches the public stock release price. Previous studies did not include this variable nor estimate a non-constant crowding out effect, suggesting omitted variable bias may explain the wide variation in existing estimates of private stock crowding out even for the same crop.

The findings of this study suggest crowding out of private stocks is substantial, at least until a non-trivial level of public stocks is reached. The crowding out cost is especially large for staple crops because of their inelastic demand. For example, in this study, the first unit of wheat public stocks crowded out one unit of private stocks, implying the first unit of wheat public stocks did not increase total stocks. The finding of sizable crowding out cost is consistent with the eventual decision of the U.S. to eliminate most public stock programs in the *Federal Agriculture Improvement* *and Reform Act of 1996* (USDA, Economic Research Service, September 1996) and raises the possibility that less developed countries with public stock programs today may eventually repeat the U.S. decision.

Variable	Unit	Obs.	Mean	S.D.	Min.	Max.
CCC Stocks	million bu.	20	608	423	97	1327
Private Stocks	million bu.	20	620	192	347	987
Annualized Consumption	million bu.	20	3088	720	1949	4189
Private Carryout Stocks-Use Ratio	%	20	20.06	4.10	13.98	29.09
Public Carryout Stocks-Use Ratio	%	20	21.91	15.92	2.68	44.27
CBOT Sep. Futures[A]	$/bu.	20	1.28	0.15	1.06	1.63
CBOT Dec. Futures	$/bu.	20	1.24	0.14	1.04	1.54
Log(Storage Cost-Adjusted Spread)	$/bu.	20	-0.07	0.03	-0.12	0.00
U.S. Loan Rate	$/bu.	20	1.24	0.23	1.03	1.62
Ratio[B] of Dec. Futures to Loan Rate	%	20	101.90	18.05	76.23	140.68
U.S. 3-month T-Bill Rate	%	20	3.55	1.58	0.93	6.85
Physical Storage Cost[C]	¢/bu.	20	3.66	0.34	3.38	4.13

Note: A. Futures prices are quoted as of August 15.
B. This ratio represents the relationship between the expected market price and the public stock release price.
C. Unit for physical storage cost is cents per bushel per 3 months.

Source: Original calculation using data from *Agricultural Statistics* of U.S. Department of Agriculture, *Annual Report of the Board of Trade of the City of Chicago*, Federal Reserve Economic Data of Federal Reserve Bank at St. Louis, and the Commodity Credit Corporation.

Table 2.1: Descriptive Statistics, U.S. Corn, 1952-1971 Crop Years

Variable	Unit	Obs.	Mean	S.D.	Min.	Max.
CCC Stocks	million bu.	20	25	49	0	171
Private Stocks	million bu.	20	40	47	1	155
Annualized Consumption	million bu.	20	694	305	278	1258
Private Carryout Stocks-Use Ratio	%	20	5.82	5.55	0.97	19.73
Public Carryout Stocks-Use Ratio	%	20	3.85	6.05	0.00	21.75
CBOT Sep. Futures[A]	\$/bu.	20	2.61	0.40	2.11	3.46
CBOT Nov. Futures	\$/bu.	20	2.55	0.35	2.14	3.30
Log(Storage Cost-Adjusted Spread)	\$/bu.	20	-0.04	0.03	-0.12	-0.01
U.S. Loan Rate	\$/bu.	20	2.25	0.21	1.85	2.56
Ratio[B] of Nov. Futures to Loan Rate	%	20	111.17	16.39	91.97	145.96
U.S. 3-month T-Bill Rate	%	20	3.55	1.58	0.93	6.85
Physical Storage Cost[C]	¢/bu.	20	2.43	0.28	2.19	2.86

Note: A. Futures prices are quoted as of August 15.
B. This ratio represents the relationship between the expected market price and the public stock release price.
C. Unit for physical storage cost is cents per bushel per 2 months.

Source: Original calculation using data from *Agricultural Statistics* of U.S. Department of Agriculture, *Annual Report of the Board of Trade of the City of Chicago*, Federal Reserve Economic Data of Federal Reserve Bank at St. Louis, and the Commodity Credit Corporation.

Table 2.2: Descriptive Statistics, U.S. Soybeans, 1952-1971 Crop Years

Variable	Unit	Obs.	Mean	S.D.	Min.	Max.
CCC Stocks	million bu.	20	692	382	102	1243
Private Stocks	million bu.	20	231	181	46	654
Annualized Consumption	million bu.	20	1231	221	851	1577
Private Carryout Stocks-Use Ratio	%	20	19.53	14.35	4.8	55.84
Public Carryout Stocks-Use Ratio	%	20	63.67	38.58	8.54	120.71
KCBOT May Futures[A]	$/bu.	20	1.88	0.34	1.33	2.27
KCBOT July Futures	$/bu.	20	1.78	0.30	1.32	2.25
Log(Storage Cost-Adjusted Spread)	$/bu.	20	-0.07	0.06	-0.24	-0.01
U.S. Loan Rate	$/bu.	20	1.69	0.39	1.25	2.24
Ratio[B] of July Futures to Loan Rate	%	20	107.05	12.58	85.51	138.25
U.S. 3-month T-Bill Rate	%	20	3.41	1.48	1.03	6.38
Physical Storage Cost[C]	¢/bu.	20	2.37	0.20	2.19	2.67

Note: A. Futures prices are quoted as of April 15.
B. This ratio represents the relationship between the expected market price and the public stock release price.
C. Unit for physical storage cost is cents per bushel per 2 months.

Source: Original calculation using data from *Agricultural Statistics* of U.S. Department of Agriculture, *Annual Statistical Report of the Board of Trade of Kansas City*, Federal Reserve Economic Data of Federal Reserve Bank at St. Louis, and the Commodity Credit Corporation.

Table 2.3: Descriptive Statistics, U.S. Wheat, 1952-1971 Crop Years

	Private Stocks-Use Ratio (= *PRI*)			
Variable	OLS I	OLS II	FGLS I	FGLS II
Public Stocks-Use Ratio (= *PUB*)	-0.23*** (0.07)	-0.88*** (0.24)	-0.21*** (0.07)	-0.97*** (0.19)
PUB^2		0.49*** (0.16)		0.55*** (0.15)
ln(Storage-Cost-Adjusted Spread) (= *SPREAD*)	0.40* (0.24)	0.54*** (0.19)	0.30* (0.16)	0.41*** (0.13)
Ratio of Distant Futures Price to U.S. Loan Rate (= *PRATIO*)		-0.23*** (0.08)		-0.20*** (0.03)
Soybeans' Crop Year Dummy (= *CYS*)	0.08*** (0.02)	0.13*** (0.02)	0.09*** (0.02)	0.13*** (0.01)
Dummy for Corn (= *CORN*)	-0.13** (0.06)	-0.24*** (0.08)	-0.11** (0.05)	-0.26*** (0.05)
Dummy for Soybeans (= *SOY*)	-0.34*** (0.06)	-0.48*** (0.08)	-0.32*** (0.05)	-0.50*** (0.05)
$PUB \times CORN$	0.16* (0.09)	0.42** (0.17)	0.13 (0.09)	0.48*** (0.13)
$PUB \times SOY$	0.48** (0.24)	0.73*** (0.28)	0.42*** (0.13)	0.81*** (0.19)
Intercept	0.37*** (0.06)	0.77*** (0.14)	0.35*** (0.05)	0.76*** (0.07)
Number of Observations	60	60	60	60
R^2	0.68	0.78	n/a^A	n/a^A

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Standard errors reported in parentheses
A. R^2 is not appropriately defined in FGLS.
Source: original calculation using data from USDA *Agricultural Statistics*, CBOT *Annual Report*, KCBOT *Annual Statistical Report*, USDA CCC, and Federal Reserve Bank at St. Louis

Table 2.4: Estimated Crowding-out of Private Carryout Stocks by Public Carryout Stocks, U.S. Corn, Soybeans, and Wheat, 1952-1971 Crop Years, Annualized Consumption Used for Use, Futures Prices Quoted at the 15th Day

Variable	Private Stocks-Use Ratio (= *PRI*) OLS I	OLS II	FGLS I	FGLS II
Public Stocks-Use Ratio	-0.23***	-0.96***	-0.21***	-0.94***
(= *PUB*)	(0.07)	(0.23)	(0.07)	(0.19)
PUB^2		0.55***		0.52***
		(0.15)		(0.15)
ln(Storage-Cost-Adjusted Spread)	0.35	0.60***	0.33*	0.46***
(= *SPREAD*)	(0.31)	(0.22)	(0.19)	(0.15)
Ratio of Distant Futures Price		-0.27***		-0.21***
to U.S. Loan Rate (= *PRATIO*)		(0.09)		(0.04)
Soybeans' Crop Year Dummy	0.08***	0.13***	0.08***	0.13***
(= *CYS*)	(0.02)	(0.02)	(0.02)	(0.01)
Dummy for Corn (= *CORN*)	-0.12*	-0.25***	-0.11**	-0.25***
	(0.06)	(0.08)	(0.05)	(0.05)
Dummy for Soybeans (= *SOY*)	-0.34***	-0.50***	-0.32***	-0.49***
	(0.06)	(0.08)	(0.05)	(0.05)
$PUB \times CORN$	0.15*	0.45***	0.13	0.46***
	(0.09)	(0.16)	(0.09)	(0.13)
$PUB \times SOY$	0.49**	0.76***	0.42***	0.74***
	(0.24)	(0.26)	(0.13)	(0.19)
Intercept	0.37***	0.84***	0.35***	0.77***
	(0.06)	(0.14)	(0.05)	(0.07)
Number of Observations	60	60	60	60
R^2	0.67	0.79	n/a^A	n/a^A

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Standard errors reported in parentheses
A. R^2 is not appropriately defined in FGLS.
Source: original calculation using data from USDA *Agricultural Statistics*, CBOT *Annual Report*, KCBOT *Annual Statistical Report*, USDA CCC, and Federal Reserve Bank at St. Louis

Table 2.5: Estimated Crowding-out of Private Carryout Stocks by Public Carryout Stocks, U.S. Corn, Soybeans, and Wheat, 1952-1971 Crop Years, Annualized Consumption Used for Use, Futures Prices Quoted at the 30th Day

2.7 Addendum

2.7.1 Derivation of Equation (2.3)

Given the assumed inverse demand function in equation (2.2), the inverse demand function associated respectively with $P_{t,t+n}$ and $P_{release}$ is:

$$P_{t,t+n} = (\frac{\alpha}{\beta}) - (\frac{1}{\beta})Q_{t,t+n} + (\frac{\epsilon}{\beta}) \tag{2.11}$$

$$P_{release} = (\frac{\alpha}{\beta}) - (\frac{1}{\beta})Q_{release} + (\frac{\epsilon}{\beta}) \tag{2.12}$$

The probability distribution function of $P_{t,t+n}$ is transformed into the probability distribution function of $Q_{t,t+n}$ as follows:

$$f_{P_{t,t+n}}(P;\mu,\sigma) = f_{P_{t,t+n}}(\{(\frac{\alpha}{\beta}) - (\frac{1}{\beta})Q + (\frac{\epsilon}{\beta})\};\mu,\sigma) = f_{Q_{t,t+n}}(Q;\mu_1,\sigma) \tag{2.13}$$

where $\mu_1 = \mu + \ln(-1/\beta)$, and the support of $f_{Q_{t,t+n}}(Q;\mu_1,\sigma)$ is $Q \in [\frac{(\alpha+\epsilon)}{\beta}, \infty)$.

The differential of P in equation (2.2) is:

$$dP = -(\frac{1}{\beta})dQ \tag{2.14}$$

Substituting equations (B.1)-(B.4) into equation (2.1) provides:

$$\begin{aligned}
C_{t,t+n} &= \int_{P_{release}}^{\infty} (P - P_{release}) f_{P_{t,t+n}}(P;\mu,\sigma)dP \\
&= \int_{P_{release}}^{\infty} \{[\frac{\alpha}{\beta} - \frac{1}{\beta}Q + \frac{\epsilon}{\beta}] - [\frac{\alpha}{\beta} - \frac{1}{\beta}Q_{release} + \frac{\epsilon}{\beta}]\} f_{P_{t,t+n}}(P;\mu,\sigma)dP \\
&= \int_{P_{release}}^{\infty} \{[\frac{\alpha}{\beta} - \frac{1}{\beta}Q + \frac{\epsilon}{\beta}] - [\frac{\alpha}{\beta} - \frac{1}{\beta}Q_{release} + \frac{\epsilon}{\beta}]\} f_{Q_{t,t+n}}(Q;\mu_1,\sigma)dP \\
&= \int_{P_{release}}^{\infty} \{[\frac{\alpha}{\beta} - \frac{1}{\beta}Q + \frac{\epsilon}{\beta}] - [\frac{\alpha}{\beta} - \frac{1}{\beta}Q_{release} + \frac{\epsilon}{\beta}]\} f_{Q_{t,t+n}}(Q;\mu_1,\sigma)[-(\frac{1}{\beta})dQ] \\
&= \int_{P_{release}}^{\infty} (-\frac{1}{\beta^2})(Q_{release} - Q) f_{Q_{t,t+n}}(Q;\mu_1,\sigma)dQ
\end{aligned} \tag{2.15}$$

where $\mu_1 = \mu + \ln(-1/\beta)$. The limits of integration in equation (B.5) need to be converted from price to quantity terms. This conversion implies the limits run from

$Q = Q_{release}$ to $Q = -\infty$. However, it is obvious that $Q > 0$. Using the quantity limits of integration and changing the direction of integration, equation (B.5) becomes equation (2.3) as follows:

$$C_{t,t+n} = \int_0^{Q_{release}} (\frac{1}{\beta^2})(Q_{release} - Q) f_{Q_{t,t+n}}(Q;\mu_1,\sigma)dQ \quad \textbf{(Q.E.D.)} \tag{2.3}$$

2.7.2 Derivation of Equation (2.5)

Given *Leibniz integration rule* and functions, $h(x,z)$, $a(z)$, and $b(z)$; the following is true:

$$\frac{\partial}{\partial z}\int_{b(z)}^{a(z)} h(x,z)dx = \int_{b(z)}^{a(z)} \frac{\partial h(x,z)}{\partial z}dx + h(a(z),z)\frac{\partial a(z)}{\partial z} - h(b(z),z)\frac{\partial b(z)}{\partial z} \tag{2.16}$$

Comparing equations (B.6) and (2.4) and letting $x = Q$ and $z = G$, $h(Q,G)$, $a(G)$ and $b(G)$ can be defined as:

$$\begin{aligned} h(Q,G) &= \frac{1}{\beta^2}(Q_{release} - (Q+G)) f_{Q_{t,t+n}}(Q;\mu_1,\sigma) \\ a(G) &= Q_{release} - G \\ b(G) &= 0 \end{aligned} \tag{2.17}$$

The partial derivatives of $h(Q,G)$, $a(G)$, and $b(G)$ with respect to G are:

$$\begin{aligned} &\frac{\partial}{\partial G}h(Q,G) = \frac{\partial}{\partial G}[\frac{1}{\beta^2}(Q_{release} - (Q+G)) f_{Q_{t,t+n}}(Q;\mu_1,\sigma)] = -\frac{1}{\beta^2} f_{Q_{t,t+n}}(Q;\mu_1,\sigma) \\ &\frac{\partial}{\partial G}a(G) = \frac{\partial}{\partial G}(Q_{release} - G) = -1 \\ &\frac{\partial}{\partial G}b(G) = \frac{\partial}{\partial G}(0) = 0 \end{aligned} \tag{2.18}$$

We additionally need to find $h(a(G),G)$, which is derived:

$$h(a(G),G) = \frac{1}{\beta^2}(Q_{release} - (Q_{release} - G + G)) f_{Q_{t,t+n}}(Q_{release} - G;\mu_1,\sigma) = 0 \tag{2.19}$$

To complete the derivation, substitute equations (B.7)-(B.9) into the process of taking the partial derivative of equation (2.4) with respect to G:

$$\begin{aligned}\frac{\partial}{\partial G}C_{t,t+n} &= \frac{\partial}{\partial G}\int_0^{Q_{release}-G}(\frac{1}{\beta^2})(Q_{release}-(Q+G))f_{Q_{t,t+n}}(Q;\mu_1,\sigma)dQ \\ &= \frac{\partial}{\partial G}\int_{b(G)}^{a(G)}h(Q,G)dQ \\ &= \int_{b(G)}^{a(G)}\frac{\partial h(Q,G)}{\partial G}dQ + h(a(G),G)\frac{\partial a(G)}{\partial G} - h(b(G),G)\frac{\partial b(G)}{\partial G} \\ &= \int_0^{Q_{release}-G}(-\frac{1}{\beta^2})f_{Q_{t,t+n}}(Q;\mu_1,\sigma)dQ + 0 - 0 \\ &= -\frac{1}{\beta^2}\int_0^{Q_{release}-G}f_{Q_{t,t+n}}(Q;\mu_1,\sigma)dQ \quad (\textbf{Q.E.D.})\end{aligned} \tag{2.5}$$

2.7.3 Derivation of Equation (2.6)

The components of using the *Leibniz integration rule* to take a partial derivative of equation (2.5) are:

$$\begin{aligned}h^*(Q,G) &= -\frac{1}{\beta^2}f_{Q_{t,t+n}}(Q;\mu_1,\sigma) \\ a^*(G) &= Q_{release} - G \\ b^*(G) &= 0\end{aligned} \tag{2.20}$$

where $*$ is denoted for new h, a, and b, not for derivatives. The partial derivatives of $h^*(Q,G)$, $a^*(G)$, and $b^*(G)$ with respect to G are:

$$\begin{aligned}\frac{\partial}{\partial G}h^*(Q,G) &= \frac{\partial}{\partial G}[-\frac{1}{\beta^2}f_{Q_{t,t+n}}(Q;\mu_1,\sigma)] = 0 \\ \frac{\partial}{\partial G}a^*(G) &= \frac{\partial}{\partial G}(Q_{release}-G) = -1 \\ \frac{\partial}{\partial G}b^*(G) &= \frac{\partial}{\partial G}(0) = 0\end{aligned} \tag{2.21}$$

We additionally need to find $h^*(a^*(G),G)$, which is derived:

$$h^*(a^*(G),G) = -\frac{1}{\beta^2}f_{Q_{t,t+n}}(Q_{release}-G;\mu_1,\sigma) \tag{2.22}$$

To complete the derivation, substitute equations (B.10)-(B.12) into the process of taking the partial derivative of equation (2.5) with respect to G. All but the second term disappears as follows:

$$\begin{aligned}
\frac{\partial^2}{\partial G^2} C_{t,t+n} &= \frac{\partial}{\partial G}[-\frac{1}{\beta^2}\int_0^{Q_{release}-G} f_{Q_{t,t+n}}(Q;\mu_1,\sigma)dQ] \\
&= \frac{\partial}{\partial G}\int_{b^*(G)}^{a^*(G)} h^*(Q,G)dQ \\
&= \int_{b^*(G)}^{a^*(G)} \frac{\partial h^*(Q,G)}{\partial G}dQ + h^*(a^*(G),G)\frac{\partial a^*(G)}{\partial G} - h(b^*(G),G)\frac{\partial b^*(G)}{\partial G} \\
&= 0 + [-\frac{1}{\beta^2} f_{Q_{t,t+n}}(Q_{release}-G;\mu_1,\sigma)]\cdot[-1] + 0 \\
&= \frac{1}{\beta^2} f_{Q_{t,t+n}}(Q_{release}-G;\mu_1,\sigma) \quad (\textbf{Q.E.D.})
\end{aligned} \tag{2.6}$$

Chapter 3: Forecasting Returns to Storage: The Role of Factors other than the Basis Strategy

3.1 Introduction

Forecasting returns to storage is a subject of interest because commodities that have a harvest must be stored to meet demand for the commodity until the next harvest. In 1953, Holbrook Working proposed a strategy, commonly referred to as the basis strategy, of storing only when the expected change in the futures-cash basis exceeds storage cost. Working argued this strategy could be profitable since changes in the cash-futures basis are more predictable than changes in either cash or futures prices. Heifner (1966), Zulauf and Irwin (1998), Siaplay et al. (2012), and Kim Zulauf, and Roberts (2014) find support for the strategy, especially for storage hedged with futures contracts; while Kastens and Dhuyvetter (1999) find inconsistent support.

All of the cited studies are univariate analyses examining whether storage return predicted by the basis strategy can explain observed storage return. Being univariate analyses, an omitted variable bias may exist if the basis strategy's predicted storage return does not fully capture other explanatory variables. This study therefore adds to the storage literature by examining whether other variables add to the basis strategy's explanation of observed return to storage.

Two potential variables discussed in the storage literature are rate of harvest progress (Zulauf et al., 1998-1999; Kim, Zulauf, and Roberts, 2014) and storage bin space (Working, 1953a; Brennan, 1958; Barry and Fraser, 1976; Beal, 1996; Saha and Stroud, 1994; Park, 2006). Using data for Illinois corn and soybeans and Fixed Effects Panel Seemingly Unrelated Regression (FEP-SUR), both variables are found to significantly improve upon the basis strategies' ability to predict observed net return to storage, especially for unhedged storage. Given this finding, storage strategies utilizing harvest progress and the ratio of demand to supply for storage space are examined. For hedged storage, the basis strategy dominates. It has the highest net return and lowest standard deviation. However, compared with hedged storage and the storage strategy, unhedged storage routinely done each year or done in combination with the harvest progress and storage bin space strategies have a higher net return. Their risk is also higher. This set of findings suggests the choice of hedged vs. unhedged storage depends on a storage agent's preference function for return vs. risk. In particular, if farmers prefer net return over risk, this finding is consistent with a common observation in the literature that farmers infrequently use hedging with futures contract (Brorsen, 1995; Collins, 1997; Carter, 1999; Peterson and Tomek, 2007; Pannell et al., 2008).

The rest of the chapter is organized as follows. Studies of the basis strategy are reviewed. Next the procedures and methods used in the empirical analysis are described, followed by a discussion of findings. The paper closes with a summary, conclusions and implications section.

3.2 Literature Review

The Efficient Market Hypothesis is a key concept in the study of speculative prices. It states an efficient market completely and accurately incorporates all available, publicly known information at the time price is determined (Fama, 1970). Because grain futures markets are generally found to be efficient (Kastens and Schroeder, 1996; Tomek, 1997), it is not surprising that studies have found that futures prices are not a useful indicator of the returns to storage (Tomek, 1997; Siaplay et al., 2012). Moreover, models that predict future cash prices also are generally found to be unreliable indicators of the returns to storage (Working, 1953b; Tomek and Peterson, 2005; Reichsfeld and Roache, 2011). However, Working (1953a) argued the basis, or difference between cash and futures prices, can guide profitable inventory control. He presented empirical evidence of a significant relationship between the initial cash-futures basis and observed gross return to subsequent storage hedged until the delivery month for Kansas City wheat over the 1922-1952 crop years (Working, 1953b). Based on this evidence, Working proposed a strategy, subsequently called the basis strategy, of storing only when the forecasted change in the cash-futures basis exceeds the cost of storage.

Since Working's seminal article, several studies have investigated the basis strategy. Using 1952-1965 Michigan corn prices, linear regression, and several storage intervals; Heifner (1966) found the initial cash-futures basis explained on average 74 percent of the variation in gross return to hedged storage but only six percent of the variation in gross return to storage not hedged. Based on Monte Carlo simulations of net returns at different levels of hypothesized storage cost, he further concluded that, relative to routine hedged storage each year, the basis strategy generally improved net returns and reduced the standard deviation of net returns to hedged storage. Usefulness of the basis strategy was also found to vary by storage interval.

Distinctive from Heifner's Monte Carlo approach, Zulauf et al. (1998-1999; also reported in Zulauf and Irwin, 1998) forecast net return to storage by using a moving average of the basis at the end of the storage period for the previous 3 years. Their examination of Ohio corn for 1964-1997 found the basis strategy increased net return to storage but only when combined with a futures hedge. In accordance with Heifner's suggestion to examine different storage periods, net storage return at the 50 percent harvest completion date was significantly higher than at either the 10 percent or 90 percent harvest completion dates. Zulauf et al. also found that the basis strategy reduced the standard deviation of net storage returns for hedged storage, but did not investigate its impact on risk for unhedged storage.

Using a methodology similar to Zulauf et al., Kastens and Dhuyvetter (1999) found, however, the basis strategy's return performance to be inconsistent for hedged and unhedged storage under multiple scenarios across 23 Kansas locations and 4 Kansas crops over the 1985-1997 crop years. They concluded it would be inappropriate to base post-harvest storage decisions on predicted returns to storage calculated using futures prices and historical basis.

Siaplay et al. (2012) used Oklahoma wheat prices from 1975 through 2005 and regression analysis to examine if the expected change in the basis provided a reliable estimate of observed net returns to storage. Expected change in the basis was calculated using an average of the basis for the previous 5 years. It was found to be a useful predictor of net returns for both hedged and unhedged storage, but its forecasting power was higher for hedged storage.

Kim, Zulauf, and Roberts (2014) found that, for Illinois corn and soybeans over the 1975-2005 crop years and relative to routinely storing each year, the basis strategy improved net return for hedged but not unhedged storage and reduced return risk for both types of storage. These findings also generally held for the higher price period after 2005 although no statistical test was conducted due to a small sample. The analysis included three harvest and two post-harvest dates. Measured in dollar per bushel, expected net return to storage was an unbiased estimate of observed net storage return in the pre-2006 period, but some forecasts were biased in the post-2005 period. Forecast performance was analyzed using FEP-SUR regression because significant cross-equation correlations were found in the disturbances of the corn and soybean equations.

3.3 Methodology

3.3.1 General Procedures

Beginning with Working's original analysis published in 1953, a standard performance test of the basis storage signal is to compare observed storage return with return predicted by the basis strategy (Heifner, 1966; Siaplay et al., 2012; Kim, Zulauf, and Roberts, 2014). Storage can be hedged with a short position in futures contracts or unhedged. For unhedged storage, return depends on changes in cash market prices once storage begins. For hedged storage, return depends on the relative change in cash and futures prices, or the change in the basis. The short futures hedge is closed out by buying back the futures contract when the cash commodity is sold.

Per bushel net return to unhedged storage (OR^{US}) and hedged storage (OR^{HS}) over the interval from $\tau 1$ to $\tau 2$ of crop year t, expressed as a percent of cash price at harvest, are:

$$OR^{US}_{\tau 1,\tau 2,t} = \frac{[c(\tau 2,t) - c(\tau 1,t)] - [P(\tau 1,\tau 2,t) + I(\tau 1,\tau 2,t)]}{c(\tau 1,t)}$$
$$OR^{HS}_{\tau 1,\tau 2,t} = \frac{[b(\tau 2,t) - b(\tau 1,t)] - [P(\tau 1,\tau 2,t) + I(\tau 1,\tau 2,t) + BF(t) + L(t)]}{c(\tau 1,t)} \tag{3.1}$$

where $c(\tau,t)$ = cash price at time $\tau 1$ of crop year t, $b(\tau,t) = c(\tau,t) - f(\tau,t) =$ cash−futures basis, $f(\tau,t)$ = futures price, P = per bushel physical storage cost to keep a commodity in useable condition, I = per bushel interest opportunity cost[30] that varies with the cash price and interest rate at the initial storage date as well as the length of the storage, BF and L =, respectively, the per bushel brokerage fee and liquidity cost of the futures trade.

Predicted percent net return to hedged storage, designated ER, over the storage interval is:

$$ER_{\tau 1,\tau 2,t} = \frac{[\widehat{b_{\tau 1}}(\tau 2,t) - b(\tau 1,t)] - [P(\tau 1,\tau 2,t) + I(\tau 1,\tau 2,t) + BF(t) + L(t)]}{c(\tau 1,t)} \tag{3.2}$$

where $\widehat{b_{\tau 1}}(\tau 2,t)$ = basis expected at $\tau 2$ as of $\tau 1$ of crop year $t = [\frac{1}{3}\sum_{k=1}^{3} b(\tau 2, t-k)]$.

Alternative techniques exist for forecasting basis; however, the agricultural economics literature generally has used a moving average of the basis in prior years because of its simplicity and ease of calculation. Jiang and Hayenga (1997) found a three-year moving average was a reasonably accurate basis forecast for U.S. corn and soybeans. Zulauf et al. (1998) and Kim, Zulauf, and Roberts (2014) used a three-year moving average for Ohio corn and Illinois corn and soybeans, respectively.

[30] A third storage cost is insurance against the physical loss of the stored commodity. Consistent with previous studies, insurance cost is not included in this analysis because of its small size.

Taylor, Dhuyvetter and Kastens (2004) recommended a two-year average for Kansas corn and three-year average for Kansas soybeans. Hatchett, Brorsen, and Anderson (2010) found no statistical difference in forecast errors for moving averages of less than four years for Illinois corn and soybeans. Given this literature, a three-year moving average is chosen.

Per bushel opportunity cost is:

$$I\left(\tau 1, \tau 2, t\right) = c\left(\tau 1, t\right) \times IR\left(\tau 1, t\right) \times \frac{\left[7 \times \left(\tau 2 - \tau 1\right)\right]}{365} \tag{3.3}$$

where $IR\left(\tau 1, t\right)$ = interest rate at $\tau 1$ of crop year t and $\left(\tau 2 - \tau 1\right)$ = length of storage interval in weeks.

Using only expected net return to storage to predict observed net return to storage may suffer from omitted variable bias if expected net return does not fully capture other potential explanatory variables. This study therefore adds to the literature by examining if variables other than expected net return to storage explain observed net return to storage.

Previous studies found net return to storage varied by the time of harvest at which storage was initiated (Zulauf et al., 1998; Kim, Zulauf, and Roberts, 2014). Both studies found net return was higher for storage that began at the 50 percent harvest completion date than at either the 10 percent or 90 percent harvest completion date. This study extends this line of investigation but uses a different approach by adding the harvest completion rate at the initial storage date as an independent variable to the regression equation.

Previous studies have also mentioned to role of storage bin space (Working, 1953a; Brennan, 1958; Barry and Fraser, 1976; Beal, 1996; Saha and Stroud, 1994; Park, 2006). Thus the ratio of demand to supply of storage bin space is added as a second independent variable to the regression equation. Net return to storage is expected to be higher the greater is the demand relative to supply of storage bin space.

Net return to storage is calculated assuming that the stored crop is sold only at the end of the storage period. More complex strategies could be investigated as in Peterson and Tomek (2007) and Wisner, Blue, and Baldwin (1998). For example, storage hedges could be initiated in the March futures contract, then rolled to later contract months until the crop is sold in the cash market. This study opted for a simple storage strategy because our interest is the base level return to storage, not the potential to enhance return by adopting more dynamic strategies.

3.3.2 Data, Variables, and Estimation Framework

Cash prices used in this analysis are average prices paid to Illinois farmers by country elevators on Thursdays during the 1989-2012 crop years[31]. They are available for seven Illinois regions[32] from the U.S. Department of Agriculture (USDA) and Illinois Department of Agriculture.

The storage hedge is placed in the July futures contract traded in Chicago. July is the last futures contract in the crop marketing year for corn. To be consistent with corn, the July contract is used for soybeans even though an August contract is traded for soybeans. A September futures contract is traded for corn and soybeans, but it may trade as a new crop contract if harvest is expected to be early. The settlement

[31] The 2013-2014 crop year cannot be used in this analysis because no cash prices were collected during the shutdown of the federal government from October 1 through October 16, 2013 resulting from a deadlocked debate over the federal budget deficit.

[32] While not elevator specific cash price data, as used by Kastens and Dhuyvetter (1999), regional data are less aggregated than state data used by Zulauf et al. (1998), Siaplay et al. (2012), and Kim, Zulauf, and Roberts (2014).

price for the July futures contract is collected for the same dates cash prices are available[33]. Source of the futures prices is Barchart.com.

Initial storage date is the second Thursday of October. This Thursday is the first in the crop year for which data are available for all years and both crops. Ending storage date is the last Thursday of June. Using this Thursday avoids problems that can emerge during a delivery month (in this case July), usually associated with limited availability of deliverable supplies on the futures contract. Length of the storage period is thus 37 weeks.

The storage opportunity cost arising from selling at harvest is calculated using the annual bank prime loan rate as of the second Thursday of October. Source is the Federal Reserve Economic Data (FRED) maintained by the Federal Reserve Bank of St. Louis. Average annual prime loan rate is 6.5 percent with a range of 3.3 to 10.5 percent (see Table 3.1).

Physical storage cost is from USDA, Commodity Credit Corporation (CCC) through the 2008 crop year. CCC then changed its methods for reporting storage rates by commodity, resulting in substantially higher rates. Thus, since 2008, physical storage rates are from an Ohio country elevator, cross checked with another Ohio elevator. This rate is more consistent with CCC storage rates prior to 2009. Average per bushel storage rate is 39 cents per year with a range of 33 to 60 cents (see Table 3.1).

Cost of trading futures contracts include a brokerage fee, assumed to be $50 for a round trip buy and sell based on inquiries of brokers, and liquidity cost. The later arises because trades cannot be executed instantaneously. Thus, the futures price at which a trade is executed likely differs from the price at which the trade is placed.

[33] If Thursday was a holiday, the cash price was assumed to be for the preceding Wednesday. Most Thursday holidays were Thanksgiving.

Based on Brorsen (1989) and Thompson and Waller (1987), liquidity cost is calculated as $25 per futures trade made before February 1 and $12.50 thereafter. Liquidity cost declines because trading volume increases as contract maturity approaches. Per bushel trading costs are calculated by dividing by 5,000 bushels, the size of a corn and soybean futures contract.

Harvest progress rate, designated HPR, is from the *Weekly Weather and Crop Bulletin* published by USDA and the Department of Commerce. Progress is reported as of Sunday (USDA, National Agricultural Statistics Service (NASS)) using survey[34] data. Because Thursday prices are used in the analysis, HPR for the preceding Sunday is used since it is the latest report available to the market. HPR varies widely across crop years, ranging from 5 to 87 percent for corn and from 6 to 79 percent for soybeans (see Table 3.1). Both minimums occurred in the 2009-2010 crop year. Both maximums occurred in the 2010-2011 crop year.

Given the analysis is for Illinois, demand for storage bin space is comprised almost entirely of corn, soybeans, and wheat in storage from prior harvests plus the current harvest. Given the second Thursday of October as the harvest date, the most recent report on stocks is the *Grain Stocks* report released by USDA, NASS at the end of September. Information on stocks are as of September 1. Stocks of corn and soybeans are from prior crop years (*i.e.*, old crop stocks) while stocks of wheat are from both prior crop years and wheat for the current crop year harvested earlier in the summer. The most recent USDA, NASS report on estimated production of the current corn and soybean crop occurred in September or October depending on when the second

[34] According to USDA, NASS, "most reporters complete their questionnaire on Friday or early Monday morning and submit it to the NASS Field Office in their State ... Regardless of the time that the questionnaire is completed, reporters are asked to report for the week ending on Sunday."

Thursday of October falls. Sum of stock and projected production, adjusted to a corn bushel basis[35], averaged 2.4 billion bushels with a range of 1.8 (2012-2013 crop year) to 3.1 (2007-2008 crop year) billion bushels. Table 3.1 contains summary statistics for the individual variables.

Supply of storage bin space is from USDA, NASS's annual survey of on-farm and off-farm storage capacity. Storage capacity is enumerated as of December 1 and reported in the subsequent January *Grain Stocks* report. The most recent report as of the second Thursday of October is for December 1 of the preceding calendar year. The first storage capacity report was issued for December 1, 1988, which is why the observation period for this analysis begins with the 1989-1990 crop year. The Illinois storage bin capacity as of December 1 averaged 2.5 billion bushels and was almost evenly split between on-farm and off-farm locations (see Table 3.1).

The ratio of demand to supply of storage bin space, designated $STORCAP$, averaged 98 percent. $STORCAP$ ranged from 63 percent (2012-2013 crop year) to 120 percent (2007-2008 crop year). The crop years were almost evenly divided into years in which demand for storage bin space was higher and lower than the supply of storage bin space. In 3 crop years the ratio was less than 90 percent while in 5 crop years it exceeded 110 percent.

Because corn and soybeans in Illinois are rotational crops grown at the same time, the unobserved heterogeneity determining their net storage return could be correlated. In their study of storing Illinois corn and soybeans, Kim, Zulauf, and Roberts (2014) found statistically significant cross-equation correlation. In this study

[35]A bushel of corn weighs 56 pounds while a bushel of soybeans and wheat weighs 60 pounds. Thus, stocks and production are converted to a corn basis by multiplying soybean and wheat bushels by 0.933 (56/60).

of storing Illinois corn and soybeans, crossequation correlation[36] averages across the seven regions 0.51 for hedged storage and 0.55 for unhedged storage. The Breusch-Pagan test for no contemporaneous cross-equation correlation in disturbances rejects the null hypothesis of no correlation at the one percent significance level. Following Kahl and Tomek's (1986) suggestion, Seemingly Unrelated Regression (SUR; Zellner, 1962) is chosen over pooled regression and equation-by-equation Ordinary Least Squares (OLS). SUR captures the cross-equation correlations and thus provides more efficient estimates.

To exam whether the ability to predict net return to storage is heterogeneous across the seven Illinois production regions, a fixed effects panel (FEP) estimation approach is used for each crop. Thus, to summarize this section, the following FEP-SUR model is estimated for hedged storage, designated HS; with a similar model estimated for unhedged storage:

$$\begin{aligned} OR^{HS}_{c,i,t} =& \alpha_{c,0} + \alpha_{c,1} \times ER_{c,i,t} + \alpha_{c,2} \times HPR_{c,t} + \alpha_{c,3} \times STORCAP_t \\ &+ \sum_{i=2}^{7} \beta_{c,i} \times R_i + \sum_{i=2}^{7} \gamma_{c,i} \times R_i \times ER_{c,i,t} + \varepsilon_{c,i,t} \\ OR^{HS}_{s,i,t} =& \alpha_{s,0} + \alpha_{s,1} \times ER_{s,i,t} + \alpha_{s,2} \times HPR_{s,t} + \alpha_{s,3} \times STORCAP_t \\ &+ \sum_{i=2}^{7} \beta_{s,i} \times R_i + \sum_{i=2}^{7} \gamma_{s,i} \times R_i \times ER_{s,i,t} + \varepsilon_{s,i,t} \end{aligned} \tag{3.4}$$

where OR = observed percent net return to storage from the second Thursday of October harvest date until the last Thursday of June, ER = percent net return to hedge storage expected at harvest over the storage period, c and s = corn and soybeans, HPR = harvest progress rate, $STORCAP$ = ratio of demand to supply

[36]The cross-equation correlation in disturbances is calculated using the residuals of equation-by-equation ordinary least squares estimation.

for Illinois storage bin space, R_i = dummy variable for region i, $\boldsymbol{\varepsilon}$ = idiosyncratic disturbance, and $(\boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma})$ = coefficients to be estimated.

Given the times series nature of the data, stationarity of the variables in the regression equation was checked. Both the Augmented Dickey-Fuller (ADF[37]) test and Phillips-Perron test rejected the null hypothesis of non-stationarity (*i.e.*, unit root) for all variables at least at the five percent significance level. Various panel-data unit-root tests including the Levin-Lin-Chu test and Im-Pesaran-Shin test also supported stationarity of the variables.

3.4 Findings

3.4.1 Net Return to Storage

Expected net return to hedged storage (ER) averaged across all years did not exceed zero and was usually negative for the Illinois regions over the 1989-2012 crop years for both corn (see Table 3.2) and soybeans (see Table 3.3). Average ER was almost always slightly less than average observed net return (OR) for hedged storage, which in turn was notably less than average OR for unhedged storage. Across all regions and years, standard deviation of OR averaged 29 vs. 6 percent for unhedged and hedged corn and 18 vs. 3 percent for unhedged and hedged soybeans. These values are consistent with both previous studies of net storage return and with the classic relationship in finance that higher returns are possible only with higher risk.

The variation across years in net return to storage is striking, especially for unhedged storage. The range, averaged over the seven Illinois regions, was -14 to 10 percent for hedged corn; -31 to 111 percent for unhedged corn; -8 to 5 percent

[37] ADF tests with and without trend, drift, and/or lags were conducted.

for hedged soybeans; and −25 to 57 percent for unhedged soybeans. This variation implies that sizable gains are possible if net storage returns can be predicted successfully.

FEP-SUR regression results are in Table 3.4 for net hedged storage return and Table 3.5 for net unhedged storage return. The first pair of result column in both tables do not include HPR and $STORCAP$. The only explanatory variable significantly associated with observed net return to hedged storage at the 10 percent statistical test level is expected net return to hedged storage (see Table 3.4). For unhedged storage, no explanatory variable, including expected net return to hedged storage, is significant at the 10 percent test level (see Table 3.5). The test for expected net return to hedged storage is one tailed because a positive relationship is expected from the literature, including Working's conceptual argument. R^2 varied notably between hedged and unhedged storage: 0.60 vs. 0.02 for corn and 0.57 vs. 0.00 for soybeans. No statistically significant heterogeneity by region is found.

The second pair of column results include HPR and $STORCAP$. For hedged storage mixed results are found. Using a two-tail test for HPR and one-tail test for $STORCAP$ based on the discussions above, at the 10 percent test level both variables are statistically insignificant for corn but statistically significant for soybeans. R^2 increases by 0.01 for corn and 0.05 for soybeans. In contrast, for unhedged storage both variables are statistically significant at the one percent test level for both corn and soybeans. R^2 increases from 0.02 to 0.21 for corn and from 0.00 to 0.32 for soybeans.[38] Expected net return to hedged storage remains statistically insignificant and no statistically significant regional heterogeneity continues to be found.

[38]The Pearson correlations between HPR and $STORCAP$ are +0.10 for corn and +0.15 for soybeans, which suggest the two variables are not bivariate collinear.

3.4.2 Return and Risk Performance of Storage Strategies

Given the FEP-SUR regression results, storage signals based on HPR and $STORCAP$ are created to examine whether their statistically significant coefficients can be translated into a profitable storage signal. The storage signal evaluated for HPR, hereafter called "the HPR strategy," is to store only if the harvest progress rate exceeds the Olympic average[39] of progress rates for the previous 5 harvests. Thus, the HPR strategy compares the current year's progress to a measure of historical normal progress. The signal evaluated for $STORCAP$, hereafter called the $STORCAP$ strategy, is to store only if demand for storage bin space exceeds supply of storage bin space, or if $STORCAP$ exceeds one.[40] Return and risk of these strategies are compared against the return and risk of the basis strategy and the strategy of routinely storing each year.

For hedged storage, the basis strategy dominated (see Tables 3.6 and 3.7). For each crop and region, it had the highest net return and lowest standard deviation. Moreover, for the years in which the strategies generated different storage signals, the nonparametric binomial test of mean net return and Levene's nonparametric test of the variance pooled across all regions found that net return was higher and risk was lower for the basis strategy than the other three strategies at the one percent test level. Nonparametric tests were used because the Shapiro-Wilk test rejected normality of percent net returns to storage for a majority of storage strategies and Illinois regions, with most rejections occurring at the five percent test level.

[39] An Olympic average limits the impact of outliers since it excludes the highest and lowest values.

[40] Various combinations of the basis, HPR, and $STORCAP$ strategies were examined, including storage only if both the HPR strategy and $STORCAP$ strategy signal storage or if either one of these strategies signal storage. None of the combined strategies consistently improved return or lowered risk more than the individual strategies.

For unhedged storage and each region-crop combination, standard deviation is smallest for the basis strategy and smaller for HPR and $STORCAP$ strategies than routine storage. Levene's test finds that, pooled across regions, these differences in standard deviation are statistically significant at the five percent test level (see Tables 3.8 and 3.9). In addition, for each region-crop combination, average net return for HPR and $STORCAP$ strategies are higher than routine storage. Binomial sign tests of this relationship pooled across regions are statistically significant at the 10 percent test level for each crop. In contrast, the basis, HPR, and $STORCAP$ strategy each has the highest net storage return for at least one region-crop combination.

Last, the best performing strategy for hedged storage, the basis strategy, had the lowest standard deviation when compared against the best performing strategies for unhedged storage, the basis, HPR and $STORCAP$ strategies; with a Levene's test rejecting the null hypothesis of equal variance at least at 10 percent test level. In contrast, the HPR strategy for unhedged corn and soybeans and $STORCAP$ strategy for unhedged soybeans had a higher net return than the basis strategy for hedged storage, with a binomial sign test statistically significant at 10 percent level.

3.4.3 Sensitivity Checks

Several sensitivity checks were conducted to assess the robustness of the empirical findings. One involved using a dollar, instead of percent, measure of net return to storage. Results from this sensitivity check are in the appendix (see Tables 3.10-3.15). Other sensitivity checks involved 1) using shorter[41] lengths including one and two

[41] Taylor, Dhuyvetter, and Kastens (2006) found that an one-year moving average is optimal in forecasting harvest and post-harvest basis for Kansas corn and soybeans. Hatchett, Brorsen, and Anderson (2010) recommended to use last year's information in forecasting futures basis for Illinois corn and soybeans when structural change in price has occurred.

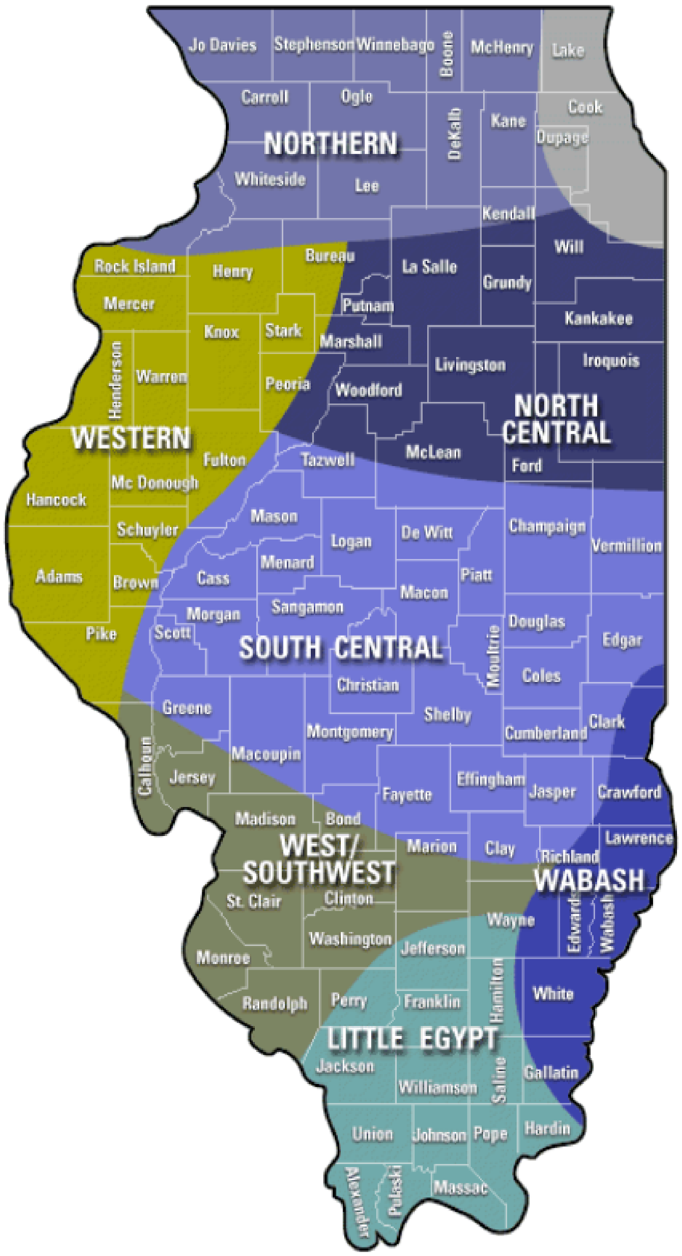
year moving averages and longer lengths such as four and five year moving averages, instead of three year moving average, to estimate the expected basis in late June; 2) using different lengths of historical (or Olympic) averages including three, four, six, and seven, instead of 5-year Olympic moving average, to generate the HPR strategy; and 3) using other storage ending dates including the last Thursday of December, February, and April, instead of June. While the results varied somewhat in terms of their numerical values, the general conclusions regarding the dominance of the basis strategy for hedged storage, the performance of the HPR and $STORCAP$ strategies for unhedged storage, and the comparative performance of the routine, HPR, and $STORCAP$ strategies for unhedged storage vs. the basis strategy for hedged storage were consistently supported.

3.5 Summary, Conclusions, and Implications

This study investigates whether other variables can add to the ability of the basis strategy to explain observed net returns to hedged and unhedged storage. Using data for the 1989-2012 crop years of Illinois corn and soybeans, both rate of harvest progress and ratio of demand to supply for storage bin space are found to significantly add explanatory power, especially for unhedged storage.

Given the regression results, storage strategies based on harvest progress and the ratio of demand to supply for storage bin space also are examined. For hedged storage, the basis strategy dominates, having statistically significant higher net return and lower standard deviation than either storing routinely each year or using the harvest progress and storage bin space strategies. However, unhedged storage in combination with routine storage or the harvest progress and storage bin space strategies can generate higher net returns to storage than hedged storage with the basis strategy, although the latter strategy has the lowest risk. This finding is consistent with the classic finance principle that higher returns are associated with higher risk.

The findings of this study need to be confirmed by other studies, especially given the limited number of observation years. Should its results be confirmed, this study finds that factors other than the basis strategy are needed to explain net returns to storage, especially for unhedged storage. In short, forecasting net returns to private storage is a richer area of study than just the basis strategy. Moreover, while the basis strategy along with hedged storage generates the lowest risk of storage return, it does not generate the highest net return to storage. Thus, the choice of hedged vs. unhedged storage depends on the risk-return preference of the storage agent. In particular, if farmers prefer higher net return over lower risk, this finding helps explain the available evidence that farmers infrequently use hedging with futures contracts.



Source: Kurfman (2011)

Figure 3.1: Illinois Production Regions

Variable (unit)	Obs.	Mean	S.D.[A]	Min.	Max.
Illinois Demand for Storage Bin Space[B]	24	2388.0	374.0	1828.0	3078.8
Illinois Stocks, September 1					
Corn (million bushels)	24	214.2	79.0	63.0	362.6
Soybeans (million bushels)	24	40.9	19.1	16.5	96.6
Wheat (million bushels)	24	40.3	11.9	16.4	61.3
Expected Illinois Production					
Corn (million bushels)	24	1641.6	327.5	1170.0	2340.0
Soybeans (million bushels)	24	415.5	53.0	336.7	512.6
Illinois Supply of Storage Bin Space, December 1					
On-Farm (million bushels)	24	1270.0	98.8	1150.0	1460.0
Off-Farm (million bushels)	24	1195.0	112.0	1069.3	1451.0
Total (million bushels)	24	2465.0	203.8	2269.3	2911.0
Demand-Supply Ratio of Storage Bin Space (%)	24	97.7	14.2	62.8	119.9
Harvest Progress Rate (%)					
Corn	24	40.5	25.4	5.0	87.0
Soybeans	24	47.3	18.3	6.0	79.0
Interest Rate (%/year)	24	6.5	2.2	3.3	10.5
Physical Storage Rate ($/year/bushel)	24	0.39	0.08	0.33	0.60

Notes: A. Standard Deviation. B. Sum of Illinois stocks and expected production.
Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain, Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.1: Descriptive Statistics, Illinois Corn and Soybeans, 1989-2012 Crop Years

Region	Variable	Obs.	Mean	S.D.^{A}	Min.	Max.
Northern	Expected Net Return	24	-4.8%	6.0%	-17.1%	7.2%
	Observed Net Return					
	Hedged Storage	24	-4.4%	6.1%	-15.9%	8.5%
	Unhedged Storage	24	-1.9%	29.9%	-34.3%	112.5%
Western	Expected Net Return	24	-4.7%	5.7%	-16.8%	5.0%
	Observed Net Return					
	Hedged Storage	24	-4.4%	5.7%	-15.8%	5.0%
	Unhedged Storage	24	-1.8%	30.0%	-33.0%	113.5%
North Central	Expected Net Return	24	-4.8%	5.4%	-16.5%	3.1%
	Observed Net Return					
	Hedged Storage	24	-4.5%	4.7%	-14.8%	3.1%
	Unhedged Storage	24	-2.0%	29.6%	-30.9%	114.0%
South Central	Expected Net Return	24	-4.2%	5.8%	-15.5%	6.6%
	Observed Net Return					
	Hedged Storage	24	-3.9%	5.5%	-12.6%	6.1%
	Unhedged Storage	24	-1.5%	28.7%	-31.0%	110.0%
Wabash	Expected Net Return	24	0.1%	9.0%	-12.5%	21.3%
	Observed Net Return					
	Hedged Storage	24	0.3%	7.2%	-11.8%	14.0%
	Unhedged Storage	24	2.6%	28.6%	-29.5%	111.7%
West Southwest	Expected Net Return	24	-2.5%	7.6%	-14.3%	20.7%
	Observed Net Return					
	Hedged Storage	24	-2.1%	7.4%	-14.1%	16.6%
	Unhedged Storage	24	0.1%	27.8%	-31.7%	103.8%
Little Egypt	Expected Net Return	24	0.0%	8.3%	-11.4%	22.3%
	Observed Net Return					
	Hedged Storage	24	0.2%	6.7%	-10.9%	15.5%
	Unhedged Storage	24	2.6%	28.9%	-29.0%	112.2%

Notes: A. Standard Deviation
Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.2: Descriptive Statistics, Average Expected and Observed Net Return to Storage as Percent of Harvest Cash Price by Region, One-Time-Sale Marketing Strategy, Illinois Corn, 1989-2012 Crop Years

Region	Variable	Obs.	Mean	S.D.^{A}	Min.	Max.
Northern	Expected Net Return	24	-3.5%	3.2%	-10.1%	2.7%
	Observed Net Return					
	Hedged Storage	24	-3.5%	3.5%	-8.2%	3.8%
	Unhedged Storage	24	5.6%	18.1%	-25.2%	56.3%
Western	Expected Net Return	24	-3.4%	3.5%	-9.7%	3.1%
	Observed Net Return					
	Hedged Storage	24	-3.3%	3.3%	-9.9%	4.1%
	Unhedged Storage	24	5.8%	18.2%	-25.0%	58.9%
North Central	Expected Net Return	24	-3.0%	3.3%	-10.0%	2.6%
	Observed Net Return					
	Hedged Storage	24	-2.7%	3.1%	-8.1%	3.6%
	Unhedged Storage	24	6.2%	18.2%	-26.2%	57.3%
South Central	Expected Net Return	24	-3.1%	3.4%	-10.9%	3.0%
	Observed Net Return					
	Hedged Storage	24	-3.0%	3.1%	-8.4%	3.6%
	Unhedged Storage	24	5.9%	17.8%	-26.6%	57.0%
Wabash	Expected Net Return	24	-1.7%	3.8%	-9.5%	3.6%
	Observed Net Return					
	Hedged Storage	24	-1.6%	3.7%	-7.0%	5.5%
	Unhedged Storage	24	7.4%	17.8%	-23.6%	57.0%
West Southwest	Expected Net Return	24	-2.7%	3.9%	-9.8%	7.7%
	Observed Net Return					
	Hedged Storage	24	-2.5%	3.7%	-8.4%	5.5%
	Unhedged Storage	24	6.4%	17.7%	-24.4%	57.3%
Little Egypt	Expected Net Return	24	-1.8%	4.0%	-9.6%	6.1%
	Observed Net Return					
	Hedged Storage	24	-1.6%	3.7%	-8.1%	5.5%
	Unhedged Storage	24	7.3%	17.6%	-23.6%	56.5%

Notes: A. Standard Deviation
Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.3: Descriptive Statistics, Average Expected and Observed Net Return to Storage as Percent of Harvest Cash Price by Region, One-Time-Sale Marketing Strategy, Illinois Soybeans, 1989-2012 Crop Years

Variable	Observed Net Return to Hedged Storage Corn (I)	Soybeans (I)	Corn (II)	Soybeans (II)
Expected Net Return to Hedged Storage[A]	0.619***	0.674***	0.586***	0.808***
($= ER$)	(0.129)	(0.135)	(0.136)	(0.135)
Harvest Progress Rate			0.014	-0.020*
			(0.013)	(0.010)
Demand-Supply Ratio of Storage Bin Space[A]			-0.023	-0.047
			(0.027)	(0.013)
Western Region Dummy	-0.001	-0.002	-0.000	-0.002
($= R2$)	(0.015)	(0.009)	(0.015)	(0.009)
North Central Region Dummy	-0.002	0.002	-0.001	0.002
($= R3$)	(0.015)	(0.009)	(0.015)	(0.009)
South Central Region Dummy	0.004	0.002	0.005	0.002
($= R4$)	(0.014)	(0.009)	(0.014)	(0.009)
Wabash Region Dummy	0.017	0.007	0.019	0.005
($= R5$)	(0.013)	(0.008)	(0.013)	(0.008)
West Southwest Region Dummy	0.013	0.006	0.014	0.005
($= R6$)	(0.014)	(0.009)	(0.014)	(0.008)
Little Egypt Region Dummy	0.017	0.007	0.019	0.004
($= R7$)	(0.013)	(0.008)	(0.013)	(0.008)
$ER \times R2$	-0.009	-0.068	0.003	-0.062
	(0.191)	(0.186)	(0.193)	(0.178)
$ER \times R3$	-0.029	-0.053	-0.009	-0.030
	(0.196)	(0.189)	(0.198)	(0.181)
$ER \times R4$	0.046	-0.005	0.067	0.004
	(0.187)	(0.187)	(0.189)	(0.179)
$ER \times R5$	0.036	0.037	0.066	0.047
	(0.157)	(0.178)	(0.159)	(0.171)
$ER \times R6$	0.137	0.038	0.174	0.034
	(0.167)	(0.177)	(0.169)	(0.169)
$ER \times R7$	-0.006	-0.002	0.024	-0.005
	(0.161)	(0.175)	(0.163)	(0.168)
Intercept	-0.015	-0.011	0.000	0.049***
	(0.010)	(0.007)	(0.030)	(0.017)
Number of Observations	168	168	168	168
R^{2B}	0.60	0.57	0.61	0.62

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, Standard errors reported in parentheses
A. One-tailed $t-$tests are implemented given positive sign is expected.
B. R^2 is reported from separate OLS estimations.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain, Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.4: FEP-SUR Estimation of Percent Net Return to Hedged Storage, One-Time-Sale Marketing, Illinois Corn and Soybeans, 1989-2012 Crop Years

Variable	Observed Net Return to Unhedged Storage Corn (I)	Soybeans (I)	Corn (II)	Soybeans (II)
Expected Net Return to Hedged Storage[A]	0.278	-0.407	-0.353	-1.726
($= ER$)	(0.784)	(0.909)	(0.841)	(0.896)
Harvest Progress Rate			0.332***	0.212***
			(0.078)	(0.070)
Demand-Supply Ratio of Storage Bin Space[A]			0.605***	0.656***
			(0.167)	(0.088)
Western Region Dummy	0.003	0.001	0.002	0.003
($= R2$)	(0.099)	(0.067)	(0.092)	(0.058)
North Central Region Dummy	0.001	0.023	-0.007	0.022
($= R3$)	(0.100)	(0.066)	(0.094)	(0.058)
South Central Region Dummy	-0.005	0.009	-0.001	0.011
($= R4$)	(0.096)	(0.066)	(0.090)	(0.057)
Wabash Region Dummy	0.032	0.032	0.062	0.052
($= R5$)	(0.090)	(0.062)	(0.084)	(0.053)
West Southwest Region Dummy	0.012	0.012	0.027	0.024
($= R6$)	(0.091)	(0.064)	(0.085)	(0.055)
Little Egypt Region Dummy	0.031	0.028	0.061	0.050
($= R7$)	(0.090)	(0.062)	(0.083)	(0.053)
$ER \times R2$	0.046	-0.043	0.014	-0.032
	(1.176)	(1.270)	(1.194)	(1.185)
$ER \times R3$	0.034	0.509	-0.131	0.217
	(1.202)	(1.287)	(1.226)	(1.207)
$ER \times R4$	-0.176	0.113	-0.175	-0.006
	(1.139)	(1.263)	(1.168)	(1.189)
$ER \times R5$	-0.060	0.384	0.011	0.213
	(0.960)	(1.214)	(0.983)	(1.136)
$ER \times R6$	-0.067	0.016	-0.019	0.061
	(1.030)	(1.214)	(1.044)	(1.128)
$ER \times R7$	-0.079	0.202	-0.049	0.179
	(0.985)	(1.194)	(1.006)	(1.117)
Intercept	-0.006	0.042	-0.762***	-0.746***
	(0.069)	(0.048)	(0.190)	(0.111)
Number of Observations	168	168	168	168
R^{2B}	0.02	0.00	0.21	0.32

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, Standard errors reported in parentheses
A. One-tailed $t-$tests are implemented given positive sign is expected.
B. R^2 is reported from separate OLS estimations.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain, Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.5: FEP-SUR Estimation of Percent Net Return to Unhedged Storage, One-Time-Sale Marketing, Illinois Corn and Soybeans, 1989-2012 Crop Years

	Average Percent Return to Hedged Storage			
Region	Routine	Basis	HPR	STORCAP
Northern	-4.4%	4.0%	0.9%	1.1%
Western	-4.4%	2.6%	1.1%	1.1%
North Central	-4.5%	2.8%	1.0%	1.0%
South Central	-3.9%	3.8%	1.4%	1.5%
Wabash	0.3%	5.1%	4.2%	4.7%
West Southwest	-2.1%	4.9%	2.5%	2.9%
Little Egypt	0.2%	4.9%	4.0%	4.4%
Average	-2.7%	4.0%	2.2%	2.4%
Binomial Sign Test[A]				
Test 1: Obs.[B] > Routine (Total Obs.[C])	–	110*** (115)	71*** (77)	77*** (77)
Test 2: Obs.[D] > Basis (Total Obs.)	–	–	4*** (48)	7*** (42)

	Standard Deviation, Percent Hedged Storage Return			
Region	Routine	Basis	HPR	STORCAP
Northern	6.1%	3.7%	5.9%	5.9%
Western	5.7%	4.7%	5.2%	5.5%
North Central	4.7%	4.1%	4.7%	5.0%
South Central	5.5%	3.2%	4.9%	5.2%
Wabash	7.2%	4.3%	5.0%	4.8%
West Southwest	7.4%	3.9%	6.2%	6.3%
Little Egypt	6.7%	4.2%	4.8%	4.9%
Average	6.2%	4.0%	5.3%	5.4%
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	33.5***	5.9**	3.9*
Test 2: Equal Variance to Basis	–	–	12.1***	16.1***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.6: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Percent Net Return to Hedged Storage, Illinois Corn, 1989-2012 Crop Years

Region	Average Percent Return to Hedged Storage			
	Routine	Basis	HPR	STORCAP
Northern	-3.5%	4.5%	1.1%	0.7%
Western	-3.3%	4.5%	1.4%	0.8%
North Central	-2.7%	3.9%	1.7%	1.3%
South Central	-3.0%	4.3%	1.8%	1.2%
Wabash	-1.6%	3.5%	2.5%	2.2%
West Southwest	-2.5%	4.8%	1.9%	1.6%
Little Egypt	-1.6%	3.4%	2.5%	2.2%
Average	-2.6%	4.1%	1.9%	1.4%
Binomial Sign Test[A]				
Test 1: Obs.[B] > Routine (Total Obs.[C])	–	136*** (136)	81*** (84)	77*** (77)
Test 2: Obs.[D] > Basis (Total Obs.)	–	–	4*** (66)	8*** (75)

Region	Standard Deviation, Percent Hedged Storage Return			
	Routine	Basis	HPR	STORCAP
Northern	3.5%	2.1%	4.9%	5.0%
Western	3.3%	2.3%	4.4%	4.8%
North Central	3.1%	3.0%	4.2%	4.2%
South Central	3.1%	2.3%	4.1%	4.4%
Wabash	3.7%	3.1%	3.6%	4.2%
West Southwest	3.7%	1.7%	4.1%	4.5%
Little Egypt	3.7%	3.1%	3.7%	4.0%
Average	3.4%	2.5%	4.1%	4.4%
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	16.6***	9.4***	17.5***
Test 2: Equal Variance to Basis	–	–	52.6***	69.3***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.7: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Percent Net Return to Hedged Storage, Illinois Soybeans, 1989-2012 Crop Years

Region	Average Percent Return to Unhedged Storage			
	Routine	Basis	HPR	STORCAP
Northern	-1.9%	1.4%	5.7%	2.7%
Western	-1.8%	6.6%	5.9%	2.8%
North Central	-2.0%	7.0%	5.7%	2.6%
South Central	-1.5%	1.7%	6.0%	3.0%
Wabash	2.6%	6.6%	8.7%	6.1%
West Southwest	0.1%	1.6%	7.0%	4.3%
Little Egypt	2.6%	6.5%	8.5%	5.9%
Average	-0.3%	4.5%	6.8%	3.9%
Binomial Sign Test[A]				
Test 1: Obs.[B] > Routine (Total Obs.[C])	–	83*** (115)	63*** (77)	58*** (77)
Test 2: Obs.[D] > Basis (Total Obs.)	–	–	23 (48)	15** (42)

Region	Standard Deviation, Percent Unhedged Storage Return			
	Routine	Basis	HPR	STORCAP
Northern	29.9%	8.6%	26.9%	26.4%
Western	30.0%	24.2%	27.0%	26.5%
North Central	29.6%	24.2%	26.7%	26.4%
South Central	28.7%	9.1%	25.7%	25.4%
Wabash	28.6%	23.9%	25.1%	24.5%
West Southwest	27.8%	9.9%	24.5%	23.8%
Little Egypt	28.9%	24.2%	25.5%	25.0%
Average	29.1%	17.7%	25.9%	25.4%
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	25.1***	4.8**	6.3**
Test 2: Equal Variance to Basis	–	–	6.7***	5.1**

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.8: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Percent Net Return to Unhedged Storage, Illinois Corn, 1989-2012 Crop Years

	Average Percent Return to Unhedged Storage			
Region	Routine	Basis	HPR	STORCAP
Northern	5.6%	4.7%	6.1%	6.4%
Western	5.8%	4.3%	6.4%	6.6%
North Central	6.2%	4.8%	6.6%	7.0%
South Central	5.9%	3.6%	6.7%	6.9%
Wabash	7.4%	5.8%	7.5%	7.9%
West Southwest	6.4%	5.3%	6.9%	7.3%
Little Egypt	7.3%	5.7%	7.4%	7.9%
Average	6.4%	4.9%	6.8%	7.1%
Binomial Sign Test[A]				
Test 1: Obs.[B] > Routine (Total Obs.[C])	–	69 (136)	49* (84)	49** (77)
Test 2: Obs.[D] > Basis (Total Obs.)	–	–	39* (66)	47** (75)

	Standard Deviation, Percent Unhedged Storage Return			
Region	Routine	Basis	HPR	STORCAP
Northern	18.1%	1.8%	12.8%	15.5%
Western	18.2%	3.3%	13.1%	15.5%
North Central	18.2%	5.0%	12.9%	15.6%
South Central	17.8%	4.1%	12.7%	15.3%
Wabash	17.8%	10.5%	12.6%	15.2%
West Southwest	17.7%	4.6%	12.3%	15.0%
Little Egypt	17.6%	10.3%	12.3%	15.1%
Average	17.9%	5.7%	12.7%	15.3%
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	100.8***	29.0***	8.8***
Test 2: Equal Variance to Basis	–	–	14.1***	38.1***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.9: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Percent Net Return to Unhedged Storage, Illinois Soybeans, 1989-2012 Crop Years

3.6 Addendum

3.6.1 A Sensitivity Check Using Dollar-Measured Net Return to Storage

	Observed Net Return to Hedged Storage			
Variable	Corn (I)	Soybeans (I)	Corn (II)	Soybeans (II)
Expected Net Return to Hedged Storage[A]	0.572***	0.731***	0.476***	0.806***
($= ER$)	(0.149)	(0.084)	(0.155)	(0.082)
Harvest Progress Rate			0.077**	-0.199***
			(0.037)	(0.061)
Demand-Supply Ratio of Storage Bin Space[A]			0.061	-0.198
			(0.092)	(0.087)
Western Region Dummy	-0.019	-0.006	-0.018	-0.004
($= R2$)	(0.048)	(0.053)	(0.047)	(0.050)
North Central Region Dummy	-0.022	0.020	-0.017	0.020
($= R3$)	(0.048)	(0.052)	(0.047)	(0.049)
South Central Region Dummy	-0.008	0.015	-0.001	0.014
($= R4$)	(0.047)	(0.052)	(0.046)	(0.049)
Wabash Region Dummy	0.043	0.026	0.053	0.019
($= R5$)	(0.043)	(0.050)	(0.042)	(0.047)
West Southwest Region Dummy	0.014	0.024	0.024	0.022
($= R6$)	(0.044)	(0.051)	(0.044)	(0.048)
Little Egypt Region Dummy	0.041	0.025	0.051	0.017
($= R7$)	(0.043)	(0.050)	(0.042)	(0.047)
$ER \times R2$	-0.106	-0.051	-0.096	-0.036
	(0.216)	(0.120)	(0.213)	(0.113)
$ER \times R3$	-0.095	0.019	-0.058	0.029
	(0.209)	(0.120)	(0.206)	(0.113)
$ER \times R4$	-0.042	0.033	0.007	0.038
	(0.201)	(0.119)	(0.198)	(0.112)
$ER \times R5$	-0.014	-0.048	0.013	-0.045
	(0.188)	(0.118)	(0.186)	(0.111)
$ER \times R6$	0.053	-0.013	0.116	-0.009
	(0.190)	(0.115)	(0.188)	(0.108)
$ER \times R7$	-0.061	-0.064	-0.030	-0.065
	(0.191)	(0.115)	(0.189)	(0.108)
Intercept	-0.026	-0.049	-0.130	0.260**
	(0.033)	(0.037)	(0.102)	(0.103)
Number of Observations	168	168	168	168
R^{2B}	0.46	0.75	0.48	0.78

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, Standard errors reported in parentheses
A. One-tailed $t-$tests are implemented given positive sign is expected.
B. R^2 is reported from separate OLS estimations.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain, Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.10: FEP-SUR Estimation of Dollar-Measured Net Return to Hedged Storage, One-Time-Sale Marketing, Illinois Corn and Soybeans, 1989-2012 Crop Years

	Observed Net Return to Unhedged Storage			
Variable	Corn (I)	Soybeans (I)	Corn (II)	Soybeans (II)
Expected Net Return to Hedged Storage^A	0.410	-0.491	0.161	-1.309
($= ER$)	(0.882)	(0.678)	(0.913)	(0.643)
Harvest Progress Rate			0.772***	0.822*
			(0.223)	(0.492)
Demand-Supply Ratio of Storage Bin Space^A			1.959***	5.364***
			(0.557)	(0.712)
Western Region Dummy	0.034	0.065	0.020	0.053
($= R2$)	(0.309)	(0.466)	(0.287)	(0.405)
North Central Region Dummy	0.033	0.175	0.019	0.153
($= R3$)	(0.309)	(0.460)	(0.287)	(0.399)
South Central Region Dummy	0.003	0.098	0.005	0.088
($= R4$)	(0.301)	(0.461)	(0.280)	(0.401)
Wabash Region Dummy	0.062	0.223	0.081	0.275
($= R5$)	(0.280)	(0.442)	(0.259)	(0.383)
West Southwest Region Dummy	0.027	0.160	0.031	0.177
($= R6$)	(0.289)	(0.453)	(0.268)	(0.393)
Little Egypt Region Dummy	0.062	0.214	0.081	0.281
($= R7$)	(0.280)	(0.442)	(0.259)	(0.383)
$ER \times R2$	0.263	0.163	0.172	0.074
	(1.293)	(0.980)	(1.260)	(0.897)
$ER \times R3$	0.276	0.488	0.202	0.270
	(1.251)	(0.979)	(1.220)	(0.896)
$ER \times R4$	0.039	0.250	0.058	0.131
	(1.198)	(0.962)	(1.173)	(0.884)
$ER \times R5$	0.071	0.339	-0.037	0.103
	(1.121)	(0.956)	(1.098)	(0.878)
$ER \times R6$	0.130	0.342	0.088	0.254
	(1.143)	(0.939)	(1.116)	(0.857)
$ER \times R7$	0.057	0.312	-0.022	0.212
	(1.139)	(0.931)	(1.115)	(0.855)
Intercept	0.029	0.336	-2.234***	-5.517***
	(0.215)	(0.330)	(0.616)	(0.835)
Number of Observations	168	168	168	168
R^{2B}	0.05	0.01	0.23	0.28

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, Standard errors reported in parentheses
A. One-tailed $t-$tests are implemented given positive sign is expected.
B. R^2 is reported from separate OLS estimations.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.11: FEP-SUR Estimation of Dollar-Measured Net Return to Unhedged Storage, One-Time-Sale Marketing, Illinois Corn and Soybeans, 1989-2012 Crop Years

Region	Average Percent Return to Hedged Storage			
	Routine	Basis	HPR	STORCAP
Northern	-0.107	0.111	0.022	0.046
Western	-0.111	0.075	0.023	0.041
North Central	-0.121	0.083	0.017	0.033
South Central	-0.110	0.111	0.022	0.041
Wabash	-0.009	0.126	0.089	0.116
West Southwest	-0.081	0.128	0.032	0.067
Little Egypt	-0.009	0.125	0.084	0.110
Average	-0.078	0.108	0.041	0.065
Binomial Sign Test[A]				
Test 1: Obs.[B] > Routine (Total Obs.[C])	–	110*** (115)	71*** (77)	77*** (77)
Test 2: Obs.[D] > Basis (Total Obs.)	–	–	4*** (48)	7*** (42)

Region	Standard Deviation, Percent Hedged Storage Return			
	Routine	Basis	HPR	STORCAP
Northern	0.184	0.081	0.173	0.163
Western	0.165	0.123	0.155	0.153
North Central	0.136	0.107	0.138	0.139
South Central	0.152	0.079	0.145	0.149
Wabash	0.186	0.102	0.137	0.120
West Southwest	0.192	0.082	0.176	0.164
Little Egypt	0.172	0.106	0.126	0.126
Average	0.170	0.097	0.150	0.145
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	50.6***	4.9**	4.8**
Test 2: Equal Variance to Basis	–	–	22.2***	26.7***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.12: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Dollar-Measured Net Return to Hedged Storage, Illinois Corn, 1989-2012 Crop Years

Region	Average Percent Return to Hedged Storage			
	Routine	Basis	HPR	STORCAP
Northern	-0.247	0.119	-0.060	-0.036
Western	-0.231	0.119	-0.036	-0.023
North Central	-0.205	0.104	-0.025	0.003
South Central	-0.223	0.119	-0.022	-0.007
Wabash	-0.133	0.119	0.028	0.052
West Southwest	-0.187	0.147	-0.010	0.021
Little Egypt	-0.136	0.112	0.025	0.050
Average	-0.195	0.120	-0.014	0.009
Binomial Sign Test^{A}				
Test 1: Obs.^{B} > Routine (Total Obs.^{C})	–	132*** (136)	78*** (84)	70*** (77)
Test 2: Obs.^{D} > Basis (Total Obs.)	–	–	5*** (66)	5*** (75)

Region	Standard Deviation, Percent Hedged Storage Return			
	Routine	Basis	HPR	STORCAP
Northern	0.307	0.060	0.317	0.237
Western	0.290	0.070	0.281	0.222
North Central	0.293	0.103	0.296	0.190
South Central	0.290	0.073	0.294	0.198
Wabash	0.290	0.144	0.240	0.207
West Southwest	0.312	0.086	0.274	0.228
Little Egypt	0.296	0.140	0.244	0.207
Average	0.297	0.097	0.278	0.213
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	79.8***	4.3**	5.6**
Test 2: Equal Variance to Basis	–	–	44.2***	85.0***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.13: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Dollar-Measured Net Return to Hedged Storage, Illinois Soybeans, 1989-2012 Crop Years

	Average Percent Return to Unhedged Storage			
Region	Routine	Basis	HPR	STORCAP
Northern	-0.030	0.045	0.179	0.125
Western	-0.034	0.212	0.180	0.120
North Central	-0.043	0.224	0.174	0.112
South Central	-0.033	0.052	0.179	0.119
Wabash	0.068	0.201	0.246	0.195
West Southwest	-0.004	0.052	0.189	0.146
Little Egypt	0.068	0.199	0.241	0.189
Average	-0.001	0.140	0.198	0.144
Binomial Sign Test[A]				
Test 1: Obs.[B] > Routine (Total Obs.[C])	–	83*** (115)	63*** (77)	58*** (77)
Test 2: Obs.[D] > Basis (Total Obs.)	–	–	23 (48)	15** (42)

	Standard Deviation, Percent Unhedged Storage Return			
Region	Routine	Basis	HPR	STORCAP
Northern	0.908	0.217	0.823	0.776
Western	0.903	0.699	0.816	0.774
North Central	0.913	0.718	0.828	0.791
South Central	0.893	0.230	0.809	0.770
Wabash	0.904	0.736	0.814	0.762
West Southwest	0.874	0.227	0.793	0.727
Little Egypt	0.907	0.739	0.819	0.770
Average	0.900	0.509	0.815	0.767
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	25.7***	3.0*	6.4**
Test 2: Equal Variance to Basis	–	–	10.0***	5.5**

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.14: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Dollar-Measured Net Return to Unhedged Storage, Illinois Corn, 1989-2012 Crop Years

Region	Average Percent Return to Unhedged Storage			
	Routine	Basis	HPR	STORCAP
Northern	0.469	0.126	0.389	0.416
Western	0.486	0.106	0.413	0.429
North Central	0.511	0.145	0.424	0.455
South Central	0.493	0.088	0.427	0.445
Wabash	0.584	0.265	0.477	0.504
West Southwest	0.530	0.206	0.439	0.473
Little Egypt	0.580	0.311	0.474	0.502
Average	0.522	0.178	0.435	0.461
Binomial Sign Test^A				
Test 1: Obs.^{B} > Routine (Total Obs.^{C})	–	65 (136)	47 (84)	40 (77)
Test 2: Obs.^{D} > Basis (Total Obs.)	–	–	41** (66)	42 (75)

Region	Standard Deviation, Percent Unhedged Storage Return			
	Routine	Basis	HPR	STORCAP
Northern	1.365	0.046	1.125	1.207
Western	1.384	0.129	1.148	1.226
North Central	1.391	0.243	1.151	1.235
South Central	1.372	0.164	1.144	1.224
Wabash	1.364	0.641	1.125	1.216
West Southwest	1.369	0.430	1.120	1.215
Little Egypt	1.359	0.714	1.119	1.212
Average	1.372	0.338	1.133	1.219
Levene's Nonparametric Test				
Test 1: Equal Variance to Routine	–	93.3***	10.1***	4.1**
Test 2: Equal Variance to Basis	–	–	32.8***	50.4***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. A. A binomial sign test (Kastens and Dhuyvetter, 1999) assumes 0.5 probability of observing higher return of a strategy relative to another strategy. B. P-value is the probability of drawing the observed number or more. C. It is the number of observations for which both strategies' returns are not the same. D. P-value is the probability of drawing the observed number or less.

Source: original calculation using data from USDA *Crop Production* report, USDA Commodity Credit Corporation, Ohio Country Elevator, USDA *Weekly Weather and Crop Bulletin*, Illinois Department of Agriculture, USDA *Grain Stocks* report, Federal Reserve Economic Data, Chicago Mercantile Exchange

Table 3.15: Return and Risk Performance of Storage Strategies, One-Time-Sale Marketing, Dollar-Measured Net Return to Unhedged Storage, Illinois Soybeans, 1989-2012 Crop Years

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