Optimal Storage Capacity Allocation in Grain Merchandizing

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Abstract

Grain storage is an important problem for both farmers and grain merchants; however, it is especially central to the success of the grain merchandizing companies because the time, price, and quantity of both the commodity purchases as well as sales determine the company’s profitability over a specific time. Since commodity storage is a finite resource, merchandizers have to dynamically allocate its capacity among competing commodities in face of uncertainty, considering opportunity cost at all times. Important decision making steps can be described as follows: which grain, how much of it, and at what price one should buy in order to sell it profitably in the future while at the same time lining up the capacity for the next commodity’s quantity with a given price.

Studies focus on on-site storage for farmers, and many research and extension programs investigate the optimal timing of sales (Musser, 1996; Lai et al., 2003; Kadjo, 2013). However, no studies analyze the storage allocation problem for a grain merchandizing line of business, with such attributes as handling more than one grain and operating under price volatility, various harvesting cycles, and a limited storage capacity. This study incorporates price distributions based on historical data to solve the optimal grain storage problem for a grain merchandizer. An optimal partial selling rule is derived in the model allowing optimal allocation to spread sales out over the storage period.

Keywords: Grain storage; optimal dynamic allocation; price volatility
I. **Introduction**

Grain storage is an important problem for both farmers and grain merchandizing companies. For farmers, on-farm storage allows timing commodity sales, which has important effects on the farm profitability (Lai et al. 2003, Williams and Wright 1991, Miranda and Rui 1999, Miranda and Glauber 1993, Cafiero et al. 2014). For merchandizers, the time, price, and quantity of both the commodity purchases and sales determine profitability and long term viability of the merchandizing house. Since commodity storage is a finite resource, merchandizers have to allocate the available storage capacity among competing for storage commodities that overlap in the turn-around cycles to maximize the house’ profit.

This dynamic optimization problem can be summarized in the simple terms as follows: which grain, what quantity, and at what price one should buy and at what time one should sell it while simultaneously planning to make storage capacity available for another commodity in consideration for purchase at a different time and with particular expected entry and exit prices. Thus, maximizing profit over purchases and sales of the multiple commodities in a one year production cycle during which purchases and sales of the commodities overlap.
The operations research and management literature addresses some aspects of this problem such as the asset selling side of it in the inventory control theory (Benavides-Perales, 2010). However, its applications are mostly focused on the manufactured goods, with a few exceptions such as Shi et al. (2013) that apply it to an agricultural commodity, coffee. Yet, Shi et al. (2013) approaches the problem from the sale decision point only.
This study connects operations research and management with agricultural economics in a way that incorporates both purchase and sale decision points. For example, Scoular’s top traded commodities such as wheat, barley, corn, and dry distiller grain are considered in order to provide an optimal policy model that can optimize the decisions of the purchase and sale time, quantity, and price range.
In some cases, storing grain with the expectation of higher prices may produce higher total returns even after accounting for storage costs. However, this strategy includes a risk due to two factors: price of the commodity at hand as well as the opportunity cost associated with having the same storage space potentially available to another crop, whose pricing structure may prove even more profitable. Thus, profit could be negatively affected not just by the conventional risk of falling prices over the storage period, but by the increase of another crop’s price that could have been a part of the merchandizer’s grain portfolio.

Researchers conduct analysis to determine the best time to buy and sell by using dynamic optimization method (Shi et al., 2013). Furthermore, most of the studies focuses on the on-site storage for farmers (Acharya, 2013). Many research and extension programs investigates the optimal timing of sales from farmers’ storage facilities (Acharya, 2013). These studies generally
concentrate on a single product. The problem is constructed by restricting the model with irreversibility and inapplicable price distributions (Lai et al. 2003). However, no studies were found that analyze the storage problem for a grain storage company, which handles more than one grain and operates under various harvesting cycles, and a limited storage capacity.

This study aims to show how the optimal grain storage problem for a grain merchandizer can be solved by incorporating realistic price distributions (based on the historical data). Stochastic dynamic programming in a discrete-time framework will be used to derive optimal storage. In the model, an optimal partial selling rule is derived at a limited storage capacity, which allows optimal allocation to spread sales out over the storage period while considering another grain’s harvest at hand.

![Figure 4](image.png)

Where $t$ is time,
$p$ is price,
$q$ is quantity

Figure 4. A schematic view of the grain merchant buy and sell decision.

II. Literature Review
Studies about the grain storage are generally linked to the behavior of commodity forward and future prices and how the decisions of the agents impacts the spot and future prices. Three types of agents are included in the storage models: 1) consumers in the demand side and their demand determine the spot price at the equilibrium point with the supply of the spot commodity; 2) producers on the supply side, who make storage and hedging decision based on the spot and future prices; and 3) speculators, whose demand for commodity futures, along with the futures hedging demand of producers, determine the commodity futures price. The behavior of commodity forward and future prices states that the speculators requires a risk premium for hedging the spot price exposure of producers, and the hedging pressure is significantly linked to future excess returns (Carter, Rausser, and Schmitz, 1983; Acharya, 2013). However, according to the theory of storage, optimal inventory management determines the forward prices and explains the decision of storage based on the expectation of the declining spot prices (Kaldor, 1939; Working, 1949; and Brennan, 1958). This theory has been tested in different studies (Fama and French, 1987; Ng and Pirrong, 1994) with various models (e.g. partial equilibrium model by Deaton and Laroque (1992), and Bobenrieth et al. (2002); computable general equilibrium model by Arseneau (2013)).

It is believed that agricultural commodity storage holds a stream of benefits called convenience explained by Brennan (1958). Fama and French (1987) introduced two basic reasons of the convenience about the inventory of the agricultural commodities. One is that producers and/or consumers who hold the commodity physically could find benefits of having supplies (stocks) of the commodity to meet the unexpected demand. The other one is that the supplies of the commodity could be used at any time as an input in a production process. Benavides-Perales (2010) tested one of the implications of the theory of storage by assuming that
spot and futures price volatilities are influenced by supply and demand fundamentals and he used convenience yields as a proxy variable for supply and demand fundamentals. Thus, the analysis will consider the influences of the convenience yields on spot and futures price return volatilities for each commodity under analysis. However, to our knowledge, none of the studies look at the decision of the storage facility which encounters several overlapping decision-point mechanism based on the limitation of the storage capacity, allocation of the storage area for several crops and the combination of the theory of storage with these subjects.

III. Data

In this study, we consider a storage facility that stores three crops: corn, soybean, and wheat. Crops are accessible by the storage facility in different times based on the crop’s own harvest date. They are subsequently sold based on the price expectation and the decision of the storage facility whether or not they want to replace the stored crop with the new harvested product. Monthly spot prices of corn, soybean and wheat are collected from US Department of Agriculture (USDA-NASS, 2016). The monthly future prices of these crops are obtained from the University of Wisconsin extension service.
Figure 5. Seasonally Adjusted Corn Price Indices and Confidence Interval

Figure 6. Seasonally Adjusted Soybeans Price Indices and Confidence Interval

Figure 7. Seasonally Adjusted Wheat Price Indices and Confidence Interval
The analysis are conducted for sample period of 22 years from January 1994 to December 2015 and the sample size is 264 observations. The data for monthly diesel #2 prices are obtained from US Energy Information System Administration (US-EIA, 2016). Lastly, the quarterly storage data, annual production, and annual storage cost for the analyzed agricultural commodities are collected from US Department of Agriculture (USDA-NASS, 2016). The storage cost per period are determined by using weighting the annual cost with the stored grain amount and it is used to calculate the adjusted spread for each crop.

IV. Model

In each period, the storage firm aims to maximize profit from buying and selling the grains (C) and store some of the grains as a composite tradable good (S). The firm decision during one-year cycle is then a profit maximization problem over harvest (H) and post-harvest period (PH).

When \( S_{t2}^* \leq S_{TOTAL} \), and \( S_{t3}^* \leq S_{TOTAL} \), storage availability is:

\[
S_{t2}^* = C_{1p}^{t1} - C_{1s}^{t2} + C_{2p}^{t2}
\]

\[
S_{t3}^* = C_{1p}^{t1} - C_{1s}^{t2} + C_{2p}^{t2} - C_{1s}^{t3} - C_{2s}^{t3} + C_{3p}^{t3}
\]
Then, the storage availability after buys are:

<table>
<thead>
<tr>
<th>Buy:</th>
<th>$C_{1p}^{t1}$</th>
<th>Buying</th>
<th>$C_{1s}^{t2}$</th>
<th>Buying</th>
<th>$C_{3p}^{t3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$p_{C1p}$</td>
<td>Commodity 1</td>
<td>$p_{C2p}$</td>
<td>Commodity 2</td>
<td>$p_{C3p}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sell:</th>
<th>$t_1$</th>
<th>Selling</th>
<th>$t_2$</th>
<th>Selling</th>
<th>$t_3$</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Commodity 1</td>
<td>Commodity 1 &amp; 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{1s}^{t2}$</td>
<td>$C_{1s}^{t3}$</td>
<td>$C_{2s}^{t3}$</td>
<td>$p_{C1s}$</td>
<td>$p_{C1s}$</td>
</tr>
</tbody>
</table>

Storage availability after sales are:

$$S_{t2}' = C_{1p}^{t1} - C_{1s}^{t2} \text{ when } S_{t2}' \leq S_{TOTAL}$$

$$S_{t3}'' = C_{1p}^{t1} - C_{1s}^{t2} + C_{2p}^{t3} - C_{1s}^{t3} + C_{2p}^{t3} \text{ when } S_{t3}'' \leq S_{TOTAL}.$$ 

Then, the revenue can be calculated as

$$R = (p_{C1s}^{t2} - p_{C1p}^{t1}) \cdot C_{1s}^{t2} + (p_{C1s}^{t3} - p_{C1p}^{t2}) \cdot C_{1s}^{t3} + (p_{C2s}^{t3} - p_{C2p}^{t2}) \cdot C_{2s}^{t3}$$

Subject to $S_{t2}' \leq S_{TOTAL}$ and $S_{t3}'' \leq S_{TOTAL},$ and so on.

V. Preliminary Results

The preliminary results suggest that the spreads are seasonal – they are the highest when it is harvesting season for the new crop. Thus, the spreads between the prices of the crop sold and bought are the highest during seasonal changes. Therefore, the most advantageous price differentials take place during this time. One of the implications of this dynamic is that a merchandizer would be better off discounting (selling cheaper than the market price) the older grain and buying a newly harvested (the same or different type of) grain since this grain would
be priced at a premium relative to the older grain. However, if this implication is not universal, and there are cases when this rule breaks down, for example, at the cusps of boom and bust cycles.

Figure 8. Cycle and Seasons in Monthly Corn Prices

Figure 9. Cycle and Seasons in Monthly Soybean Prices
Figure 10. Cycle and Seasons in Monthly Wheat Prices
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