Are stockholders rational? An experimental approach to testing the competitive storage model

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Abstract

The competitive storage model has been the main workhorse of the analysis of the role of storage in commodity price formation since Gustafson proposed his model in 1958. The main approach to testing the competitive storage model has been the comparison of the characteristics of the predicted prices series with actual commodity price series. This paper introduces a new approach to testing the competitive storage model. A relatively simple model is taken to the experimental laboratory. Participants in the experiment are asked make storage decisions within a competitive storage model framework. Their behaviour and the resulting price series are compared to the model assumptions and predictions. The experiment will be run at the University of Trento in April 2014.

Keywords Agricultural Commodity Prices, Storage, Experiment

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1. Introduction

Low stocks are one of the factors often cited as contributing factors to the 2007/08 and 2010/11 grain price peaks. Stocks-to-use ratios were low for a number of agricultural commodities around the time of the 2007/08 price rises (European Commission, 2008; OECD, 2008; Wiggins and Keats, 2010). Thirle et al. (2009, p. 1) even suggested that “if a single factor is to be identified as the cause of the recent price spikes, it has to be low stocks.”

The importance of stock-holding in price formation especially for agricultural commodities has long been acknowledged. Models analysing the link between intertemporal price formation and storage go back to at least the 1930s and 1940s. Working’s seminal work on the role of storage for futures markets and intertemporal price formation is an important example of these earlier studies (e.g. Working, 1948, 1949).

Samuelson (1957) contributed with the introduction of his model of intertemporal price equilibrium. Under the assumptions of the model, prices follow a regular intertemporal pattern. The model assumes that demand and supply are known. Storage is subject to costs. Demand is constant and continuous. Supply is also constant but not continuous. There is only one harvest per year. This simple model predicts that prices are at their lowest point at harvest and then rise gradually until the next harvest when prices fall back to the level of the previous harvest. Prices rise steadily between harvests because of storage and interest costs. The simple model can be extended to allow for variable production of known size. In this case, prices again follow a zigzag pattern but in a more irregular fashion.

Gustafson (1958) introduced the stochastic competitive storage model by adding uncertainty to the model of storage and price formation. In his model, harvests are subject to yield shocks. The outcome of the shock is not known at the time production decisions are made. However, the distribution of the harvest shocks is known to market participants. The non-negativity constraint on storage makes the model analytically intractable. Gustafson solved the infinite horizon model using dynamic programming techniques anticipating modern macroeconomic savings theory. In effect, Gustafson’s optimal storage model is basically a rational expectations model and was published three years before Muth (1961) introduced the concept of rational expectations. Since then, the competitive storage model has been the main workhorse of the analysis of the role of storage in commodity price formation.

The main approach to testing the competitive storage model has been the comparison of the characteristics of the predicted prices series with actual commodity price series. Williams and Wright (1991) investigate implications of storage within the competitive storage model for price series of storable commodities. Deaton and Laroque (1992, 1996) set out to examine the empirical relevance of the competitive storage model. Deaton and Laroque (1992) compare actual commodity prices with prices predicted by the competitive storage model. The characteristics of the model price predictions are similar to actual commodity prices with respect to the asymmetry of price movements and the presence of price spikes. However, with respect to the persistence in prices, the model does not predict the extent of the autocorrelation seen in actual commodity price series (Deaton and Laroque, 1996).

The question of the real world relevance of the competitive storage model is revisited in a number of recent papers. Cafiero et al. (2011) base their model on the Deaton and Laroque models but use different, and in their view more realistic, parameters. They also use
a finer grid when approximating the equilibrium price function while using the same model and econometric estimation techniques as Deaton and Laroque (1996). With these adjustments to the Deaton and Laroque models autocorrelations are of similar magnitude to observed autocorrelations for the commodities studied.

Miao et al. (2011) extend the Deaton and Laroque model by introducing trends in demand and supply and variable interest rates. They conclude that their model replicates the main characteristics of actual commodity price series, among them observed autocorrelations of commodity price series. Arseneau and Leduc (2013) incorporate a competitive storage model in a general equilibrium model. In this extended model, the interest rate is endogenous. They also find that prices predicted by their model can replicate the levels of autocorrelation in actual commodity prices.

This paper introduces a new approach to testing the competitive storage model. A relatively simple version of the competitive storage model is taken to the experimental laboratory. To the best of our knowledge, this is the first experimental study of the competitive storage model.

Abbink et al. (2011) present an experimental study of storage decisions of maize traders in Zambia. The studies focus is on the two sectors of the market that can exert market power in the Zambian maize market, large traders and government. The presence of players with market power complicates the analysis as it introduces strategic behaviour and requires a game-theoretic approach. The model on which their experimental design is based is, therefore, a game of strategic interaction between government and a small number of private stockholders.

The absence of experimental work on the competitive storage model in the literature is all the more surprising because experiments on optimal savings theory go back to the 1980s (Hey, 1988; Hey and Dardanoni 1988). As Gouel (2013) points out, the competitive storage model is formally very similar to the rational expectations model of optimal savings under income uncertainty. Experimental work on optimal saving have generally found that subjects save less than predicted by optimal savings models (Brown et al., 2009).

In our experiment participants are asked make storage decision within a competitive storage model framework. Their behaviour, the aggregate stock level and the resulting price series are compared to the model assumptions and predictions.

2. The competitive storage model

The competitive storage model is a model rational expectations model of optimal storage for a commodity where production is uncertain and the commodity is storable from one period to another, such an annual agricultural crop that is storable. The model can be formulated with a single state variable, a single control variable and one arbitrage equation.

In every period $t$, stockholders start holding a pre-determined level of the commodity in storage, $s_{t-1}$. The quantity of the commodity available in period $t$, availability $a_t$, is the state variable. Availability is the quantity in storage at the beginning of $t$, $s_{t-1}$, plus the harvest in period $t$. The quantity harvested is an exogenous random variable $\varepsilon_t$. Availability in period $t$, $a_t$, can be used for consumption and storage. The amount used for consumption, $c_t$ is sold to consumers at the price that clears the market, $p_t = P(c_t)$. The difference between availability, $a_t$, and consumption, $c_t$, is the amount stored $s_t$, the control variable in the model. In the next period $t+1$, pre-determined storage at the beginning is $s_t$ which together with exogenous production, $\varepsilon_{t+1}$, gives the total amount available in period $t+1$, $a_{t+1}$. The transition equation of the dynamic model therefore is:
\[ a_{t+1} = s_t + \epsilon_{t+1} \]  \hspace{1cm} (1)

Availability in \( t+1 \), \( a_{t+1} \) depends on the exogenous variable \( \epsilon_{t+1} \) and the endogenous variable, \( s_t \).

The stockholders’ objective is to maximise their expected profit which leads to the storage arbitrage equation.

\[ \delta E_t[p_{t+1}] - p_t - c = \pi_t \]  \hspace{1cm} (2)

Where \( \delta \) is the discount rate, \( E_t[p_{t+1}] \) is the expected price for period \( t+1 \) in period \( t \), \( p_t \) is the price in period \( t \), \( c \) is the unit storage cost and \( \pi_t \) is expected profit. As noted before, \( s_t \) the amount of the commodity stored from period \( t \) to period \( t+1 \), is the control variable that the agents in the model, the stockholders, adjust to maximise their profits. In a competitive market and in the absence of storage capacity limitations, stockholders will adjust the storage level until the expected profits are zero. The arbitrage equation can be written as a function of the state variable \( a \) and the control variable \( s \).

\[ \delta E_t[P(a_{t+1} - s_{t+1})] - P(a_t - s_t) - c = \pi_t \]  \hspace{1cm} (3)

As a whole, the economy cannot borrow production from future periods. Therefore, storage cannot be negative. The non-negativity constraint limits arbitrage when storage is zero and in these situations expected profits are negative.

\[ \delta E_t[P(a_{t+1} - s_{t+1})] - P(a_t - s_t) - c = \pi_t \]  \hspace{1cm} (4)

\[ s_t \geq 0, \ \pi_t \leq 0, \ s_t > 0 \Rightarrow \pi_t = 0 \]

When profits are positive, that is when the discounted expected price in period \( t \) for period \( t+1 \) exceeds the current price minus storage costs, stockholders will store another unit which will lower availability and increase the price in period \( t \) and increase availability and decrease the price in period \( t+1 \). Stockholders will continue to increase storage until expected profit is zero is reached. When profits are negative, that is when the discounted expected price in period \( t \) for period \( t+1 \) is lower than the current price minus storage costs, stockholders will reduce storage. Reducing storage increases availability and reduces the price in period \( t \) and at the same time lowers availability and increases the price in period \( t+1 \). When stocks are zero, arbitrage is limited and expected profit from storage is negative.

In a rational expectations model, agents’ expectations for variables in the next period have to be consistent with the resultant distribution of these variables given the structure of the model, the parameters in the model and the expectations. In the present model the expectations are with respect to the price in the next period. In the simple version of the model, stockholders are the only agents. They have to make a decision on how much of the commodity to store from one period to the next and this decision depends on their expectation of the price in the next period. The model does not have a closed-form solution because of the non-negativity constraint on storage and needs to be solved numerically.

3. The experiment

3.1 Participants and Procedures
The experiment will be run at the Cognitive and Experimental Economics Laboratory (CEEL) of the University of Trento in April 2014 (sessions planned for 8th and 15th of April 2014). Four sessions each with 24 participants are foreseen. Participants are generally undergraduate students at the University of Trento from different faculties of the university. At the start of the experiment, participants will be randomly assigned to three groups of eight. The composition of the group will not change during the experiment (“partner matching”). Each session will consist of 25 periods. The experiment will be run as a computerised experiment, programmed and conducted using the z-Tree software (Fischbacher, 2007).

Before the start of the experiment, participants will be given written instructions which will also be read out aloud after participants had a chance to read them privately. The experiment will only start after participants had a chance to ask questions and after all have answered a number of control questions correctly. The control questions relate to the number of rounds, the group composition, the price function, the price mechanism and the initial endowment they receive. The experiment is framed as a wheat storage experiment.

Participants will be paid a show-up fee of 3.00 Euro plus the amount that they will have at their disposal at the end of the 25th round. This amount will depend on the transactions they make during the 25 rounds. It will be calculated as the initial endowment plus any profit made from buying and selling units of wheat on the market or minus any loss from buying and selling units of wheat. To lessen a potential terminal period effect, participants with wheat left in storage after round 25 will receive the average price over the 25 rounds for the wheat in storage.

At the end of the experiment, participants will be asked to fill in a short questionnaire including questions about their age, gender, field of study as well as their assessment of the experiment. The payments will be made in private at the end of the experiment.

3.2 Experimental Design

All participants in the experiments have exactly the same role, namely that of wheat traders, who can buy, sell and store wheat. They compete in a market with the other members of their group. To keep the initial experiment as simple as possible storage costs and discounting are not included in the experiment.

There is a single wheat harvest in each round. To keep experiment as simple as possible and facilitate communication of the main aspects to participants, a three point distribution was chosen for the harvest: a small harvest of 50 units, a medium of 60 units and good harvest 65 units. In each round, the probability that the harvest is 50 units is 20%, that it is 60 units is 40% and that it is 65 units is 40%.

Consumers are implicit in the market clearing demand function. While in the literature constant elasticity functions are generally assumed, in this experiment a linear demand function was chosen because it is easier to communicate the main aspects of a linear function to participants.¹

For the experiment a linear demand function is used with elasticity $E_d = -0.5$ at the mean harvest of 60 units.

The market clearing demand in the experiment is:

$$C(p_t) = 90 - 20 \cdot p_t \quad (5)$$

¹ Gustafson (1958) used a constant elasticity demand function (p. 23f) with price elasticity of demand of -0.5 (for feed grains). However, he also carried out sensitivity analysis using a linear demand function where the price elasticity of demand at the "normal yield" is -0.5.
where \( C \) is consumption and \( p_t \) is the price in period \( t \).

The equivalent inverse demand function, or price function, is:

\[
P(c_t) = 4.5 - 0.05 \cdot c_t
\]

If the mean harvest of 60 units is consumed, the price is 1.5 as in Gustafson (1958).

At the beginning of the experiment, each participant receives an endowment of 10 euro that can be used to buy units of wheat. At the start of the experiment all participants start without wheat in storage. It would be possible to randomly assign units of wheat to participants at the start. However, this would introduce another random process to the experiment which has to be explained to participants creating an unnecessary additional level of complexity and possibly leading to confusion of the random processes.

To keep the experiment as simple as possible, each participant has a capacity of storage of one unit leading to a maximum storage capacity at the market level of eight. Wheat can only be bought, sold and stored in full units. In each period the participants will therefore be either a potential buyer (those participants that do not have any storage at beginning of the period) or a potential seller (those participants that hold one unit of storage at the beginning of the period).

At the beginning of each round participants are informed about the size of the harvest, (50, 60 or 65 units) and the total number of units of wheat stored by all group members (which can be between zero and eight). They are also reminded how many euro they have available. The price that would occur if no changes to storage were made is also displayed to help participants in their use of the consumption function. They are also reminded that whether or not the storage level changes, will depend on the decision taken by the participants.

Those participants with a unit of wheat in storage are potential sellers in that round and are asked to submit the minimum price for which they would wish to sell their unit of wheat (in steps of 0.05 euro). If the market price in the round is above the minimum price submitted their unit will be sold at the market price, if the market price is below the minimum price submitted their unit will not be sold. If the market price is exactly the same as the price submitted the unit might be sold or not depending on the stock adjustments necessary to clear the market.

The participants without any wheat in storage are potential buyers in that round and are asked to submit the maximum price for which they would want to buy a unit of wheat (in steps of 0.05 euro). Buyers cannot submit a maximum price that is higher than the amount in euro they have available in that round. If the market price in the round is below the maximum price submitted they buy a unit of wheat at the market price and if the market price is above the maximum price submitted they not buy a unit of wheat. If the market price is exactly the same as the price submitted they might by a unit or not depending on the stock adjustments necessary to clear the market. In each round, wheat not stored will be consumed according to the price function (6).

An algorithm included in the z-Tree program finds the market price. The market price is the unique price at which

a) all participants with a unit in storage sell if they submitted a minimum price higher than the price in the round and don’t sell if they submitted a price lower than the price in the round
b) all participants without a unit in storage buy if they submitted a maximum price lower than the market price in the round and don’t buy if they submitted a price higher than the price in the round

c) the number of units of wheat not stored at the market price are given a) and b) are demanded by consumers at the price in the round

If prices submitted by participants coincide with the market price, the number of transactions are made that are necessary to clear the market and if necessary participants to make transactions are chosen at random.

Given the market price determined for the round, the units in storage are adjusted and payments are made. Sellers receive the price for the unit they sold and buyers have to pay the price for the unit they bought.

At the end of each round, participants are informed about the market price in the round, their new level of storage, the payment they made or received and how many Euro they have available after the transactions. The storage level at the end of one round is the storage level at the start of the next round.

3.3 Competitive storage model predictions

In this section, the predictions using a continuous model with the same parameters as in the experiment are presented: a three-point distribution for the harvest (50, 60 and 65 units with probabilities of 0.2, 0.4 and 0.4, respectively), a linear demand function as specified in (6) and a maximum storage capacity of eight.

The storage function suggests that up to a level of availability (harvest plus stocks at the start of the period) of 57 units storage will be zero and that from a level of availability of 70 units storage will be at its maximum level of 8 units.

Figure 1 shows the equilibrium price function (upper kinked line) and the price function without storage (lower straight line). It shows that up to the level of availability below which no storage takes place, 57 units, the price is the same. When availability exceeds 58 units, the optimal storage rule leads to storage and thus to an increase in the price compared to the no storage scenario. The second kink in the equilibrium price function is at 70 units of availability. At 70 units of availability optimal storage reaches the maximum capacity level of 8 units and due to the limited capacity for storage, storage cannot increase further at higher availability levels and the equilibrium price function from that point onwards is parallel to the price function without storage.
Figure 1: Equilibrium price function and price function without storage

Figure 2 shows the expected path of the control variable, storage, when, as in the experiment, all participants start with zero stocks. The results are based on a model simulation of 2000 simulated series of 20 periods. Expected storage increases in the first two periods and reaches a level of just under 5 units in period 3.
The mean storage level is 4.7 units over all years. If the first three periods are excluded the mean level of storage is 4.9 units. The mean price is 1.51 with a standard deviation of 0.17. Excluding the first 3 periods, the mean price is 1.50 with a standard deviation of 0.17. Without storage, the mean price would be 1.5 and the standard deviation of the price would be 0.27. Optimal storage behaviour leads to a marginal increase in the mean price and to a 38% reduction in the standard deviation.

4. Hypotheses tested

The competitive storage model is based on two testable assumptions. Firstly, the competitive storage model assumes that storage decisions are only dependent on the state variable, availability, in the same period and thus that storage decisions are not dependent on history. Secondly, in the model rational stockholders base their storage decision on availability i.e. on the sum of storage at the beginning of the period and production in that period. One unit in storage has exactly the same effect on the storage decision as one unit of new production.

In addition, the main predictions with respect to the level of storage in the market and the resulting price can be tested. As reported in section 3.3, the model predicts a mean storage level of 4.7 units. This prediction will be compared to the average storage level in the experiment. Experiments on optimal saving theories have shown that subjects under-save compared to the prediction of the optimal savings model (Brown et al., 2009). Whether or not subjects under-store will be shown by the experiment.

When storage is optimal the resulting price series has a mean only marginally above the mean that would occur without storage but a 38 percent reduction in the standard deviation of the price series. The mean and standard deviation of the price series will be compared to those predicted by the optimal storage model.
5. Planned analysis and further research

At the outset of the analysis, a decision needs to be made whether or not to include all periods. Despite paying participants the average price for units in storage, there might still be a terminal period effect. If that is found to be the case, the last periods will be excluded.

The first two hypotheses can be analysed both at the individual level as well as at the group level. The optimal storage model suggests that if competitive stockholders are rational there decisions will depend exclusively variables in the current period. For the experiment this means that given a certain level of availability, the prices submitted by individual stockholders should not depend on any past variables. However, it is possibly that, even though individual decisions may not be rational, the market dynamics resulting from the individual decisions might nevertheless approach the dynamics suggested by the rational expectations model. Therefore, the first hypothesis can be also tested at the group level. At the group level, group storage should only depend on the current period and not on history of any variable. Both aspects of the hypothesis can be tested using regression analysis testing for significance of lagged variables.

Similarly, the second hypothesis can be tested at the individual and group level. According to the model, units harvested and units in storage at the beginning of the period have identical impacts on the storage decision. Again, a regression analysis can shed light on whether or not this assumption also holds for participant of the experiment.

The competitive storage model predicts an average level of storage of 4.9 after period 3. The average storage level from the experiment can be compared to the prediction. However, it will also be possible to look at how close storage in the experiment is to the prediction for each level of availability.

With regards to the resulting price series, the variation in the price is of more interest than the mean price. As discussed above, the mean price predicted by the optimal storage model is very close to the mean price without storage. The main effect of storage is the reduction in the variation of the price. The competitive storage model predicts a decrease in the standard deviation of the price of 38 percent which will be compared to the change in the standard deviation of the prices in the experiment.

It is possible that learning effects will occur in the experiment. Brown et al. (2009) found learning effects in their experiment on optimal savings. With overall 25 periods in the experiment, it will be possible to check for learning effects by splitting the sample and checking for difference between the early periods and later periods.

As outlined above, the aim of the current experiment is to keep the experiment as simple as possible. Future research on more complex and realistic settings would help to improve our understanding of real world storage decisions. The inclusion of storage costs is one obvious addition that could be made. Other possible extensions are the introduction of more complex harvest distributions, incomplete information on the harvest distribution and adding consumers and/or producers to the set-up.
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