Storage Subsidies and Supply Response

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Abstract

This paper investigates the supply response to a storage subsidy. From the ex post sales decision problem we derive the reservation price below which all risk averse farmers hold some inventory. While sales and storage decisions are made ex post, production decisions are made ex ante before the current market price is known. Storage subsidies are shown to encourage risk averse as well as risk neutral farmers to expand output. The analysis implies that storage subsidies should be incorporated in estimating supply response.

STORAGE SUBSIDIES AND SUPPLY RESPONSE

1. Introduction

In the context of the Uruguay Round of GATT negotiations and internal policy discussions in the United States much attention has been given to the effects of government programs on market and trade distortions. The focus of studies on this question has primarily been on price and income support programs. Potential distortions arising from storage subsidies have been ignored, although storage subsidies have been an important instrument in U.S. government programs especially since the establishment of the Farmer-Owned Reserve in 1977 (Burnstein and Langley).[1]

Following the Waugh-Oi-Massell contributions, the recent literature has emphasized the comparison of no-storage regime with the regime which allows competitive storage. In these studies market demand and supply are subject to additive shifts and are independent of storage subsidies, and the arbitragers in the storage industry are risk neutral (e.g., Helmberger, Weaver, and Haygood; Helmberger and Akinyosoye). Using this framework for soybeans, Helmberger and Akinyosoye concluded that if agents are risk neutral, "competitive storage has essentially no impact on the expected values of production, consumption and price" (p. 120). Since risk premium must be added to storage cost for risk averse arbitragers, they further pointed to the need for analyses of private storage for risk averse agents. Using the aggregate social surpluses, Helmberger and Weaver also demonstrated that in a competitive economy net social welfare is maximized when the storage is at the competitive level.

In a recent AJAE article Glauber, Helmberger and Miranda evaluated four alternative methods of stabilizing producer prices in the soybean sector. In their analysis producers are also assumed risk neutral and market supply is independent of storage subsidies. In this framework they discovered that as a means of stabilizing market price, *storage subsidy programs were the most cost effective.* In view of the significance of their finding, it is important to investigate whether production decisions are affected by storage subsidies.

The purpose of this paper is to investigate the impacts of storage subsidies on *supply response* which has been neglected in the literature. We focus on the firm level storage decisions of risk neutral and risk averse producers. Our approach differs from the literature in two important respects. First, we consider a risk neutral or risk averse farmer with the option of holding inventory. While the stocks can be held for more than one period, multiperiod inventory decisions are broken into a sequence of inventory decisions. In each period the producer decides to sell output or hold it as inventory. Second, sales and storage decisions are made ex post, but production decisions are made ex ante before the current market price is known. Although price variability has a negative output effect on the risk averse competitive producer (Baron; Sandmo), we show that storage subsidies induce risk neutral farmers to expand output. Intuitively, storage options reduce the risk that farmers have to sell their output at low prices.

Most analyses of storage subsidy programs assume that market supply and demand depend only on the expected market price, but not on storage subsidies. Our analysis suggests that even when producers are risk neutral, market supply responds positively to storage subsidies and hence the storage subsidy should be explicitly incorporated when estimating the aggregate supply response. Risk aversion may weaken the supply response to storage subsidies. How important the supply response of risk averse producers is to a storage subsidy is an empirical question.

2. Ex Post Sales and Storage Decisions

The inventory holding can be viewed as a speculative activity which incurs attendant storage costs and yields a random return. The major factors to be considered in assessing the return and risk of holding inventory are the current market price, the cost of storage, the storage subsidy, and the final selling price. The length of storage period is unknown. However, it is not an exogenous variable but is consciously controlled when the inventory decision is made each period. Although the output may be held for more than one period, the farmer faces a single decision at the beginning of each period: whether to sell the output at the known price or hold it as inventory and sell it at the unknown price in the next period.

The farmer may have inventory carried over from the preceding period. Profit in the preceding period is calculated based on the assumption that the inventory would be sold at the current price. Of course, the farmer can revise the plan and may hold the stock for one more period. In this case, however, a question arises regarding when the profit from speculative inventory accrues.

We assume that the speculative profit from holding output as inventory accrues to the current period when the current inventory decision is made, and does not accrue to the preceding period. This treatment is appropriate because when the farmer revises the sales plan and holds the same output as inventory one more period, the inventory decision is the sum of two transactions: (i) selling the inventory at the current market price as planned originally, and (ii) buying it back at the same price for speculative purposes. The speculative profit from the latter decision to hold inventory then should accrue to the current period. This storage decision depends on the profitability, evaluated at the current period, of holding inventory for one more period. Thus, for sales and storage decisions, it is not necessary for farmers to know the selling prices n periods ahead. As shall be shown shortly, these decisions are based on the current price, the storage subsidy, the storage cost, and the distribution of random market price one period ahead.

The following symbols are used to analyze the impacts of storage subsidy on production and sales decisions.

K = inventory at the beginning of period

Y = production

X = sales, $X \leq K + Y$

I = inventory at the end of period; $I = K + Y - X$

C(Y) = production cost

p = current market price

f = future market price

s = storage subsidy

t = private on-farm storage cost

$v = f + s - t$ = net future producer price

δ = discount factor.

$\pi = pX - C(Y) + \delta v(K + Y - X)$ = profit

$\mu = Ev$ = expected net future producer price

G(v) = distribution function of net future producer price

F(p) = distribution function of current price

Ex Post Supply and Inventory Decisions

The behavior of a risk neutral arbitrager seeking to maximize expected profit has been investigated in the literature (Helmberger, Weaver, and Haygood; Helmberger and Weaver; Helmberger and Akinyosoye). The present approach differs from these by considering a risk averse farmer with the option of holding speculative inventory.

Production and storage decisions of a farmer can be analyzed in two stages. We shall first consider the sales decision of a corn producer, given that the production decision has already been made and current price has been revealed. At the end of the production period the farmer has to make a decision concerning the supply of output X ($< K + Y$) at the known market price p, and the quantity of output to be held as inventory I, which will be sold at an unknown future price q.

Let f be the random future market price with distribution function H(f). Let s and t be the storage subsidy and the storage cost per unit of inventory the farmer incurs in the next period, respectively.[2] Then $v = f + s - t$ is the net future producer price, i.e., the price the farmer receives for output held as inventory and sold in the next period. For given s and t, the distribution of future market price H(f) induces a distribution G(v) of the net price the farmer receives. Specifically, an increase in s or a decrease in t results in a rightward shift in the distribution G(v). At the end of the period the farmer observes the current market price p and storage subsidy s, but the future price f is unknown. Since output is predetermined, the farmer allocates the total available supply, K + Y, between sales X and inventory (K + Y - X). Thus, the farmer's problem at the end of the period is to choose X to maximize the expected utility of profit,

$$EU(\pi) = \int_a^b U[pX - C(Y) + \delta v(K + Y - X)]dG(v)$$

subject to: $0 \leq X \leq K + Y$,

where $v \in [a,b]$ is the random net future producer price; δ (< 1) is the discount rate, $\pi = pX - C(X) + \delta v(K + Y - X)$ is random profit; and U(.) is a von Neumann-Morgenstern utility function assumed to be monotone increasing and concave, $U'(\pi) > 0$ and $U''(\pi) \leq 0$. Following Helmberger, Weaver and Haygood, the average storage cost t is assumed to be constant.

Let X_i, K_i, and Y_i respectively denote the quantities of output sold in the current period, the output carried over from the preceding period, and the output produced in the current period by farmer i. For a given individual, the quantity of output sold X_i can be negative, or exceed the sum of carryover and production ($X_i > K_i + Y_i$). However, if $X_i < 0$, then all other farmers and speculators must engage in an offsetting transaction to accommodate farmer i's speculative purchase. Similarly, if X_i exceeds $K_i + Y_i$, all other farmers and speculators must engage in accommodating transactions. In this paper we are concerned with the production and inventory behavior of the representative producer. Hence, the amount of sales in the current period, X_i, is limited between 0 and $K_i + Y_i$.

Collective decisions of farmers to hold more inventory reduce aggregate supply, and raise the market clearing price in the current period. However, to focus on the production and storage decisions at the individual farmer level, we assume that the representative farmer is a price taker. That is, the farmer behaves as if the inventory decision has no effect on the distribution of future price H(f), or the distribution G(v) of the net future producer price. For simplicity of exposition, the subscript i is dropped henceforth. Differentiating (1) with respect to X yields

$$EU_X = E[U'(p - \delta v)] = E[p - \delta v]\cdot EU' + Cov(U', p - \delta v). \qquad (1')$$

Since $0 \leq X \leq K + Y$, the Kuhn-Tucker conditions for a solution to (2) are

$$EU_X \begin{cases} \leq 0 & \text{if } X = 0, \\ = 0 & \text{if } 0 < X < K + Y, \\ \geq 0 & \text{if } X = K + Y. \end{cases} \qquad (2)$$

Note that if $X = K + Y$, then $\pi = pY - C(Y)$ is not random, and hence $Cov(U', p - \delta v)$ in (1′) is zero. However, if $X < K + Y$, then $Cov(U', p - \delta v)$ is positive. Let

$$p^* \equiv \delta\mu \tag{3}$$

be the reservation price for holding inventory, where $\mu \equiv Ev \equiv Ef + s - t$ is the expected net future producer price. The reservation price p^* can be interpreted as the expected value of holding one unit of inventory. Let $I = K + Y - X$ denote the inventory held at the end of period. Then the last inequality in (2) implies that for all risk averse farmers $I = 0$ if $p \geq p^*$. That is, *the producer holds inventory only if the current market price is less than the reservation price.*[3]

PROPOSITION 1: For all risk averse farmers the reservation price for holding output as inventory is $p^* \equiv \delta\mu$. That is,

$$I > 0 \text{ if } p < p^*, \text{ and } I = 0 \text{ if } p \geq p^*.$$

This result has a straightforward economic meaning. A risk averse farmer avoids a "fair" gamble (δv) and chooses expected value $p^* = \delta\mu$ with certainty. Thus, if $p = p^* \equiv \delta\mu$, holding inventory only increases risk without changing expected profit. In this case, the risk averse farmer sells all the available output, $K + Y$. When $p < p^*$, inventory holding is equivalent to owning a lottery offering better than fair odds. In this case the Kuhn-Tucker condition requires that the covariance term be positive, and hence the risk averse farmer will hold some inventory at the end of period ($X < K + Y$).

If the current market price is sufficiently low, the risk averse firm will hold its entire output ($K + Y$) as inventory. The highest value of the current price at which this occurs, p^a, is defined by equating $X = 0$ in equation (1′) and setting

$$E\{U'[- C(Y) + \delta v(K + Y)]\cdot(p^a - \delta v)\}$$

$$= EU'E(p^a - \delta v) + Cov(U',p^a - \delta v) = 0. \tag{4}$$

Note that $dU'/df = U''\delta(K + Y)$. For the risk neutral farmer, $U'' = 0$ and $p^a = p^*$. For a risk averse farmer, $Cov(U',p^a - \delta v) > 0$ and hence $E(p^a - \delta v)$ must be negative. That is, *a risk averse farmer has a lower reservation price than a risk neutral farmer,*

$$p^a < \delta\mu \equiv p^*.$$

Thus, the ex post supply function, $X(p,Y)$, of the risk averse farmer can be written as

$$X = K + Y \qquad \text{if } p \geq p^*,$$

$$K + Y > X > 0 \qquad \text{if } p^* > p > p^a$$

$$X = 0 \qquad \text{if } p^a \geq p. \tag{5}$$

We now investigate the properties of the ex post supply function $X(p,Y)$. Differentiating (1′) with respect to Y and rearranging terms gives

$$\partial I/\partial Y \equiv 1 - (\partial X/\partial Y) = (p - C')B/A; \tag{6}$$

$$A \equiv \int_a^b U''[\pi](p - \delta v)^2 dG(v),$$

$$B \equiv \int_a^b U''[\pi](p - \delta v)dG(v).$$

Note that risk aversion implies that A is negative. It is shown in the Appendix that given diminishing absolute risk aversion (DARA) B is negative. Thus,

$$\partial X/\partial Y \leq 1, \qquad \text{if } p \geq C' \qquad (7)$$

$$> 1, \qquad \text{if } p < C'.$$

This result has an intuitive interpretation. If $p \geq C'$, an increase in f increases profit ex post. DARA implies that speculative inventory, as a risk taking activity, is a normal good, i.e., inventory increases with profit. The inequality, $(\partial X/\partial Y) < 1$, implies that more risk is being assumed by holding more inventory as output Y increases $(\partial I/\partial Y > 0)$. On the other hand, when $p < C'$, an increase in output decreases profit and hence the farmer holds less inventory.

Differentiating (1′) with respect to p yields

$$\partial X/\partial p = -(XB + EU')/A. \qquad (8)$$

Since XB and EU′ have opposite signs, an increase in the current sales price may not increase the quantity supplied. However, when evaluated at $p = p^a$, $(\partial X/\partial p)$ is positive. Thus, the ex post supply curve is initially positively sloped but it can bend backward beyond a certain point. We assume that the ex post supply curve is positively sloped for $p \in [p^a, p^*]$.[4]

We close this section by considering the effect of increased uncertainty in net future producer price v on the ex post supply function. For instance, for given s and t, an increase in uncertainty in the future sales price f increases uncertainty in the net future producer price v. Replacing v by $\mu + \gamma(v - \mu)$ in equation (1′), differentiating it with respect to γ, and evaluating the result at $\gamma = 1$ gives

$$\partial X/\partial\gamma = E\{U'[\pi]\delta(v - \mu) - U''[\pi]I(p - \delta v)\delta(v - \mu)\}/A.$$

Using $\delta(v - \mu) = -(p - \delta v) + (p - p^*)$, the above expression can be rewritten as

$$\partial X/\partial \gamma = I + (p - p^*)\ E\{U'[\pi] - IB\}/A > 0 \tag{9}$$

since X < Y is defined for p < p*. Thus, for given sales price p, less inventory will be held if uncertainty in future price increases around a given expected value.

3. Ex Ante Production Decision

In this section we investigate the ex ante production decision of a competitive farmer given that the current sale price p has not been revealed. The optimal ex post supply function derived in the previous section will be incorporated into the analysis. For convenience of exposition, we rewrite the profit function

$$\pi = p(K + Y) - c(Y) + (p - \delta v)(X - K - Y), \tag{10}$$

where X is now a random variable, dependent on the value of the selling price realized at the end of the period.

Assume that current price p and future price f are independently distributed. Let F(p) be the distribution function of the current sales price. Given the distribution functions, G(v) and F(p), the competitive farmer's problem is to choose output Y to maximize the expected utility of profit

$$EU = \int_0^\infty \int_0^\infty U[p(K + Y) - C(Y) + (p - \delta v)(X - K - Y)]dF(p)dG(v). \tag{11}$$

The competitive firm considered by Baron and Sandmo does not hold inventory and must sell all its output. This no-speculation behavior of the competitive firm can be viewed as arising in a special case where the storage cost is high and/or the storage subsidy is low or nonexistent. For example, if $p > \delta\mu \equiv \delta(Ef + s - t)$, then the farmer will not hold any inventory. For such a low storage subsidy, the ex post supply always equals total output, Y, (since K = 0) and profit reduces to $\pi = pY - c(Y)$.

The first order condition for a maximum of expected utility is:

$$\int_0^\infty (p - C') \int_0^\infty U'[\pi] dG(v) dF(p) \tag{12}$$

$$+ \int_0^{p^a} (\partial X/\partial Y - 1) \int_0^\infty U'[\pi](p - \delta v) dG(v) dF(p)$$

$$+ \int_{p^a}^{p^*} (\partial X/\partial Y - 1) \int_0^\infty U'[\pi](p - \delta v) dG(v) dF(p)$$

$$+ \int_{p^*}^\infty (\partial X/\partial Y - 1) \int_0^\infty U'[\pi](p - \delta v) dG(v) dF(p) = 0.$$

Note that by (2), $\int U_X dG(v) = 0$ if $0 < X < K + Y$. Alternatively, for $p \in [p^a, p^*]$,

$$\int_0^\infty U'[\pi](p - \delta v) dG(v) = 0. \tag{13}$$

Thus, the third term on the left side of (12) is obtained by multiplying $(\partial X/\partial Y - 1)$ by (13) and integrating it over the range $[p^a, p^*]$, which is still zero. Since $X = K + Y$ and $(\partial X/\partial Y) = 1$ for all $p > p^*$, the last term on the left side of (12) is also zero. Next, consider the second term. If storage cost t exceeds Ef + s, then $\mu < 0$ and $p^* = 0 = p^a$, hence $F(p^*) = F(p^a) = 0$. If the storage cost is not prohibitively high, i.e., $t < Ef + s$, then $\mu > 0$ and $0 < p^a < p^*$. For $p < p^a$, $(\partial X/\partial Y) = 0$. Thus, the second term is zero if $F(p^a) = 0$, and is positive if $F(p^a) \neq 0$.

To evaluate the sign of the first term, let

$$\phi(p;G) = \int_0^\infty U[\pi|p] dG(v)$$

be the expected utility for a given p, and

$$\phi'(p;G) = \int_0^\infty U'[\pi|p]dG(v) \tag{14}$$

denote the conditional expected marginal utility of profit for a given p. The first term on the left side of (12) can be written as

$$E[(p - C')\phi'] = E(p - C')E\phi' + Cov(p,\phi'). \tag{15}$$

Differentiating ϕ' with respect to p yields

$$\partial\phi'/\partial p = \int_0^\infty U''[\pi]XdG(v) + B(\partial X/\partial p). \tag{16}$$

The first term on the right side of (16) is nonpositive. When $p < p^a$, $X = 0$ and the second term $B(\partial X/\partial p)$ is zero, so $\partial\phi'/\partial p = 0$. Given the plausible assumption of a positively sloped ex post supply curve in the region $[p^a,p^*]$, the second term on the right side of (16) is negative, and hence $\partial\phi'/\partial p$ is negative for $p \in [p^a,p^*]$. If $p \geq p^*$, then $X = Y$ and $\partial X/\partial p = 0$. This implies that the second term on the right side of (16) is zero, and $\partial\phi'/\partial p$ is negative for $p \geq p^*$. Since $\partial\phi'/\partial p$ is zero for $p < p^a$, and is negative for $p \geq p^a$, $Cov(p,\phi')$ in (15) is negative for a risk averse producer.

Price Uncertainty and Production

We are now in a position to evaluate the effect of the introduction of price uncertainty on the output of the competitive farmer with storage capability. To make a fair comparison, assume that current and discounted net future producer prices have an identical mean, i.e., $Ep = \delta\mu$. If Ep and $\delta\mu$ are observed with <u>certainty</u>, the farmer produces the level of output for which $Ep = C'$ and sells the entire output $X = K + Y$, holding no inventory. Thus, when Ep ($= \delta\mu$) is observed with certainty, the storage options do not affect production decision under certainty. However, under price uncertainty the storage options have a positive output effect for risk averse farmers and may more than offset the negative output effect arising from risk aversion.

Case I: $F(p^a) = 0$.

First, consider the case where $F(p^a) = 0$ due to a prohibitively high storage cost. This makes the second term on the left side of (12) zero. Since the first order condition for optimal production in (15) must be zero and $Cov(p,\phi')$ is negative in equilibrium, we have for a risk averse farmer,

$$Ep - C' > 0 \qquad\qquad \text{if } F(p^a) = 0. \tag{17}$$

This is the standard result of Baron and Sandmo: if the storage options are not viable due to a prohibitive storage cost, the risk averse competitive farmer produces less under price uncertainty.

Case II: $F(p^*) > 0$, $U''(\pi) = 0$.

Next, consider the case where $F(p^*) > 0$ and the farmer is risk neutral. Recall from (3) that an increase in the storage subsidy increases the reservation price p^*, and hence increases the cumulative probability $F(p^*)$ that the random price falls below p^*. Thus, for a sufficiently high storage subsidy $F(p^*)$ becomes positive. For risk neutral farmers, $p^a = p^*$ and $Cov(p,\phi') = 0$. Thus, if $F(p^*) > 0$, the second term on the left hand side of (12) is positive. This implies that when storage cost is not prohibitively high or the storage subsidy is sufficiently high, $F(p^*) > 0$, we have for risk neutral farmers,

$$Ep - C' < 0 \qquad\qquad \text{if } F(p^*) > 0. \tag{18}$$

That is, a risk neutral farmer with storage options produces more under price uncertainty. Intuitively, storage options eliminate the downside risk of selling output at low prices by truncating the distribution of market price at the reservation price. Thus, storage options encourage the risk neutral farmer to expand output.

Case III: $F(p^a) > 0 > U''(\pi)$.

Finally, consider the case where $F(p^a) > 0$ and the farmer is risk averse. Without the storage capability the risk averse farmer produces less under price uncertainty. However, this negative output effect of price uncertainty is partially or more than offset by the positive output effect of storage options. Whether the farmer produces more under price uncertainty depends not only on risk attitude but also on the storage subsidy, storage cost and discount factor which determine the relative magnitudes of $Cov(p,\phi')$ and the second term in (12). If the storage cost is low and the farmer does not discount future sales revenue heavily, fluctuations in output price can induce the risk averse farmer to produce more than if price were stable. These results are summarized below.

PROPOSITION 2: If $F(p^*) > 0$, a risk neutral farmer with storage options produces more under price uncertainty than if the mean prices Ep and μ are observed with certainty. If $F(p^a) > 0$, then price uncertainty may not have a negative output effect on a risk averse farmer with storage options.

We conclude this section by considering the effect of storage subsidy on the output of the competitive producer. For the relevant comparison of outputs with and without a storage subsidy, we assume that (a) in the absence of a storage subsidy the producer does not hold inventory due to a high storage cost, i.e., $F(p^*) = 0$, and (b) the initial inventory is zero ($K = 0$) with a storage subsidy. For the risk neutral firm, let Y^s be the optimal output with a sufficiently high storage subsidy s such that $F(p^*) > 0$, and let Y^o be the optimal output with zero subsidy. Since the entire output is sold each period, sales is also equal to output ($X = Y^o$) in the no storage situation. Thus, the optimal output in the no storage situation can be obtained from the maximization problem in (11) by imposing the constraint that $F(p^*) = 0$ or $X = Y^o$. Since U' is constant for the risk neutral firm, Y^o satisfies the first order condition

$$\int_0^\infty (p - C')\cdot U'[pY - C(Y)]dF(p) = 0. \tag{19}$$

That is, expected price must be equated to marginal cost of production.

If the storage subsidy is sufficiently high, then $F(p^*) > 0$ and some output may be held as inventory. To compare Y^s and Y^o, it is necessary to compare the left side of (12) at $Y = Y^o$. Recall that if the firm is risk neutral, $p^a = p^*$, and the third term vanishes and the fourth term is zero on the left side of (12). However, the second term is positive. For the risk neutral firm the first term when evaluated at $Y = Y^o$ reduces to (19) and is zero. Thus, when evaluated at $Y = Y^o$, the left side of (19) reduces to the second term, which is positive. This implies that $Y^s > Y^o$.

PROPOSITION 3: If the output price p is uncertain, a sufficiently high storage subsidy such that $F(p^*) > 0$ induces a risk neutral farmer to produce more than with no storage subsidy, i.e., $Y^s > Y^o$.

Does a storage subsidy have a positive effect on the output of a risk averse farmer? Let Y^{as} and Y^a denote the output of a risk averse producer with and without a storage subsidy, respectively. With a storage subsidy, we have shown for a risk averse firm that in (12) the third and fourth terms vanish, while the first term is negative and the second term is positive at Y^{as}, since $F(p^a) > 0$. The sign of the first term when evaluated at $Y = Y^a$ is indeterminate since X is a function of the random price p when the firm receives the storage subsidy. This ex post sales flexibility makes it difficult to evaluate the first term at Y^a when some inventory is held. However, at the equilibrium output Y^{as} the first term has to be negative. This suggests that while the possibility that $Y^a > Y^{as}$ cannot be ruled out, it is likely for the storage subsidy to induce the risk averse firm to produce more than without them.

4. Concluding Remarks

This paper investigated the supply response to a storage subsidy by focusing on the firm level storage decisions of risk averse producers. Our approach differs from the literature in two important respects. First, we focus on a risk neutral or risk averse farmer with the option of holding inventory. Although inventories can be held for many periods, the multiperiod inventory decision is broken into a sequence of inventory decisions. In each period the producer decides to sell output or hold it as inventory. From the ex post sales decision we derived the reservation price below which all risk averse farmers hold some inventory. This reservation price is equal to the expected net future producer price.

Second, while sales and storage decisions are made ex post, production decisions are made ex ante before the current market price is known. We have shown that a storage subsidy encourages the risk neutral farmer to expand output. Proving that a storage subsidy will increase output for all risk averse producers is as difficult as proving that demand curves are negatively sloped regardless of ordinal preferences. However, as price variability is reduced, a storage subsidy is likely to encourage risk averse farmers to expand output.

The analysis of this paper has an important implication on empirical investigations of storage subsides. Most analyses of storage subsidy programs assume that market supply and demand depend only on the expected market price, but not on storage subsidies. The results of this paper suggest that even when producers are risk neutral market supply responds positively to storage subsidies, and hence the storage subsidy should be incorporated in estimating supply response. Risk aversion tends to dampen supply response to a storage subsidy. How important the supply response of risk averse producers is to a storage subsidy is an empirical question.

APPENDIX

We show that $B = \int_0^\infty U''[\pi](p - \delta v)dG(v)$ is negative given diminishing absolute risk aversion. Let $R(\pi) = -U''[\pi]/U'[\pi]$ denote the index of absolute risk aversion and let f* denote the critical value of net future producer price for which $p - \delta v = 0$. Then for all positive inventory $I > 0$,

$$R(\pi) \geq (<) R(\pi^*) \qquad \text{if } v \geq (<) v^*, \tag{A1}$$

where $\pi^* = pX - c(Y) + \delta vI$. Multiply both sides of (A1) by $\{-U'[\pi](p - \delta v)\}$ to obtain

$$U''[\pi](p - \delta v) \leq -R(\pi^*)U'[\pi](p - \delta v), \text{ for all } v. \tag{A2}$$

Integrating (A2) over v gives

$$B \leq -R(\pi^*) \int_0^\infty U'[\pi](p - \delta v)dG(v). \tag{A3}$$

The right side of (A3) is zero by the first order condition (1′), and hence $B \leq 0$.

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FOOTNOTES

1. Some storage subsidy was implicit in U.S. commodity loan programs for decades, since interest rate charges were generally below conventional rates. Direct storage subsidies were used briefly in the 1960s but became a central feature of commodity programs when the Farmer-Owned Reserve program was initiated in 1977. Annual storage subsidy payments exceeded $800 million twice in the 1980s.

2. A storage subsidy may be paid in advance at the beginning of each year. Since the storage subsidy paid in the next period is discounted, timing of storage payment does not affect the analysis.

3. It can be shown that this result also follows if storage cost is variable. If the storage cost is denoted by $t(Y - X)$, the reservation price in (4) is replaced by $po = \delta q + s - t'$. This would complicate the ex ante production decision.

4. If the supply curve is backward bending ($\partial X/\partial p < 0$) for some price interval, it must again turn in the right direction for a higher price interval. Note that $X(p,K+Y) < K+Y$ for all $p < p^\circ$ and $X(p^\circ,K+Y) = K+Y$. Thus, $X(p,K+Y)$ approaches $(K+Y)$ as p approaches p°, and hence $\partial X/\partial p$ is also positive in the (small) left neighborhood of p°.