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JOINT MANAGEMENT OF BUFFER STOCKS FOR WATER AND COMMODITIES

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JOINT MANAGEMENT OF BUFFER STOCKS FOR WATER AND COMMODITIES

Richard E. Just, Erik Licktenberg, and David Zilberman

Extensive research has been devoted to price stabilization and buffer stock management for commodities (see Just, Hueth, and Schmitz; Newbery and Stiglitz; and Turnovsky for reviews of this work). One of the primary sources of instability in empirical models of price stabilization is stochastic weather conditions. It is well known, however, that farmers who irrigate sometimes vary water applications depending on weather circumstances. This raises the issue of formally incorporating water policy into commodity stabilization policy. To date, no studies have addressed this possibility.

One consideration in joint buffer stock management of water and commodities is the periodicity of variability. Some might argue that any cycle in, say, groundwater stocks is so much longer than for commodity stocks that no gains from joint buffer stock management are possible. Indeed, typical time periods between surplus and shortage in commodity markets may be from three to ten years whereas groundwater shortages seem to be realized only over periods of 40 or 50 years. However, meteorological studies have identified cycles in rainfall and drought conditions on the order of 11 to 19 years (Currie; Thompson) which suggests that joint consideration of the two problems is appropriate. Furthermore, the long term depletion of groundwater stocks that has occurred appears to be due to long term overuse rather than a regular cyclical response. As a water storage facility, groundwater capacity is practically unlimited and may offer a relatively cheap way of smoothing the effects of weather variations on commodity markets with proper management. By comparison, storage for a period of ten years in many surface water reservoirs may be expensive. Nevertheless, designating some surface water capacity for accomodation of drought conditions may be a suitable alternative to expanding commodity storage facilities at the margin. Such possibilities apparently have not been considered seriously previously.

The purpose of this paper is to examine the possibilities for joint management of water and commodity storage. A simple model with stochastic commodity demand and random rainfall and associated supply conditions is examined. Traditional policies are characterized by a commodity price stabilization rule whereby stocks are adjusted according to the relationship of current price to normal price and a water storage rule whereby water stocks facilitate a normal level of irrigation plus a drought related level of irrigation that is higher in short rainfall years. This paper compares these rules to an optimal joint management rule whereby both commodity and water stocks are adjusted in response to both commodity market and rainfall conditions. It is found that the optimal rule for both types of stocks should indeed be responsive to both types of conditions.

The Cost of Storage as a Stabilization Activity

Before proceeding to develop a model of optimal stabilization through joint management of water and commodity storage, a discussion of the cost structure is useful. In many circles, water storage is considered on the basis of average needs rather than as a means of counter balancing adverse weather or other conditions. Storage for stabilization purposes requires some additional considerations.

Two types of cost are important: pumping and distribution cost and capacity cost. As with most economic activity, it is reasonable to assume in both cases that cost is increasing at an increasing rate. For pumping cost, this may be due to capacity constraints on the system, increased costs of scheduling, increased break down of pumping equipment in an overworked system, the need to draw from more remote and less economical water supplies, etc. For capacity costs, this could be due to capacity limitations on reservoirs that are inexpensive to operate, increasing environmental damage as reservoirs are filled above normal levels, increasing cost of finding additional suitable locations to build storage facilities, etc.

Consider the cost curve for pumping depicted by C_p in Figure 1. Suppose average water use is given by $\bar{W}$. If random weather and other phenomena lead to water use W_1 from storage in surplus years and water use W_2 from storage in shortage years, each with probability .5, then the average cost is C_p^0 (where $W_2 - \bar{W} = \bar{W} - W_1$). Now suppose that an alternative storage policy is adopted that increases the variability of water use. That is, suppose water storage facilities are used to a greater extent to compensate for abnormal weather circumstances. If water use is reduced to W_1^* in surplus years and increased in shortage years to W_2^*, then the average cost is increased to C_p^* (where $W_2^* - \bar{W} = \bar{W} - W_1^*$). Clearly, $C_p^* > C_p^0$ when cost is increasing at an increasing rate which demonstrates how water pumping costs increase on average with the variance of water use. This increase is an additional consideration beyond any increase in pumping cost that would be incurred with an increase in average water use $\bar{W}$.

Consider next the cost of capacity MC_c as illustrated in Figure 2. The capacity needed to support average water use is represented by $\bar{W}$. If a water storage policy is adopted that requires water quantity W_1 in surplus years and water quantity W_2 in shortage years, then water storage capacity must be at least W_2 which leads to capacity cost C_c^0. If an alternative water storage policy is adopted that requires more variation in water use then a larger capacity is necessary to meet the demands of shortage years. If the policy requires water use W_1^* in years of surplus and W_2^* in years of shortage, then capacity must be increased to W_2^* which increases the cost of capacity to C_c^*. As with pumping cost, it is thus clear that capacity cost increases with the variability of water use as well as with average water use.

Following this intuitive justification, the water storage cost function used for the theoretical analysis of this paper is specified as a function of both the mean and variance of water use with the mean component quadratic in average water use. Further justification of this form of cost function is presented later in the empirical section.

The cost of commodity storage is considered similarly aside from the mean component. On average, commodity stocks cannot be allowed either to accumulate or decline continually in order to have a viable storage rule. (This is not the case with water because water storage is recharged by rainfall; the viability requirement for water is that mean use be equal to average annual recharge designed into the storage facility.) Commodity storage cost is assumed to be increasing in the variance of commodity stock transactions because (1) larger stocks must be held to enforce a storage rule with larger variance and (2) as in the case of water, larger capacity must be used for given circumstances of unusual surplus with higher variance and the cost of capacity is likely to be increasing at an increasing rate because of capacity limitations of existing storage facilities, the increasing opportunity cost of facilities diverted from other uses, etc. Additional justification of this form of cost function is also presented in the later empirical section.

A Simple Market Model with Weather and Demand Shocks

Let demand for a commodity be represented by a linear relationship with

(1) $D = a - bp + \epsilon$

where D is the quantity demanded, p is price, and ϵ is a random disturbance in demand conditions. Let supply be characterized by

(2) $S = \phi + \theta(R + \Delta W)$

where S is the quantity of the commodity produced and supplied, R is the random rainfall level, and ΔW is the amount of water taken out of water storage facilities and used for irrigation. Note that ϕ and θ may functions of expected price and other conditioning factors of supply but these will be held constant for the derivation here.

The commodity buffer stock identity is represented by

(3) $I = I_{-1} + \Delta I$

where I is the ending level of inventory, I_{-1} is the beginning inventory level, and ΔI is the current change in commodity stocks. The supply-demand identity is thus

(4) $D = S + \Delta I.$

The water storage identity is represented by

(5) $W = W_{-1} + \lambda^{*}R - \Delta W$

where W is the ending level of water stocks, W_{-1} is the beginning level of water stocks, and λ^{*} is a factor reflecting the size of watershed designed to feed the water storage facility. Thus, $\lambda^{*}R$ is the total level of water storage recharge.

In this framework, consider a general commodity buffer stock policy conditioned on the stochastic elements of the system, ϵ and R. One possibility for this purpose would be

$$\Delta I = \hat{\psi}_0 + \hat{\psi}_1 \epsilon + \hat{\psi}_2 R.$$

Imposing long run viability on this rule such that stocks are expected neither to accumulate nor decline, i.e., $E(\Delta I) = 0$, implies

$$(6) \quad \Delta I = \psi_1 \epsilon + \psi_2 (R - \bar{R})$$

where $E(\epsilon) = 0$ and $E(R) = \bar{R}$ are expectations, i.e., normal price and rainfall, respectively. If $\psi_1 > 0$ and $\psi_2 < 0$, this rule implies that commodity stocks are depleted in periods of high demand and low rainfall and accumulated in periods of low demand and high rainfall.

Similarly, a viable long-run water policy is reflected by

$$(7) \quad \Delta W = \eta_1^* \epsilon + \eta_2^* (R - \bar{R}) + \nu.$$

The latter term, ν, represents the normal level of irrigation whereas the other two terms represent deviations from the normal level associated with current conditions. If $\eta_1^* > 0$ and $\eta_2^* < 0$, this rule implies that irrigation is increased in periods of high demand to mitigate conditions of shortage and in periods of low rainfall to mitigate drought conditions.

Note that long-run viability of the water policy requires $\nu = E(\lambda^* R) = \lambda^* \bar{R}$ which will be imposed throughout this paper. (As noted above, this is a condition that apparently has not been imposed with traditional groundwater policy as evidenced by the secular decline in groundwater tables in some areas.) Imposing this condition and reparametrizing for purposes of later simplicity, equation (7) becomes

(8) $\Delta W = \frac{1}{\theta} [\eta_1 \epsilon + \eta_2 (R - \bar{R}) + \lambda \bar{R}]$

where $\eta_i^* = \eta_i/\theta$ and $\lambda^* = \lambda/\theta$.

To determine equilibrium, the system is first reduced by substituting (1), (2), (6), and (8) into (4),

(9) $a - bp + \epsilon = \phi + \theta R + \left(\eta_1 + \psi_1\right)\epsilon + \left(\eta_2 + \psi_2\right)(R - \bar{R}) + \lambda\bar{R},$

and then solving for price,

$$p = \frac{1}{b} [a + \epsilon - \phi - \theta R - \left(\eta_1 + \psi_1\right)\epsilon - \left(\eta_2 + \psi_2\right)(R - \bar{R}) - \lambda\bar{R}]$$

From this result, one can determine both the mean and variance of price as

(10) $\bar{p} = \frac{1}{b} [a - \phi - (\theta + \lambda)\bar{R}]$

(11) $\sigma_p = \dfrac{(1 - \eta_1 - \psi_1)^2 \sigma_\epsilon + (\theta + \eta_2 + \psi_2)^2 \sigma_R}{b^2}$

where $\sigma_\epsilon = \text{Var}(\epsilon)$ and $\sigma_R = \text{Var}(R)$. Note that the covariance of ϵ and R is assumed to be zero for simplicity since there is little reason to expect weather conditions and random variations in demand to be correlated.

Following the discussion of the previous section, the cost of operating the buffer stock activity for the commodity is assumed to be a function of the variance of stock transactions. Just and Schmitz present a formal justification of this storage cost function for price stabilization policies of the form investigated here where the cost of storage follows a quadratic function of the amount stored. Where the cost of the buffer stock activity is approximated by a linear function of the variance of stock transactions, it is represented by

(12) $C_B \equiv C_\psi \text{ Var}(\Delta I) = C_0^* + C_\psi\left(\psi_1^2 \sigma_\epsilon + \psi_2^2 \sigma_R\right).$

Similarly, the cost of operating the storage and distribution activity for water is assumed to be approximated by a linear function of the variance of water use plus a quadratic function of normal water use. Thus, water storage and distribution costs are represented by

$$(13)\quad C_W \equiv \theta^2 C_\eta \,\mathrm{Var}(\Delta W) + C_0\lambda + C_\lambda\lambda^2 = C_\eta\left(\eta_1^2\,\sigma_\epsilon + \eta_2^2\,\sigma_R\right) + C_0\lambda + C_\lambda\lambda^2.$$

(Note that the θ^2 term is included here for later convenience; note also that additional constant terms in these cost functions do not affect results below.)

These functions may be conditioned on political restrictions with respect to the probability that stocks will be adequate to enforce the storage rules in cases of extreme shortage or may include directly the social cost of running out of stocks in cases of extreme shortage.

Social Welfare and the Policy Criterion

In the context of this model, the welfare or policy criterion is assumed to be the maximization of producer plus consumer surplus less the cost of storage activities for the commodity and water. The welfare calculations are represented in Figure 3. Consumer demand for a particular level of the disturbance ϵ is given by D. At price p_1 this results in quantity demanded q_1. The quantity supplied for a particular level of rainfall is q_2. The difference in supply and demand is made up by a stock adjustment $\Delta I = q_1 - q_2$. Consumer surplus is area abp_1. Producer revenue is area $p_1cq_20 = p_1S$. The additional amount, area $cbq_1q_2 = p_1\Delta I$, represents a revenue to the government from selling stocks. Adding these three welfare measures together produces a gross welfare of area abq_10.

To arrive at net social welfare, one must subtract from this the cost of commodity and water storage and the cost of production. The point of Figure

3 is that, for any particular manifestation of disturbances in demand and rainfall, gross welfare is measured by the area under the demand curve and left of the quantity consumed. (In the event that ΔI is negative, the associated area, $p_1 \Delta I$, is a cost to the government of acquiring stocks and must be subtracted from the revenue of producers, $p_1 S$.) This gross welfare is represented mathematically by

$$(14)\quad G = \frac{1}{2}\left[\frac{a + \epsilon}{b} + p\right](a - bp + \epsilon).$$

The cost of production is assumed to depend on planned or expected production rather than actual production -- a common specification for agricultural production problems. Assuming risk neutrality, the expected cost of production is determined by the prices of non-water inputs and the expected price of output -- all of which are held constant in this paper -- as well as expected water availability, $E(R + \Delta W) = (1 + \lambda/\theta)\bar{R}$. Hence, the expected cost of production can be approximated by

$$(15)\quad C_p = \alpha - \beta\left[1 + \frac{\lambda}{\theta}\right]\bar{R}.$$

The net welare criterion is thus

$$U = G - C_p - C_B - C_W$$

which using (11) has expectation

$$(16)\quad E(U) = \frac{1}{2b}\left(a^2 + \sigma_\epsilon\right) - \frac{b}{2}\left(\bar{p}^2 + \sigma_p\right) - C_p - C_B - C_W.$$

Characterization of the Social Optimum

Two general policy regimes are considered as a means of maximizing the policy criterion in (16). One considers independent water and commodity price stabilization policy where, for example, the water policy depends only on water circumstances and not on commodity prices or demand conditions. The other considers coordinated water and commodity policy. Consider first the maximization of net social welfare with respect to all of the policy instruments simultaneously. This alternative yields coordinated storage policies and will be called the social optimum.

Using (12), (13) and (16), the first order conditions are

$$(17)\quad \frac{\partial E(U)}{\partial \lambda} = \frac{\partial E(G)}{\partial \lambda} - \frac{\partial C_P}{\partial \lambda} - \frac{\partial C_W}{\partial \lambda} = \bar{p}\,\bar{R} + \frac{1}{\theta}\,\beta\bar{R} - C_0 - 2C_\lambda \lambda = 0$$

$$(18)\quad \frac{\partial E(U)}{\partial \psi_1} = \frac{\partial E(G)}{\partial \psi_1} - \frac{\partial C_B}{\partial \psi_1} = \frac{1}{b}\left(1 - \eta_1 - \psi_1\right)\sigma_\epsilon - 2C_\psi \psi_1 \sigma_\epsilon = 0$$

$$(19)\quad \frac{\partial E(U)}{\partial \eta_1} = \frac{\partial E(G)}{\partial \eta_1} - \frac{\partial C_W}{\partial \eta_1} = \frac{1}{b}\left(1 - \eta_1 - \psi_1\right)\sigma_\epsilon - 2C_\eta \eta_1 \sigma_\epsilon = 0$$

$$(20)\quad \frac{\partial E(U)}{\partial \psi_2} = \frac{\partial E(G)}{\partial \psi_2} - \frac{\partial C_B}{\partial \psi_2} = -\frac{1}{b}\left(\theta + \eta_2 + \psi_2\right)\sigma_R - 2C_\psi \psi_2 \sigma_R = 0$$

$$(21)\quad \frac{\partial E(U)}{\partial \eta_2} = \frac{\partial E(G)}{\partial \eta_2} - \frac{\partial C_W}{\partial \eta_2} = -\frac{1}{b}\left(\theta + \eta_2 + \psi_2\right)\sigma_R - 2C_\eta \eta_2 \sigma_R = 0.$$

Condition (17) implies that water storage capacity allocated to normal use should be chosen to equate the marginal gross welfare with the marginal cost of storage and distribution facilities. Conditions (18)-(21) imply that the optimal degree to which commodity and water storage rules should depend on demand and weather disturbances equates marginal gross expected welfare and marginal cost of the respective storage activity. Comparing (18) and (19) reveals in particular that the responsiveness of commodity storage and water storage to demand conditions should equate the marginal costs of the two forms of storage. Conditions (20) and (21) similarly reveal that the responsiveness of commodity storage and water storage to weather conditions should equate the marginal costs of the two forms of storage.

Conditions (17)-(21) yield the specific optimal choices of the policy parameters given by

$$(22)\quad \lambda^* = \frac{1}{2\theta C_\lambda}\left[\,\bar{R}(\bar{p}\theta + \beta) - C_0\theta\,\right]$$

$$(23)\quad \psi_1^* = \frac{C_\eta}{C_\psi + C_\eta + 2bC_\psi C_\eta}$$

$$(24)\quad \eta_1^* = \frac{C_\psi}{C_\psi + C_\eta + 2bC_\psi C_\eta}$$

$$(25)\quad \psi_2^* = -\frac{\theta C_\eta}{C_\psi + C_\eta + 2bC_\psi C_\eta}$$

$$(26)\quad \eta_2^* = -\frac{\theta C_\psi}{C_\psi + C_\eta + 2bC_\psi C_\eta}\,.$$

Clearly, these results show that water and commodity storage policy should be determined jointly. The optimal level of each form of stabilization depends substantively on the costs of both forms of storage.

Evaluation of Uncoordinated Storage Policies

This section considers various degrees of independence in water and commodity storage formulation. There is little doubt that the current political system does not jointly formulate water and commodity storage policy. However, it is not clear to what degree each political process takes into account market considerations that are a manifestation of the other policy. Apparently there are some circumstances where independent policy formulation can in equilibrium lead to the social optimum.

Independent Water Policy Conditioned on Weather. Consider first the case of using water storage facilities only to facilitate normal water use and to compensate (partially) for year-to-year rainfall variation. In other words, no capacity and sensitivity of water storage is included for the purpose of responding to nonnormal demand for agricultural commodities. In this case the policy parameters consist of λ and η_2 (with $\psi_1, \psi_2, \eta_1 = 0$) and the water policy rule is

(27) $\Delta W = \frac{1}{\theta} \left[\eta_2(R - \bar{R}) + \lambda\bar{R} \right].$

The associated first order conditions for maximization of the social welfare criterion in (16) follow from (17) and (21) and are given by

(28) $\frac{\partial E(U)}{\partial \lambda} = \bar{p}\ \bar{R} + \frac{1}{\theta}\ \beta\bar{R} - C_0 - 2C_\lambda \lambda = 0$

(29) $\frac{\partial E(U)}{\partial \eta_2} = -\ \frac{1}{b}\ \left(\theta + \eta_2\right)\sigma_R - 2C_\eta \eta_2 \sigma_R = 0.$

Condition (28) leads to the same result as in (22) so the correct level of normal water use is built into the water storage system. Condition (29), however, implies

$$\eta_2 = -\ \frac{\theta}{1 + 2bC_\eta} < -\ \frac{\theta}{1 + 2bC_\eta + C_\eta/C_\psi} = \eta_2^*.$$

Thus, independent determination of water storage policy results in too much response of water use to current weather conditions (η_2 is larger in absolute value than η_2^*). This, however, does not result in building too much capacity into water storage and distribution facilities. To see this, note that water capacity allocated to compensation for nonnormal weather conditions is determined by $\mathrm{Var}(\Delta W) = \left(\eta_1^2\ \sigma_\epsilon + \eta_2^2\ \sigma_R\right)/\theta^2$. This variance can possibly be less even though water policy is overly responsive to weather conditions ($\eta_2 < \eta_2^*$) because water policy does not respond at all to demand conditions ($\eta_1 = 0 < \eta_1^*$).

Independent Commodity Storage Policy Conditioned on Demand. Consider next the independent determination of commodity storage policy. Several policy alternatives may be considered for this case. If the commodity storage policy is operated only to compensate for random variations in demand, then the only policy parameter is ψ_1 and the associated first order condition for maximization of social welfare follows from (18) and is given by

$$\frac{\partial E(U)}{\partial \psi_1} = \frac{1}{b}\left(1 - \psi_1\right)\sigma_\epsilon - 2C_\psi \psi_1 \sigma_\epsilon = 0$$

which implies

$$\psi_1 = \frac{1}{1 + 2bC_\psi} > \frac{1}{1 + 2bC_\psi + C_\psi/C_\eta} = \psi_1^*.$$

Thus, independent determination of commodity storage policy results in too much response to current demand conditions. Parallel to the independent water storage result, however, this does not necessarily result in building too much commodity storage capacity relative to the social optimum because no capacity is included for the purpose of responding to nonnormal weather circumstances.

Independent Commodity Storage Policy Conditioned on Both Demand and Weather. Typically, commodity storage policies are not sensitive only to demand conditions. One possibility would be to monitor both supply and demand conditions and determine stock transactions accordingly. In the model of this paper, this would be equivalent to monitoring both demand and weather conditions with a commodity buffer stock rule in the form of (6). If this rule is optimized without regard to water policy, the resulting first order conditions follow from (18) and (20) and are given by

$$\frac{\partial E(U)}{\partial \psi_1} = \frac{1}{b}\left(1 - \psi_1\right)\sigma_\epsilon - 2C_\psi \psi_1 \sigma_\epsilon = 0$$

$$\frac{\partial E(U)}{\partial \psi_2} = -\frac{1}{b}\left(\theta + \psi_2\right)\sigma_R - 2C_\psi \psi_2 \sigma_R = 0.$$

Solving these equations yields

$$(30)\quad \psi_1 = \frac{1}{1 + 2bC_\psi} > \frac{1}{1 + 2bC_\psi + C_\psi/C_\eta} = \psi_1^*.$$

$$(31)\quad \psi_2 = -\frac{\theta}{1 + 2bC_\psi} < -\frac{\theta}{1 + 2bC_\psi + C_\psi/C_\eta} = \psi_2^*.$$

In this case, it is clear that ignoring stabilizing effects of water storage results in more response to both demand and weather conditions than in the social optimum. This clearly also results in building too much storage capacity for commodity stocks.

Independent Commodity Storage Policy Conditioned on Price. Examples of commodity buffer stock policies that monitor and respond directly to both demand and weather conditions are difficult to identify. Perhaps, a more representative commodity storage policy is to deplete reserves when prices rise too high and accumulate reserves when prices fall too low. The farmer owned reserve support, release, and call prices, for example, are roughly reflective of such a policy rule. If commodity storage responds to nonnormal price variations, then the storage rule is indirectly sensitive to both demand and weather conditions.

Suppose in place of the commodity storage rule in (6) that commodity stocks are adjusted following

(32) $\Delta I = \psi_3(p - \bar{p})$

where $\psi_3 > 0$ implies that stocks are depleted in times of shortage and high prices and accumulated in periods of surplus and low prices. In this case the equilibrium condition in (9) becomes

$$a - bp + \epsilon = \phi + \theta R + \psi_3(p - \bar{p}).$$

The equilibrium price is

$$p = \frac{1}{b + \psi_3} \left[a + \epsilon - \phi - \theta R + \psi_3 \bar{p} \right]$$

which has mean and variance

$$\bar{p} = \frac{1}{b} \left[a - \phi - \theta \bar{R} \right]$$

$$\sigma_p = \frac{\sigma_\epsilon + \theta^2 \sigma_R}{(b + \psi_3)^2}.$$

These are in the same form as in (10) and (11) if

(33) $$\psi_1 = \frac{\psi_3}{b + \psi_3}$$

(34) $$\psi_2 = - \frac{\theta \psi_3}{b + \psi_3}$$

assuming water policy parameters are ignored $(\lambda, \eta_1, \eta_2 = 0)$. Noting that the cost of the commodity policy is $\mathrm{Var}(\Delta I) = \psi_3^2 \sigma_p$, using (33) and (34) in (16) and differentiating with respect to ψ_3 obtains the first order condition

$$\frac{\partial E(U)}{\partial \psi_3} = \left\{ \left(1 - \psi_1\right)\sigma_\epsilon - 2bC_\psi \psi_1 \sigma_\epsilon + \frac{1}{\theta}\left[\left(\theta + \psi_2\right)\sigma_R - 2bC_\psi \psi_2 \sigma_R\right]\right\} \frac{1}{\left(b + \psi_3\right)^2} = 0$$

which upon substituting (33) and (34) and solving for ψ_3 yields $\psi_3 = 1/2bC_\psi$ which is the same solution as in (30) and (31). Thus, the associated conclusions appear to have practical relevance for commodity buffer stock rules governed simply by commodity price conditions.

Independent Water Policy Conditioned on Both Demand and Weather. Many water storage policies do not appear to have built-in responses to commodity demand conditions. For example, publicly controlled reservoirs do not appear to be regulated in response to, say, the prices of cotton, alfalfa or fruits and vegetables. Farmers have a private incentive to adjust use of irrigation according to commodity market conditions (which are determined by demand and weather conditions) but appropriate response is induced only to the extent that the full marginal social cost is charged for water. This is generally not the case for public water projects. Farmers likely do not face the full marginal social cost of irrigation from groundwater either but the discrepency is likely not as great. Thus, the results of this section are likely more pertinent to groundwater policy considerations while those in the section on *Independent Water Policy Conditioned on Weather* are likely more pertenent to public surface water projects.

Consider the case where the water storage policy responds to both supply and demand conditions, i.e., and water policy rule as in (8). If this rule is optimized without regard to commodity policy, the resulting first order conditions follow from (17), (19), and (21) and are given by

$$(35)\quad \frac{\partial E(U)}{\partial \lambda} = \bar{p}\,\bar{R} + \frac{1}{\theta}\beta\bar{R} - C_0 - 2C_\lambda \lambda = 0$$

$$(36)\quad \frac{\partial E(U)}{\partial \eta_1} = \frac{1}{b}\left(1 - \eta_1\right)\sigma_\epsilon - 2C_\eta \eta_1 \sigma_\epsilon = 0$$

$$(37)\quad \frac{\partial E(U)}{\partial \eta_2} = -\frac{1}{b}\left(\theta + \eta_2\right)\sigma_R - 2C_\eta \eta_2 \sigma_R = 0.$$

Solving these equations yields (22) and

$$\eta_1 = \frac{1}{1 + 2bC_\eta} > \frac{1}{1 + 2bC_\eta + C_\eta/C_\psi} = \eta_1^*.$$

$$\eta_2 = -\frac{\theta}{1 + 2bC_\eta} < -\frac{\theta}{1 + 2bC_\eta + C_\eta/C_\psi} = \eta_2^*.$$

In this case, it is clear that ignoring stabilizing effects of commodity storage results in more response to both demand and weather conditions than in the social optimum. This clearly also results in building too much irrigation capacity.

Informed Independent Policy Formulation. In the various independent policy cases examined thus far, each policy has been assumed to be formulated as though the other did not exist. Another possibility is to recognize the presence of the other policy and take the associated policy parameters as given. In this case, if the water policy is conditioned on both demand and weather conditions, the associated first order conditions will be given by (17), (19), and (21). If the commodity policy is conditioned on both demand

and weather conditions, the associated first order conditions are given by (18) and (20). The two policies would reach an equilibrium only by satisfying all five conditions simultaneously. This results in the social optimum given by equations (22)-(26). Incidentally, the same conclusion holds if the commodity policy is based on price alone as in (32) rather than directly on demand and weather conditions as in (6). In this case, the optimal policy parameters are given by (22), (24), (26), and

$$(38)\quad \psi_3 = \frac{1}{2C_\psi} .$$

Interestingly, neither policy authority needs to know the cost conditions faced by the other -- only the resulting policy parameters selected. That is, the first order conditions for water storage in (17), (19), and (21) do not involve C_ψ and the first order conditions for commodity storage in (18) and (20) do not involve C_0, C_λ, or C_η. Thus, optimal policies can be achieved with a high degree of independence between the two policy formulation processes. The main issues in this case are how fast the adjustment process converges to the optimum and how fast policies can adapt to structural changes given the cumbersome process of successively calibrating each policy to changes in the other. These are dynamic issues beyond the scope of this paper.

It is unlikely, however, that water and commodity policies fit this characterization particularly in the case of public water projects. As noted above, there is little evidence that reservoir regulation takes commodity prices or demand conditions into account and farmers do not have proper incentive if they do not face the full marginal social cost of water use. A more likely characterization is that water policy is conditioned only on weather following (27) and commodity policy is conditioned only on commodity price following (32). In this case the market equilibrium condition in (9) becomes

$$a - bp + \epsilon = \phi + \theta R + \psi_3(p - \bar{p}) + \eta_2(R - \bar{R}) + \lambda\bar{R}$$

for which equilibrium price is

$$p = \frac{1}{b + \psi_3} \left[a + \epsilon - \phi - \theta R + \psi_3\bar{p} - \eta_2(R - \bar{R}) - \lambda\bar{R} \right].$$

From this result, the mean and variance of price are

$$\bar{p} = \frac{1}{b} \left[a - \phi - (\theta + \lambda)\bar{R} \right]$$

$$\sigma_p = \frac{\sigma_\epsilon + (\theta + \eta_2)^2\sigma_R}{(b + \psi_3)^2}.$$

These are in the same form as in (10) and (11) if

(39) $$\psi_1 = \frac{\psi_3}{b + \psi_3}$$

(40) $$\psi_2 = -\frac{(\theta + \eta_2)\psi_3}{b + \psi_3}$$

assuming the water policy parameter for demand conditions is ignored ($\eta_1 = 0$). Using (39) and (40) in (16) and differentiating with respect to λ, η_2, and ψ_3 obtains the first order conditions given by (17) and

$$\frac{\partial E(U)}{\partial \psi_3} = \frac{\sigma_p}{b + \psi_3} \left(b + 2C_\psi\psi_3^2\right) - 2C_\psi\sigma_p\psi_3 = 0$$

$$\frac{\partial E(U)}{\partial \eta_2} = -\frac{\left(\theta + \eta_2\right)\sigma_R}{\left(b + \psi_3\right)^2} \left(b + 2C_\psi\psi_3^2\right) - 2C_\eta\sigma_R\eta_2 = 0.$$

These equations are solved by (22) and

$$\psi_3 = \frac{1}{2C_\psi}$$

$$\eta_2 = -\frac{\theta C_\psi}{C_\psi + C_\eta + 2bC_\psi C_\eta}.$$

Substituting into (39) and (40) yields

$$\psi_1 = \frac{1}{1 + 2bC_\psi} > \frac{1}{1 + 2bC_\psi + C_\psi/C_\eta} = \psi_1^*.$$

$$\psi_2 = -\frac{\theta + \eta_2}{1 + 2bC_\psi} < -\frac{\theta}{1 + 2bC_\psi + C_\psi/C_\eta} = \psi_2^*.$$

In this case, the water policy accomodates the correct level of normal water use and responds appropriately to nonnormal weather conditions even though it fails to respond to nonnormal demand conditions.

The commodity storage policy, on the other hand, is too sensitive to both demand and weather conditions and is even more sensitive to weather conditions than the cases above with *Independent Commodity Storage Policy Conditioned on Both Demand and Weather* and *Independent Commodity Storage Policy Conditioned on Price* where the water policy parameters are ignored (it is equally sensitive to demand conditions). This implies a second best type of result where commodity policy may be better off to ignore water policy if water policy is not formulated appropriately.

In summary, for what appears to be the most realistic characterization of public water projects, the results of this section imply a substantive shortcoming due to a failure to condition water storage policy on random variations in commodity demand. This failure causes public commodity storage facilities to be expand beyond the social optimum whether or not the water policy is taken into account in formulating commodity policy. This phenomena is a form of the LeChatlier Principle whereby understabilization with one instrument leads to overstabilization with another. In economic terms, by ignoring the possibility of smoothing commodity market conditions with water policy, the marginal cost of price stabilization through commodity storage variation is pushed beyond the marginal cost of price stabilization through water storage variation.

Public Versus Private Markets and the Need for Intervention

To operationalize the policy considerations of this paper, one must consider the behavior of private stock holding activities. In the literature on commodity price stabilization with buffer stocks, some studies have raised the issue of whether private stock holding activities are adequate without government intervention. Suppose for example that private commodity stock holders have a storage cost function $C_s = \gamma q^2$ with $\gamma > 0$, have a future price expectation $\bar{p}$, and face current price p.[1] An upward bending storage cost function such as γq^2 reflects the effect of limited storage capacity and the increasing opportunity cost of alternative uses of storage facilities as stocks are expanded. Stock holders with this problem have expected profit $\pi = (\bar{p} - p)q - \gamma q^2$ which is maximized with a demand for private stocks of $(\bar{p} - p)/2\gamma$. This achieves the optimal commodity storage response in (38) taking into account both demand and weather conditions without any government intervention in commodity markets if $\gamma = C_\psi$, i.e., if private storage costs are the same as public storage costs.[2] If private storage costs are different from public storage costs, then the optimal government commodity storage rule simply needs to make up the difference, i.e.,

$$\Delta I = \left[\frac{1}{2C_\psi} - \frac{1}{2\gamma}\right](p - \bar{p}).$$

Unfortunately, matters are not so simple in the case of optimal water storage. The difficulty is that water storage is a public good problem. In the case of surface water, if farmers pay only a nominal cost for water and water quotas are not effective then commodity market conditions are likely to have little impact on their water use decisions. If water quotas are effective then commodity market conditions will have no effect on their water use decisions. In either case, if the water authority does not directly consider commodity market conditions, then social optimality cannot be achieved. If the water authority attempts to account for commodity market conditions, then the use of a nonnegligible water price below the marginal social cost will cause farmers to adjust water use in response to commodity market conditions but to a suboptimal degree (assuming water quotas are not binding). The difference is difficult for a water authority to determine without information on farmers' cost structures. On the other hand, water quotas are difficult to determine appropriately because of a similarly burdensome requirement of farmer-specific information. A simple solution is reached only by charging farmers the full marginal social cost of water in which they are induced to adjust water use optimally in response to changing commodity market conditions.

The case of groundwater use has similar considerations. If the irrigation equipment and pumping cost faced by the farmer reflects the full social cost of irrigation, then farmers may be induced to modify water use appropriately with respect to commodity market conditions assuming that quotas are not applicable. However, groundwater policy has been moving increasingly in the direction of applying pumping quotas which prevents farmers from fully taking commodity market conditions into account in determining water use. The results of this paper suggest that this policy should be reconsidered in view of commodity market stabilization considerations.

Non-Storable Commodity Market Stabilization

Many commodities are not storable. This is perhaps more true of commodities grown in heavily irrigated areas such as the fruit and vegetable areas of California. These markets tend not to involve direct government intervention in commodity markets. Nevertheless, commodity market considerations should enter into water policy formation. The framework of this paper is directly applicable upon setting the commodity storage policy instruments and associated costs to zero ($\psi_1, \psi_2, C_\psi \equiv 0$). Making these changes in (11) and (16) results in first order conditions (35)-(37) which in this case describe the social optimum. The resulting solution is given by (22) and

$$\eta_1 = \frac{1}{1 + 2bC_\eta}$$

$$\eta_2 = -\frac{\theta}{1 + 2bC_\eta} .$$

In this case, these policy instrument levels attain the social optimum. Clearly, for this case, coordination of water and commodity policy authorities is not an issue. However, the water policy clearly depends to commodity market conditions as well as on weather conditions. The relative importance of commodity market conditions in optimal water policy (η_2/η_2) is directly proportional to the impact of water on crop production ($\partial S/\partial \Delta W = \theta$). Based on observed regulation of surface-water reservoirs, this adjustment of water use in response to commodity demand does not appear to be practiced. Given pricing of water from public water projects below marginal cost, there is no mechanism in place to take such conditions into account properly. With respect to groundwater use, on the other hand, considerable adjustment to commodity market conditions is evident in the widespread shutdown of certer pivot irrigation systems in the Great Plains during the weak commodity market period of the 1980s. Whether this response is at an optimal level, however, depends on whether farmers equipment and pumping costs reflect the full marginal social cost of groundwater use.

The Magnitude of Importance of Joint Policy Formulation

Although the theoretical results of this paper show that coordination or joint sensitivity of commodity and water policies is desirable, it remains to investigate whether the optimal extent of joint sensitivity is substantially different from partial and independent policy formulations. To do this, some estimates from other studies and judgement are used to develop rough estimates for the necessary parameters of the model. These calculation are made for 1983 since the irrigation cost estimates pertain only to that year.

Consider first the cost of storing grain. Paul has estimated grain storage costs finding that a quadratic relationship best reflects the cost relationship compared to linear and log-linear alternatives. Specifically, he finds the price of binspace in 1963 cents per bushel for wheat, corn, sorghum, soybeans, barley, oats, rye, and flaxseed is

$$C_s = -.68745 + 2.3\ (I/K)^2 + .985\ (S/K)^2$$

where I is average off-farm inventory, K is off-farm binspace capacity, and S is sales from farms (coefficients converted from Paul's use of monthly sales and percentages of capacity). Substituting from (3) and taking expectations obtains[4]

$$E\left(C_s\right) = -.68745 + 2.3\ \left(I_{-1}/K\right)^2 + 2.3\ \mathrm{Var}(\Delta I)/K^2 + .985\ E(S/K)^2.$$

Note further that the necessary average storage level represented by I_{-1} must also increase with Var(ΔI) to insure viability of the storage policy. For example, with normality and a 97.5 percent probability of viability, the necessary average inventory level would be 2 $[\mathrm{Var}(\Delta I)]^{1/2}$. Replacing I_{-1} by this term, the long-run cost equation would be

$$E\left(C_s\right) = -.68745 + 11.5\ \mathrm{Var}(\Delta I)/K^2 + .985\ E(S/K)^2.$$

Considering the first and last right hand terms as constant, this equation is in the form of (12) with C_ψ reflected by $11.5/K^2$. To convert to aggregate cost, however, this cost of storage must be multiplied by the average storage level, by 12 to get from monthly to annual cost, divided by 100 to get to dollars, and then appropriately reinflated. Converting to 1983 dollars using the GNP deflator implies a reinflation factor of 3.176. Note that average storage of the major grains examined by Paul in 1983 was 4.201 billion bushels.[5] With these considerations, the appropriate coefficient C_ψ of $\mathrm{Var}(\Delta I)$ in aggregate storage cost is $11.5 \times 4{,}201{,}000{,}000 \times 12 \times 3.176 / 100 / K^2$. Data on storage capacity are not readily available but 1983 was a peak storage year for grains and with a peak storage level for the grains considered here of 5,057,000 bushels.[6] Thus, C_ψ is estimated by $11.5 \times 4{,}201{,}000{,}000 \times 12 \times 3.176 / 100 / 5{,}057{,}000{,}000^2 = 7.200 \times 10^{-10}$.

Turning to water storage, Todd and Jacob have found that drawdown in pumping groundwater follows a quadratic relationship with

(41) $D = C_1\ \Delta W + C_2\ (\Delta W)^2$

where D is drawdown and Δw is water pumped from a single well. Taking expectations using (8), this leads to an expected drawdown of

$$E(D) = C_1\ \lambda\bar{R} + C_2\ (\lambda\bar{R})^2 + C_2\ \mathrm{Var}(\Delta W).$$

Thus, where the cost of pumping per foot of lift is given by k, the expected change in cost from a change in water policy can be calculated as the change in kE(D). This justifies the cost function in (13) where $C_0 = kC_1/\bar{R}$, $C_\lambda = kC_2/\bar{R}^2$, and $C_\eta = kC_2/\theta^2$. While these parameters could be used to find the optimal λ following (22), the primary focus here is on stability so these calculations will be omitted to save space.

Todd and Jacob estimate (41) at the micro level for an individual well where drawdown is in meters and pumping is measured in cubic meters per minute. They report reasonable levels of C_2 in the range of 0.5 to 4.0 with moderate conditions corresponding to $C_2 = 1.0$. To turn their estimates into an aggregate function, assume the average well serves 160 acres and is pumped continuously over a 150 day growing season. Note that 1 cubic meter per minute is equal to 175.1 acre feet per 150 day growing season and that 1 meter is 3.281 feet. Thus, a drawdown of 1 meter per unit of variance in cubic meters per day is equal to a drawdown of $3.281/(175.1)^2 = .0001069$ per unit of variance in acre feet per 150 day growing season. This, however, is per unit of variance on water flow from an individual well. Considering a total U.S. irrigated acreage of grains (wheat, corn, sorghum, soybeans, barley, and oats) of 19,721,481 acres (1982 Census of Agriculture) and an average of 160 acres per well implies that 1 unit of variance on an individual well is equal to $(19{,}721{,}481/160)^2$ units of variance in aggregate water use.[3] Thus, the value of $C_2 = 1.0$ from Todd and Jacob corresponds to a value of $C_2 = .0001069 \times (160/19{,}721{,}481)^2 = 7.0366 \times 10^{-15}$ for units of measurement used here (acre feet) at the aggregate level.

Next, to estimate C_η, assume that the cost per foot of pumping lift is \$.293 per acre foot pumped following estimates by Bitney, et al., for use of electricity. (This is the efficient form of energy excluding natural gas which is not widely available.) According to Earle Raun of Crop Management Consultants, Lincoln, Nebraska, an average water use of 1.5 acre feet in supplemental irrigation leads to an average increase in yield of 30 bushels per acre for corn. Using these numbers as representative of all grains, an average water use of 1.5 acre feet of water on 19,721,481 irrigated acres amounts to k = \$.293 × 1.5 × 19,721,481 = \$8,667,591, and an increase in production of θ = 20 bushels per acre foot of water applied. Thus, the estimate of $C_\eta = kC_2/\theta^2$ is $8,667,591 \times 7.0366 \times 10^{-15}/10 = 6.100 \times 10^{-9}$.

The remaining parameter necessary to calculate optimal instruments and compare to the independent policy cases is the slope of demand, b. While estimates of the aggregate elasticity of demand for the group of grains considered here are not available, recent econometric estimates for wheat and corn are in the neighborhood of -1. To convert this elasticity into a slope, consider the case of corn since this is the crop on which marginal irrigation effects are most likely. Domestic disappearance of the corn for the 1983 crop year was 6.571 billion bushels and average price was \$3.20 per bushel. This implies a demand slope of b = 2,053,562,500 bushels per dollar.

With these parameters, the optimal policy instrument levels in (23)-(26) are $\psi_1^* = .2454$, $\eta_1^* = .02896$, $\psi_2^* = -4.908$, and $\eta_2^* = -.5793$ and the various suboptimal (independent) levels are

$$\psi_1 = \frac{1}{1 + 2bC_\psi} = .2527$$

$$\eta_1 = \frac{1}{1 + 2bC_\eta} = .03838$$

$$\psi_2 = -\frac{\theta}{1 + 2bC_\psi} = -5.054 \qquad \psi_2 = -\frac{\theta + \eta_2}{1 + 2bC_\psi} = -5.248$$

$$\eta_2 = -\frac{\theta}{1 + 2bC_\eta} = -.7677.$$

These results indicate that the magnitude of error in policy instruments by not accounting for the joint interactions of commodity and water policy is substantial. Commodity policy instruments in the various partial and independent cases are about 3 percent too high indicating about a 3 percent over-response in commodity storage to variations in weather and/or commodity demand conditions (except in the most likely case where response to weather conditions is about 7 percent too high). Water policy instruments in the partial and independent cases are considerably worse with 33 percent over-response. If policies are formulated for this over-response, then either storage capacity for both water and commodities is over-built or it is inappropriately allocated to response to various conditions (for example, in the case where water storage does not respond to commodity demand conditions). The reason the over-response is so great for water storage is that a relatively expensive form of storage is being used to compensate for conditions that can be partially mitigated by cheaper commodity storage. Nevertheless, the increasing cost structure of both forms of storage implies that some substantive mix of the two storage activities is the best form of stabilization.

Further considering the form of (16) and (11) implies that producers and consumers jointly enjoy greater benefits from this over-response if both policies are sensitive to both weather and demand while costs of storage activities borne by government or private storage operations is beyond the social optimum. In some policy cases, however, much different outcomes occur. To get some indication of this relationship, Table 1 is constructed assuming that half of the commodity market price variability is due to demand disturbances and half is due to weather disturbances is the case of no stabilization activities (which implies $\sigma_\epsilon = 400\ \sigma_R$). These results indicate that 53 percent of the benefits of stabilization are lost if water is not used for stabilization purposes at all -- and this comes with commodity storage costs and capacity beyond the optimum. If both policies are fully conditioned on both demand and weather but policy formation is independent and uncoordinated, then producers and consumers gains from stabilization are beyond the optimum by 5 percent but storage costs are as much as 76 percent beyond the optimum because of stabilization beyond the optimum. If policy formation is coordinated but water policy does not respond to demand conditions (a likely case if current policy instruments are used), then producer and consumer gains are about the same as the social optimum but commodity storage costs are 10 percent beyond the optimum because commodity storage is used to compensate for the underutilization of water storage possibilities. In general, these results suggest substantive gains from joint consideration of commodity and water storage policies.

Conclusions

This paper investigates the importance of joint formulation of storage policies for water and commodities. The results indicate that benefits of joint formulation of policies can be substantial and that considerable errors in policy instruments can be made otherwise -- particularly for water policy. Potential exists to formulate and administer water and commodity policies separately if appropriate account is taken of other policy activities but this cannot be done without formulating water storage rules that are sensitive to commodity demand conditions. Charging less than marginal social cost for public project water and application of water use quotas that are not sensitive to commodity market conditions limits farmers' ability or incentive to adjust water use appropriately in response to varying commodity market conditions.

The results of this paper must be viewed as tentative to a large extent. Empirical work to support this kind of analysis is highly lacking. The empirical results derived here by relying on other studies provide only crude estimates. Parameter estimates are being used in a much different context than for which they were generated. Nevertheless, the magnitude of results is substantial and calls for further research to generate more appropriate data and empirical work as well to refine the conceptual analysis of joint considerations in water and commodity policy analysis.

Footnotes

[1] Note that adding a constant and a linear term to this cost function does not substantively alter the results. A constant term is like a fixed cost and does not alter marginal conditions. A linear term produces a constant term in the storage demand function below which can be considered as a change in the constant term in the market demand in (1).

[2] Note that expected private storage costs for this case are $E(\gamma q^2) = E[(\bar{p} - p)^2/4\gamma] = \sigma_p/4\gamma$ whereas public storage costs in the optimal case of (38) are $C_\psi \psi_3^2 \sigma_p = \sigma_p/4C_\psi$. Thus, public and private storage costs are identical when $C_\psi = \gamma$.

[3] Here we assume that all of this acreage is irrigated from groundwater. Although this is not accurate, most of the irrigated acreage in the major states producing each of the crops considered here is irrigated from groundwater.

[4] In reality, sales from storage may also vary in relation to ΔI in which case the coefficient of $Var(\Delta I)$ may be somewhat different. For the crude purposes here, such considerations are needlessly cumbersome and, in any case, appear to be secondary to the term considered here.

[5] This figure is calculated from *Agricultural Statistics*, 1986, for wheat, corn, sorghum, soybeans, barley and oats. Paul also considered rye and flaxseed but these crops are of minor and declining importance and some of the data are no longer published.

[6] See footnote 5.

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Table 1. Estimated Effects of Various Water and Commodity Policy Coordination Scenarios

	Policy Scenarios							
	Uncoordinated						Coordinated	
Commodity Policy Conditioned on								
Demand	X		X	X		X		X
Weather	X			X		X		X
Price		X			X		X	
Water Policy Conditioned on								
Demand						X		X
Weather			X	X	X	X	X	X
Welfare Effect (Percent of Optimum)								
Gains from Stabilization (Consumers and Producers)	47	47	55	90	99	105	101	100
Commodity Storage Costs (Stabilization Purposes)	106	106	53	106	106	106	110	100
Water Storage Costs (Stabilization Purposes)	0	0	88	88	88	176	88	100

Source: Calculated from equations and estimates in the text.