Political Weights and Cooperative Solutions to Externality Problems: The Case of Irrigation Water

Edna Loehman

Department of Agricultural Economics and Economics
Purdue University

Ariel Dinar

Department of Agricultural Economics
University of California, Davis
and
USDA-ERS

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Abstract

Cooperative technology improvements may ameliorate externalities. However, cooperative solutions may not be achieved without appropriate institutional mechanisms. Here, design of such an institutional mechanism is proposed based on combining aspects of games proposed for public goods and externality problems. A solution concept, an "acceptable cooperative solution", is also proposed; such a solution would be accepted because it is unanimously preferred to the status quo and to a noncooperative "threat point."

The proposed institutional design is based on a repeated Prisoner's Dilemma game. Both noncooperative and cooperative outcomes are defined in terms of political weights on game players. Cost shares in the cooperative case are used to cover the cost of joint facilities, and Pigouvian taxes are used to give appropriate information signals. Cost shares are equal to political weights to give incentives for correct demand revelation. At the equilibrium of such a game, a set of political weights is produced corresponding to an acceptable cooperative solution.

Concepts are applied to an irrigation externality problem in the Central Valley of California to demonstrate existence of an acceptable solution.

Introduction

For externality problems, the Pigouvian tax has traditionally been proposed as a solution which, at least in theory, equates marginal social and private costs but may have implementation problems (Baumol and Oates, 1975). Regardless, such a solution produces a noncooperative (private response) outcome. This paper argues that another type of solution, a cooperative solution involving joint action, may produce a preferred social outcome. However, it may also be difficult to achieve a cooperative solution because of the need to share joint costs. This paper concerns the development of institutional arrangements and a political process such that a cooperative solution will be adopted in preference to a noncooperative solution for an externality problem.

Although there are many externality problems in current economic systems (both local, national, and international), an important type of externality problem concerns water utilization and, in particular, irrigation. The situation of irrigation externalities, with pollution and water scarcity, is used as an example in this paper to demonstrate that cooperative solutions should be preferred to noncooperative solutions and may be possible to achieve given appropriate institutional arrangements.

Irrigation water used for agricultural production under certain conditions may result in wetlands, acquifers, lakes, and rivers receiving elevated levels of pollutants such as selenium and other trace elements present in soil (SJVDP, 1990). Such pollutants can affect recreation benefits of those engaged in hunting, fishing, and bird-watching (Loomis, et al.. 1991). For example, selenium is known to reduce reproduction rates of fish (Saiki, et al., 1991) and waterfowl (Skorupa and Ohlendorf, 1991). Fo high enough selenium levels, health effects may also occur to those who consume local water and produce. However, food consumption is not considered to be a problem for local consumers since food is usually purchased from multiple sources (Klassing, 1991). A high water table may also have negative effects on production for downslope producers (Rhoades and Dinar, 1991).

Externality problems result from water use decisions made by individual producers. Adoption of improved irrigation technologies by individual producers could alleviate water scarcity problems as well as improve drainage water quality (Dinar and Zilberman, 1991). Examples of such technologies are sprinklers and drip irrigation which localize the delivery of water, as opposed to gravitational technologies such as border and furrow irrigation. Because of their increased capital and labor costs, improved technologies may not be adopted without incentives.

Regional systems requiring cooperation among irrigation water users could either complement or substitute for improvements in privately applied technologies. Such systems include drainage collection, water treatment, and recycling of treated water. Because of economies of scale, the unit cost of achieving an improvement in water quality may be lower with regional water systems than with privately applied technologies. Regional collection and recycling of runoff could also help to ease water scarcity. In spite of these potential benefits, a regional cooperative solution may not be achieved because of problems associated with information, coordination, and cost sharing required for regional cooperation.

The problem of achieving regional cooperation in water management is viewed here from a game theory perspective. A case study for the San Joaquin Valley in California is used to demonstrate that a cooperative solution may be achieved to ameliorate an externality problem resulting from irrigation practices. Similar externality problems can be found in other geographic areas.

In contrast to market situations with large numbers of participants, the game situation in the San Joaquin Valley involves a relatively small number of players. Agricultural producers are organized into water districts, with a board and a water district manager. The district manager has the power to set water rates and determine water use practices for the district with the acquiescence of the board. A regulatory body exists as well, namely the California Water Quality Control Board. To achieve a cooperative solution instead of a noncooperative solution, here we suggest that an expanded role for the district manager may be required: the manager must collect information, negotiate agreements, develop procedural rules, and emplement cooperative water activities.

The organization of this paper parallels welfare economic results for the case of perfect competition. For the case of an externality with the possibility of amelioration through a cooperative technology, the paper will first define a desired solution concept and a mechanism or sequential game process which may achieve this solution. The existence of a solution is then shown for the particular case of irrigation in the San Joaquin Valley. An algorithm is presented to locate such a solution; this method can be applied by the manager to implement the sequential game process.

Comparison to Traditional Economic Solutions and Game Theory

Traditional economic solutions for externality problems proposed in economic literature include use of Pigouvian taxes and Coasian bargaining.

Use of a Pigouvian tax will set the level of the externality at a Pareto optimal level for a noncooperative (private) response. In the noncooperative case, given market prices, participants do not need to obtain information about the preferences of others to choose their own actions.

However, a central authority such as the regional manager would require preference information in order to set the Pigouvian tax.

It is well-known that Coasian bargaining solutions, preceded by a necessary definition of property rights, will also achieve Pareto optimality as long as transaction costs are not large. Such solutions would be cooperative in that direct communication is required to reach agreements, but they may fail to achieve an outcome requiring joint action unless problems of achieving cooperation are specifically addressed.

Game theory has previously been applied to externalities and public goods separately, whereas here the situation involves the combination of externalities and public goods.

Cooperative and noncooperative game situations differ with respect to the nature of interactions among participants and related information requirements. In a cooperative setting, to make binding agreements regarding joint action requires communication among participants (Bacharach). One view stated by Samuelson (1985) is that with information asymmetry "the parties affected by an externality will, in general, be unable to negotiate efficient agreements...". Here, the presence of the manager may help to overcome such information problems.

Cost sharing to finance a regional system is one critical aspect for achieving cooperation. Cost allocation literature (Young; Loehman and Whinston) has viewed cost sharing as a cooperative game. Core allocations are sought such that each participant and subcoalition of participants is better off than acting separately after joint cost for a cooperative activity is financed.

Here, a regional cooperative system also requires that definition of the quantity of a public good -- the level of water quality to be achieved -- be determined. Therefore, the situation studied here is more complex than a cost allocation problem because the water quality to be achieved must be determined as well as allocation of the joint treatment cost.

Literature concerning game theory applied to public goods has addressed how to determine the quantity and finance of a public good. Restrictive assumptions are required. In order that public good quantity and cost allocation are separable decision problems, utility must be linear in the value of private goods (Bergstrom and Comes). For the Lindahl equilibrium, a type of solution (Feldman) for which tax shares are used to finance a public good, tax shares, and quantity are determined such that each person's net benefits are maximized but marginal cost is assumed to be constant -- rather than exhibiting economies of scale as in the situation here.

A regional system would provide benefits jointly to producers and consumers who would value such improvements differently. As with other types of public goods, determining demand or benefits for a regional system may induce incentive problems such as free-riding. Recent research in public goods concerns avoiding the free rider problem by using a demand revealing mechanism, or "truth tax", to induce truthful behavior as the best strategy. Such schemes generally do not satisfy Pareto optimality because generally there will be a budget surplus (Hurwicz, 1975, reported in Feldman).

Less attention has been given to alleviating externality problems in a cooperative game setting. Game theory applied to two firms shows that the maximum of joint profits for firms involved in externalities may be achieved through a taxation scheme as long as there is not a bilateral externality (Bacharach; Davis and Whinston). A focus in more recent externality literature, as in the public goods literature, has been on the need for a demand-revealing process to elicit truthful information about values (Groves). Regardless, the core of an externality game may not exist when there are more than two players (Shapley and Shubik, 1969).

Here, in designing a mechanism for a cooperative solution to an externality problem with economies of scale in amelioration, demand revelation schemes are not utilized since their advantages are somewhat debatable (Roth, 1985). Instead we will assume that the regional manager has access to some information about preferences. By obtaining value information in a way not directly connected to solving the problem at hand (eg. by using general surveys of willingness to pay for recreation -- the basis for empirical work here), demand revelation problems may be lessened.

Definition of an Acceptable Solution

Because of potential problems with subcoalition formation and existence of the core, this paper proposes use of a weaker solution concept than the core. Core conditions requiring benefits for each subcoalition are ignored. The proposed solution concept satisfies a necessary condition for the formation of "the grand coalition," namely that each player be better off than acting individually. The rationale for ignoring subcoalitions is that the high associated information costs may prevent their formation, whereas information problems for the grand coalition are reduced by the regional manager.

The solution concept proposed here is called an "acceptable cooperative solution". A threat for a cooperative solution is a noncooperative solution representing the same political power for game participants as the cooperative solution (explained below). An "acceptable cooperative solution" should satisfy the following properties:

(i) each player is better off than at the status quo;

(ii) each player is better off than at the noncooperative solution;

(iii) joint costs are covered by cost shares paid by players.

That is, the acceptable cooperative solution would be voluntarily adopted, compared to both the noncooperative solution and the status quo, because all participants in the grand coalition are made better off.

Game theory research usually studies existence and uniqueness for any proposed solution concept. Here, existence of an acceptable solution is not guaranteed because of nonconvexities associated with externalities (Starrett) and economies of scale (Calsamiglia). Therefore below we demonstrate existence of an acceptable cooperative solution for a situation representative of that in the San Joaquin Valley.

Technical Efficiency, Pareto Optimality, and Political Weights

Welfare economic results for perfect competition (the noncooperative case) concern the relationship between technical efficiency and Pareto optimality (Negishi; Takayama). This section discusses this relationship and its nature in the cooperative case and the role of political weights.

Technical efficiency is represented by a production frontier. Figure 1 illustrates the production frontier for agricultural production (Y) and water quality (Q). Consider the case when there are several private water technologies $\{r_j\}$ where j denotes private technologies such as traditional furrow irrigation, sprinklers, and drip irrigation. Each technology is represented by a locus in terms of possible combinations of agricultural production and water quality produced for a given quantity of water and land available. The production frontier for a given set of technologies is the envelope of the loci for this set of technologies; production is said to be efficient if it occurs on this frontier. Introducing a regional cooperative technology (**T**) in combination with a set of private technologies adds another locus over which the envelope is taken.

Figure 1. Noncooperative Production Frontier related to Fnreto Optimality and Political Weights.

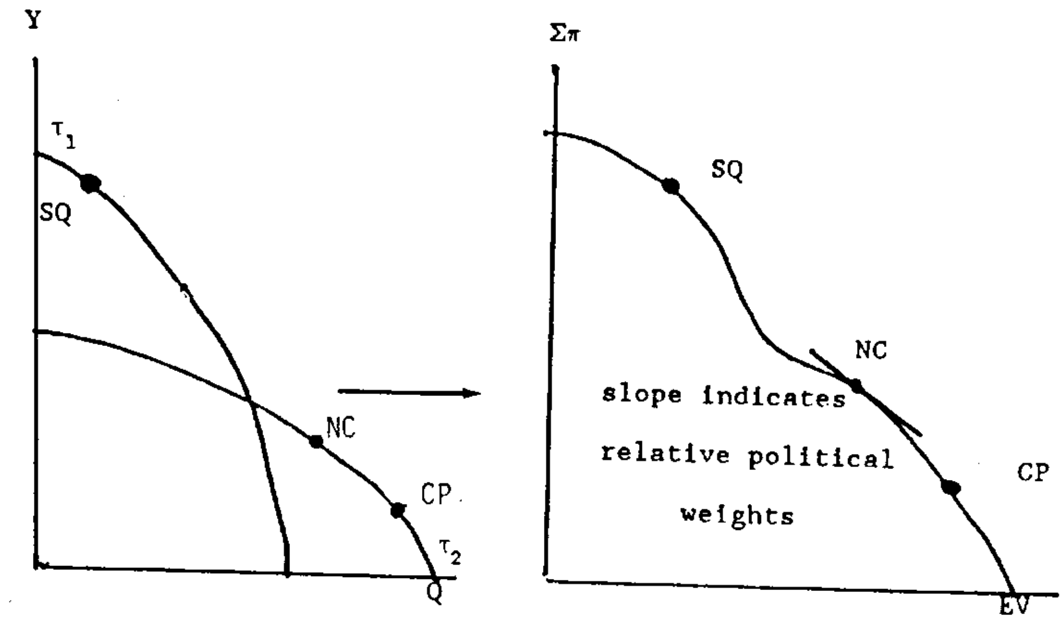
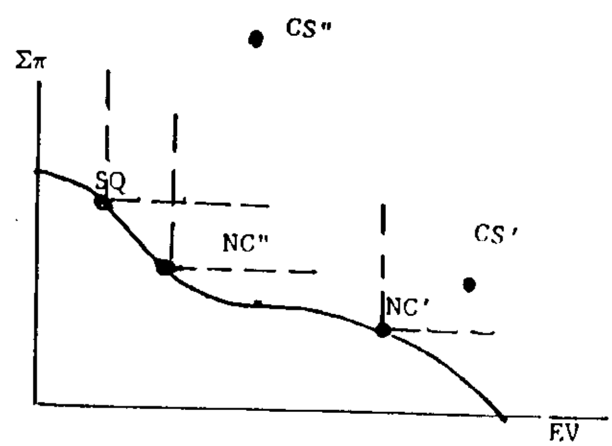


Figure 2. Acceptable and Unacceptable Cooperative Solutions



Note that the envelope formed in this way may define a nonconvex set even if the underlying loci are associated with convex production sets. In the noncooperative case, externalities cause nonconvexity, and in the cooperative case, nonconvexity may also occur because of increasing returns (Calsamiglia). Therefore, nonconvexity may cause problems in achieving Pareto optimal solutions through market incentives such as taxes (Starrett). Regardless, a production frontier (e.g. including cooperative technolgies) would be socially preferred to one inferior to it (e.g. with only private technologies) because Pareto improvements in individual welfare are at least hypothetically possible (Samuelson, 1950).

Pareto optimality is traditionally represented by a utility possibility frontier. To obtain the utility possibility frontier, each point on the production frontier is associated with preference functions, either utility or payoff function levels, for each relevant person or interest group. Any point along the noncooperative efficiency frontier can be represented, for some set of weights, as a solution of maximizing a weighted sum of preference functions (Negishi) over the given set of technologies.

Defining the appropriate tradeoff between water quality and agricultural production (at a point such as NC) is a social choice problem requiring the balancing of consumer and producer interests. Each noncooperative solution can be associated with the relative political power of these interest groups in determining the social outcome. For example, the status quo point (SQ) in Figure 1 corresponds to a maximization of agricultural profit with private water use technologies, i.e., a zero weight on consumer interests. An improved water quality corresponds to a greater weight on consumer interests. (In Figure 1, total profits are used to represent producer preferences while value of environmental benefits relative to the status quo represents consumer preferences.) The slope of the frontier at a chosen outcome corresponds to the relative power or political weight of interest groups.

If externalities are severe enough, consumers may organize politically to cause regional and/or state authorities to set improved water quality standards. The countervening political power of producers limits the extent to which purely environmental objectives can be met. A point such as NC in Figure 1 may represent a political solution between the status quo and the point along the noncooperative frontier preferred by consumers (CP). Such a solution can also be associated with a set of political weights.

Any solution on the noncooperative production frontier could be achieved as a noncooperative Nash equilibrium in which private technologies are chosen by individual profit maximizing decisions by producers in response to Pigouvian taxes. (Permits limiting land and water use may be needed as extra incentives because of nonconvexities.) There is a corresponding tax and noncooperative Nash equilibrium solution for each set of political weights.

If cooperative technologies such as a regional treatment plant allow improved drainage water quality to be obtained without a decrease in agricultural profit because of economies of scale, the cooperative efficiency frontier will lie outside the noncooperative frontier. However, in the cooperative case, the utility possibility frontier cannot be specified without defining the costs shares to be paid by each party, and the location of the utility possibility frontier therefore depends on the method of cost allocation. Shared costs incurred to improve water quality to make consumers of recreation better off would generally make producers worse off unless improved technologies offset their additional costs. Therefore, a technically efficient solution on the cooperative production frontier may not be acceptable, and conversely a given acceptable solution may not correspond to technical efficiency. (See Appendix A).

In searching for an acceptable cooperative solution, Figure 2 illustrates two possible cases. In the first case, the cooperative solution (CS') is preferred to the noncooperative solution (NC) but is not Pareto superior to the status quo, because it is too expensive for producers after paying their share of joint costs to produce a gain relative to the status quo. The second case (CS") is an acceptable cooperative solution because all parties are better off both compared to the status quo and to the noncooperative solution (NC").

If cost shares for producers in the cooperative solution are less than the taxes in the noncooperative case and agricultural output is not diminished in the cooperative solution, then the cooperative solution would be preferred to the noncooperative solution by producers; however it may not be preferred to the status quo because of cost shares. Consumers will generally be better off in the noncooperative solution than at the status quo because the externality is reduced and no cost sharing is required. Consumers may prefer a noncooperative to a cooperative solution if their share of joint costs is too large. Therefore, the existence of an acceptable solution is not automatic.

Below, we define a process based on a sequential Prisoner's Dilemma game to locate an acceptable cooperative solution as related to political weights. A pair of cooperative and noncooperative solutions is defined for each set of political weights. The noncooperative solution, imposed through taxes on water and land use, serves as a reference point or "threat point" (Thompson, 1981; Friedman,1986) that is the outcome if players do not agree on a cooperative solution. Such a process may have no acceptable solution or may have multiple solutions. Therefore, here an empirical example is used to demonstrate the existence of an acceptable solution in the irrigation problem case.

Principles of Mechanism Design Applied to the Externality Problem

The sequential game process proposed here for the purpose of finding political weights and related cost shares draws upon several previously proposed games, including repeated Prisoner's Dilemma games (Rosenthal, 1981; Axelrod, 1984), Lindahl equilibrium (Feldman, 1980; Binger and Hoffman, 1987), games of fair division (Friedman and Rosenthal, 1986), and alternating offer games (Rubenstein, 1982).

Principles of mechanism design are used to design this process. Mechanism design (Hurwicz, 1972) refers to the design of organizational structure, allocation rules, and information systems to achieve a desired social outcome based on economic principles. Here, the desired social outcome is locating an acceptable cooperative solution.

Generally, the goal of resource allocation has been to achieve social efficiency (Bohm, 1973). In mechanism design, social efficiency is defined more broadly not only in terms of Pareto optimality and technical efficiency but also in terms of minimizing the social costs associated with information collection and enforcement of agreements. Principles for design of resource allocation systems were first defined by Hurwicz (1972) for "nonclassical environments" by generalizing from the characteristics of a market mechanism operating under perfect competition. Preferred characteristics of mechanisms identified by Hurwicz are: incentive compatibility, individual rationality, information decentralization, unbiasedness, and nonwastefulness. "Nonwastefulness" refers to being on the production frontier. "Unbiasedness" refers to having the possibility of achieving any Pareto optimum by a lump sum redistribution of income. (To apply "unbiasedness" to our externality case, consumers could be given lump sum income supplements to ease budget constraints to enable them to pay a greater share of joint costs.) Truthful demand revelation is a more recent aspect of mechanism design focussing on avoiding free-rider effects in obtaining preference information (Groves and Ledyard, 1977).

Once conditions of perfect competition do not hold, it is not possible simultaneously to minimize the social costs of waste, information, and enforcement (Feiwel). In particular, complete information decentralization is not possible in nonclassical environments such as when objectives such as reducing externalities are pursued.

Game theory can be the basis for designing a resource allocation mechanism in a nonclassical environment. For example, the Prisoner's Dilemma game applies to many institutional settings (Brams, 1975; Schotter, 1981). In a game, players determine choice strategies consistent with their own objectives given rules of the game regarding resource allocation and information revelation. Termination rules define when the game ends. A game may either stop when equilibrium is achieved (i.e. no player wants to continue the game); or if no equilbrium is achieved, the game may have a termination rule such as a time limit.

The voluntary choice between a pair of cooperative and noncooperative solutions in finding an acceptable solution is related to a Prisoner's Dilemma game. This problem is usually used to demonstrate that a noncooperative solution may be chosen over a cooperative solution even when the cooperative solution is Pareto optimal. The selection of noncooperation over cooperation may occur if there is no communication among players and there are no incentives to cooperate or penalties for noncooperation beyond the relative payoff values (Oppenheimer, 1990). Here, the presence of the regional manager ameliorate the Prisoner's Dilemma. In addition to providing information to reduce transactions costs of bargaining, the regional manager can also act as a mediator during the process of finding political weights corresponding to an acceptable solution.

Once a cooperative agreement is obtained, the manager is also responsible for emplementing the cooperative solution in terms of operating joint facilities, computing and collecting taxes and cost shares, and monitoring activities for compliance with the agreement. Therefore, the regional manager has a much more important role in the proposed game than in a traditional Pigouvian tax solution.

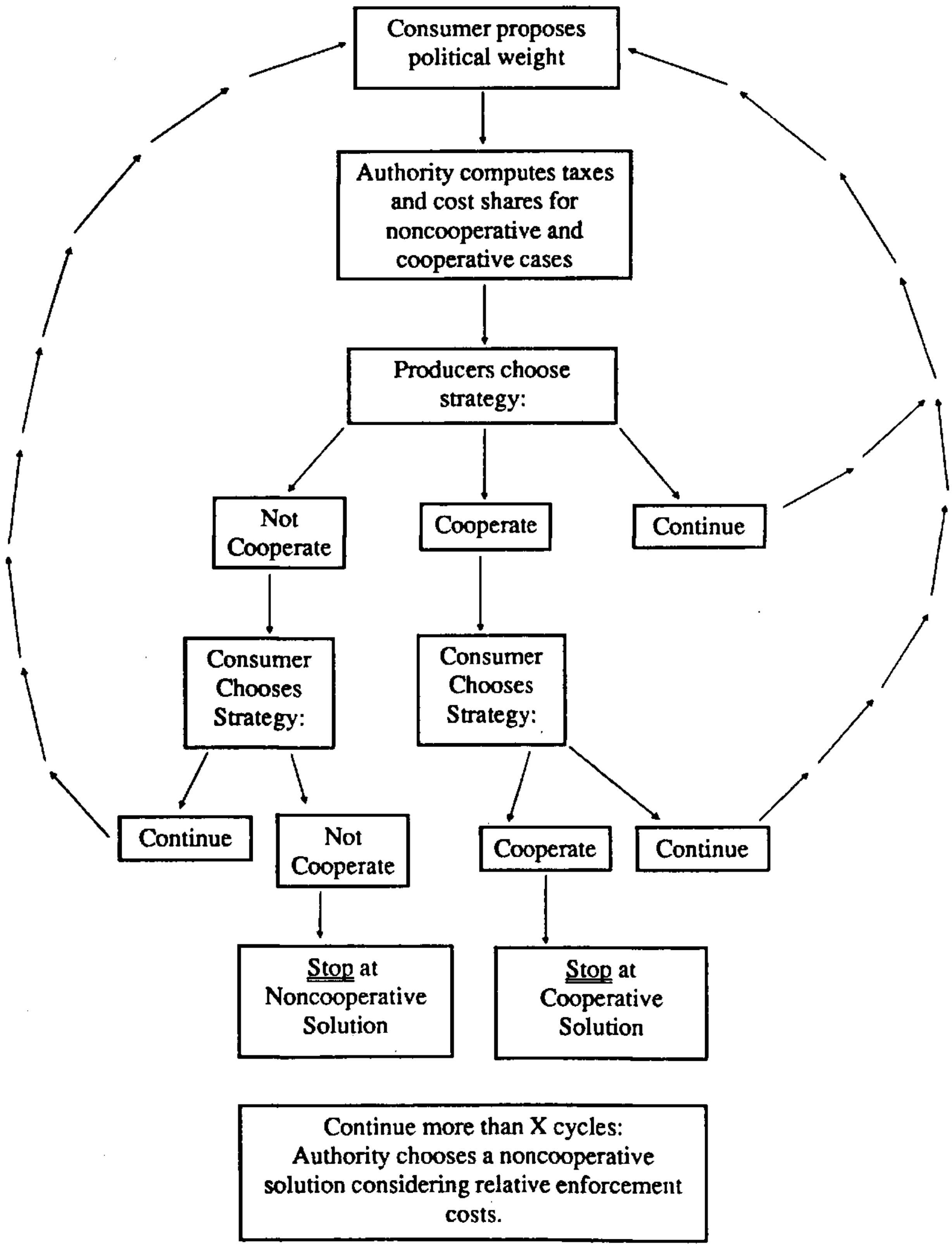
An important part of the cooperative game rules is to define how joint costs will be apportioned among consumers and producers. Here, it is proposed that joint costs be allocated according to shares similar to a Lindahl game. For incentive compatibility purposes, shares will be set equal to political weights. If the consumer's share of the joint costs is equal to the consumer's political weight, a greater weight in determining the tradeoff between water quality and agricultural profit along the production frontier will then imply a larger share of joint cost.

Other more complicated cost allocation schemes have been proposed in game theory literature; such procedures have desirable properties such as fairness and belonging to the core (Young). This procedure is relatively simple to complete and it can also correspond to core solutions (Loehman, 1985). The relation of cost shares to political weights is also related to "fairness": a person's influence on the social outcome has a relation to willingness to pay for joint costs.

Figure 3 illustrates the sequential nature of the proposed game. To begin the game (using a representative consumer), the consumer first announces the political weight to be placed on the consumer's payoff function. Here, we assume that producers are weighted equally (this could be modified) so that the selection of a weight for the consumer also determines the weight on producers. In proposing a weight, consumers will consider their benefits from increasing water quality to their costs for making such improvements. (At this point, actual cost shares and taxes are not yet known to the participants.)

Figure 3

Cooperative Weight Determination Game



Corresponding taxes and cost shares are then determined by the manager as related to the proposed weight. Given a pair of noncooperative and cooperative solutions, the producers then choose between noncooperative and cooperative solutions. If neither solution is attractive to producers in comparison to the status quo, they can require that the game continue and that political weights be revised.

Depending on the producers' choices between cooperation, noncooperation, and continuation, the consumer again chooses whether or not to cooperate or to continue the search for a set of political weights. If all parties agree to cooperate for a given set of weights, then the game stops at the cooperative solution. If such a process stops at a cooperative solution, the resulting equilibrium is an acceptable cooperative solution. If all agree not to cooperate rather than to continue, then the process stops at a noncooperative solution. Hopefully this case would not occur unless there were grounds to believe that no set of weights would produce mutual benefits.

If no equilibrium is found after a number of continuation cycles, a noncooperative solution could be imposed by the regional manager, chosen in accordance with management and enforcement costs. Knowing that such an event may happen -- but not which noncooperative outcome would be selected by the manager -- would give additional incentive for players to locate an acceptable cooperative solution.

For both the cooperative and noncooperative cases, Pigouvian taxes can be used to decentralize decisionmaking regarding resource use by producers. In the cooperative case, taxe revenues can be used to help finance joint costs. Because of economies of scale, joint costs will not be fully covered by tax revenues, so cost sharing would still be required.

Tax revenues by law must be returned to the system since a water district is non-profit. In the noncooperative case, tax revenues should not be used for purposes directly related to producers' water use. If taxes were given back to producers directly, then there would be no incentive to adopt improved technologies. Tax revenues should also not be used to compensate consumers directly because then consumers would have incentives to overstate their political weights (Baumol and Oates). Also, if tax revenues are used as compensation for the regional manager, his/her incentive for finding a cooperative solution would be reduced.

Algorithm for Noncooperative and Cooperative Solution Pairs

Below, we present an algorithm to determine noncooperative and cooperative solution pairs for each set of political weights. The irrigation situation analyzed is a simplified representation of the situation in the San Joaquin Valley of California. Two producers (upslope and downslope) and one consumer represent others in the geographic area.

Application of game theory to real world problems has been limited because of the problem of representing preferences in common monetary units. Here, producer payoffs are naturally defined as profits. Following recent environmental literature, the concept of equivalent variation is used to represent consumer preferences for environmental quality in monetary terms. Below, payoff functions are described in more detail as related to pollution load (inversely related to water quality) and production.

Producers' Payoffs

Profit for each type of producer (upslope -- π^u; downslope -- π^d) is revenue from production minus: annual fixed costs per acre for water technologies used, denoted by $F(\tau^i)$ for technologies τ^i for each type of producer (i=u,d); variable water-related production costs ($v(\tau^i)$ per unit of water); and taxes for water and land use (t_ω^i, t_ℓ^i, i=u,d). In the status quo case (denoted by π_o^i), there are no taxes. Water and land constraints are represented by $\bar{W}^i$ and $\bar{A}^i$.

The upslope producer's yield (Y^u) per unit land area is related to the irrigation technology (τ^u) and water use (w^u) per unit land area:

$$Y^u = Y^u(w^u;\ \tau^u). \qquad (1)$$

The upslope producer maximizes profits by choosing acres planted in each crop (A^u), total water use for each crop (W^u), and irrigation technologies. The profit maximization problem is:

$$\max_{\tau^u, W^u, A^u}\ [p_f Y^u - v(\tau^u)w^u - F(\tau^u) - t_\ell^u]\ A^u - t_\omega^u\ W^u \qquad (2)$$

$$\text{s.t.} \quad A^u \leq \bar{A}^u$$

$$w^u A^u = W^u \leq \bar{W}^u$$

$$Y^u = f(w^u;\tau^u).$$

(To represent several crop activities and technologies, Y, w, A, and τ can be vectors. Assuming equal application, water use per acre (w^u) is determined by W^u and A^u.)

The downslope producers' yield is also related to water use per acre (w^d), the irrigation technology used, but is also affected by the externality due to the water use of the upslope producer. Drainage caused by total water use of upslope producers will reduce yield of downslope producers if there is excess water and salinity in the root zone. A factor (k) adjusts for the amount of water received downslope, where $0 \leq k \leq 1$:

$$Y^d = Y^d(w^d,\ kW^u;\ \tau^d). \tag{3}$$

The proportion k depends on the topography, soil type, and upslope technologies.

The downslope producer chooses total water use, acres planted, and irrigation technology to maximize profit. The optimization problem for this producer is similar to the above:

$$\max_{\tau^d, W^d, A^d} \ [p_f\ Y^d - v(\tau^d)w^d - F(\tau^d) - t_\ell^d]\ A^d - t_\omega^d\ W^d \tag{4}$$

$$\text{s.t.} \quad A^d \leq \bar{A}^d$$

$$w^d\ A^d = W^d \leq \bar{W}^d$$

$$Y^d = f(w^d,\ kW^u;\ \tau^d).$$

Pollution Impacts

Total pollution reflects the effects of both upslope and downslope producers' land, water, and technology decisions. Pollution (S^u) produced by the upslope producer can be described by

$$S^u = \delta^u(\tau^u)\ W^u; \tag{5}$$

that is, pollution is proportional to the total amount of water used depending on the water technology and the topography and soils. The downslope producer's own effect on pollution is similarly represented, except that the resulting pollution includes both effects from his/her own water use and the drainage from the upslope producer:

$$S^d = \delta^d(\tau^d)\ (W^d + kW^u). \tag{6}$$

The total pollution load (S) is the sum of S^u and S^d:

$$S = S^u + S^d. \tag{7}$$

A tax could be assessed per unit of pollution load, but because of information problems associated with nonpoint source pollution, land and water are more easily taxed than pollution load if physical relationships such as (1), (3), (5), and (6) are known.

Consumers' Payoffs

Preferences of consumers are usually represented by a utility function which, because utility is not in dollar units, is not directly comparable to producer profits. The equivalent variation provides a dollar measure of welfare which gives the same ranking of outcomes as utility (McKenzie).

The expenditure function is defined from the indirect utility function:

$$\tilde{U} = \tilde{U}(M, S, p_f, p_h, p_r, p_z) \qquad (8)$$

where M denotes initial wealth or income, S denotes pollution, and p_i, i = f,h,r,z denote respectively prices of food, health, recreation, and other goods (Loehman, 1991). Reduction of drainage water or improvement of its quality would improve consumer welfare. The amount of money (EV) which is equivalent to a change in pollution load satisfies the following relation when the pollution level is reduced from S^o to S' with $S^o > S'$:

$$\tilde{U}(M + EV, S^o, p_f, p_h, p_r, p_z) = \tilde{U}(M, S', p_f, p_h, p_r, p_z). \quad (9)$$

The equivalent variation is an implicit function of initial drainage water quality, change in water quality, income, and prices. Note that $\partial EV/\partial S < 0$, i.e. as the pollution load decreases, the equivalent variation increases. To define net consumer benefit in income terms when water quality improves with a cost share to be paid by consumers, EV will be reduced by the amount of the cost share.

We will assume that the market for products grown in the region is open so that food prices are not affected by changes in technology.

The Noncooperative Solution and Corresponding Pigouvian Taxes

The optimization problem solved for the noncooperative solution is to maximize the weighted sum of payoffs subject to production and pollution constraints. The weighted sum of payoffs for consumers and producers is maximized over the set of private water technologies, acres planted, and water use for each producer. Constraints for the joint maximum problem include water and land constraints, and yield and pollution production functions. For the noncooperative solution corresponding to the set of political weights a, the optimal pollution level is a function of a denoted by S(a; NC).

$$
\begin{aligned}
JW(\alpha;NC) = \max_{\substack{A^u, A^d,\\ \tau^u, \tau^d, W^u, W^d}} \quad & \alpha_c EV(S;\ S^o) + \alpha_u [p_f Y^u - F(\tau^u) - v(\tau^u) w^u] A^u \\
& + \alpha_d [p_f Y^d - F(\tau^d) - v(\tau^u) w^d]\ A^d \\
\text{s.t.}\quad & A^u \le \bar{A}^u \qquad\qquad (10) \\
& A^d \le \bar{A}^d \\
& w^u A^u = W^u \le \bar{W}^u \\
& w^d A^d = W^d \le \bar{W}^d \\
& S^u = \delta^u(\tau^u)\ W^u \\
& S^d = \delta^d(\tau^d)\ (W^d + kW^u) \\
& S = S^u + S^d \\
& Y^u = Y^u(w^u; \tau^u) \\
& Y^d = Y^d(w^d,\ kW^u; \tau^d).
\end{aligned}
$$

Denote the above expressions for profits before taxes for upslope and downslope producers by $\hat{\pi}^u(\alpha)$, $\hat{\pi}^d(\alpha)$.

Pigouvian taxes to achieve a given noncooperative equilibrium are found from setting the first order conditions for the noncooperative joint maximum problem equal to zero; they depend on the specified political weights. The Pigouvian taxes (t^i_ω, t^i_ℓ) on water and land use are the right hand sides of the expressions below, evaluated at the optimum technologies and water and land use:

$$\frac{\partial \hat{\pi}^u}{\partial W^u} = \frac{\mu^u}{\alpha_u} - \frac{\alpha_c}{\alpha_u} \frac{\partial EV}{\partial S} (\delta^u + \delta^d k) - \frac{\alpha_d}{\alpha_u} \frac{\partial \hat{\pi}^d}{\partial W^u}; \tag{11}$$

$$\frac{\partial \hat{\pi}^d}{\partial W^d} = \frac{\mu^d}{\alpha_d} - \frac{\alpha_c}{\alpha_d} \frac{\partial EV}{\partial S} \delta^d. \tag{12}$$

$$\frac{\partial \hat{\pi}^u}{\partial A^u} = \frac{\lambda_u}{\alpha_u} - \frac{\mu^u}{d^u} w^u \frac{\alpha_c}{\alpha_u} \frac{\partial EV}{\partial S} (\delta^u + \delta^d k) w^u - \frac{\alpha_d}{\alpha_u} \frac{\partial \hat{\pi}^d}{\partial A^u} \tag{13}$$

$$\frac{\partial \hat{\pi}^d}{\partial A^d} = \frac{\lambda_d}{\alpha_d} - \frac{\mu^d}{\alpha^d} w^d \frac{\alpha_c}{\alpha_d} \frac{\partial EV}{\partial S} \delta^d w^d. \tag{14}$$

The multipliers μ^i are associated with the water constraints $\overline{W}^i$; μ^i will be zero if water constraints are met. λ_u and λ_d are multipliers associated with the land constraints, they represent land rental values. Because of the upslope external effect on the downslope producer, even if land rent values and water allocations are equal for upslope and downslope producers and the weights α_u, α_d are equal, the upslope producer would pay a higher tax per unit than the downslope producer because of the externality effect on the downslope producer.

Net profits for the noncooperative solution for a given set of weights α are obtained by subtracting taxes from profits $\hat{\pi}^i$ in the joint maximum:

$$\pi^{u}(\alpha;\ NC) = \hat{\pi}^{u}(\alpha) - t_{\omega}^{u}(\alpha;\ NC)\ W^{u} - t_{\ell}^{u}(\alpha;\ NC)\ A^{u} \qquad (15)$$

$$\pi^{d}(\alpha;\ NC) = \hat{\pi}^{d}(\alpha) - t_{\omega}^{d}(\alpha;\ NC)\ W^{d} - t_{\ell}^{d}(\alpha;\ NC)\ A^{d} \qquad (16)$$

By maximizing profits with the prescribed taxes, each producer will then make individual land and water use decisions corresponding to the noncooperative joint solution when solving (2) and (4). Water and land use are reduced by the taxes compared to that for the status quo since the status quo solution satisfies $\frac{\partial \hat{\pi}^{i}}{\partial W^{i}} = 0$ and $\frac{\partial \hat{\pi}^{i}}{\partial A^{i}} = 0$.

The Cooperative Solution

In the cooperative case, regional cooperative technolgies are available in addition to the private technologies used in the noncooperative case. Regional water technology improvements in the cooperative case could include regional drainage systems, regional water treatment plants, technical advice for operation of more sophisticated private technologies, regional systems for storage and reuse of treated water, etc.

The algorithm below for the cooperative case defines an optimization problem independent of the cost sharing method. Cost allocation can then be determined ex post. Regional cooperative technologies are denoted by τ^{R}. The joint regional cost of treating and reusing water is a function of polution load and water treated denoted by $JC(S,W^{CS};\tau^{R})$. Variable charges associated with water use (v'), may be less than in the corresponding noncooperative solution because the recycling of drainage water can reduce the marginal cost of water supply, and management cost per unit of water can also be reduced through cooperation.

The objective function is the weighted sum of payoffs minus joint cost (JC):

$$JW(\alpha;\, CS) = \max_{\substack{W^u,\, W^d, A^u, A^d, \\ W^{CS},\, \tau^u, \tau^d, \tau^R}} \alpha_c\, EV(S;\, S^o) + \alpha_u\, [p_f Y^u - F(\tau^u) - v'(\tau^u, \tau^R) w^u]\, A^u \qquad (17)$$

$$+ \alpha_d [p_f Y^d - F(\tau^d) - v'(\tau^d, \tau^R)\, w^d]\, A^d \;-\; JC(S,\, W^{CS};\, \tau^R).$$

$$\text{s.t.} \quad A^u w^u = W^u \leq \bar{W}^u$$

$$A^d w^d = W^d \leq \bar{W}^d$$

$$A^u \leq \bar{A}^u$$

$$A^d \leq \bar{A}^d$$

$$W^u + W^d \geq W^{CS}$$

$$S^u = \delta^u(\tau^u)\, W^u$$

$$S^d = \delta^d(\tau^d)\, (W^d + kW^u)$$

$$S = S^u + S^d$$

$$Y^u = Y^u(w^u;\tau^u)$$

$$Y^d = Y^d(w^d,\, kW^u;\, \tau^d).$$

Similar to the noncooperative case, Pigouvian taxes on land and water use computed from the first order conditions for (17) will make private decisions about individual land and water use consistent with the joint welfare maximum. As above, tax levels are related to political weights. In addition to externality effects, the tax now also includes marginal (variable) cost for the joint facility. Because of economies of scale, joint costs are not covered by such taxes, so that cost sharing is still necessary to cover costs. Here, cost shares (C^i) are shares of the remaining cost after subtracting tax revenues:

$$C^i = \alpha_i[JC-TR], \ i = c,u,d \tag{18}$$

where TR denotes total tax revenue collected from the Pigouvian taxes.

The solution to (17) will satisfy a necessary condition for acceptability. (See Appendix A for a discussion of alternative optimization problems and their relationships.) After solving this problem, acceptability conditions must be tested.

The two optimization problems (10) and (17) are solved, with corresponding tax and cost share computations for varying political weights until an acceptable solution is found.

Irrigation Externality Application

Applying the algorithm above, we present a simplified example from the San Joaquin Valley to demonstrate that it is possible to find a set of political weights that provide an acceptable cooperative solution.

Upslope and downslope producers grow one crop (cotton) with yield related to water use including the downslope externality effect of drainage water. Two irrigation technologies are included here at the individual producer level: technology 1 -- furrow irrigation, and technology 2 -- sprinklers which reduce irrigation water use and drainage generated for the same amount of water applied because of better distribution of water. Use of sprinklers requires less water per unit ouput but involves higher capital and labor costs because it is a more complex technology. Private technology choices exhibit indivisibilities or "lumpiness" because they must be done on large acre units (here, 100 acre increments).

The type of regional cooperation is a treatment plant to remove selenium (Se). There are economies of scale in the volume of drainage water treated. The regional treatment plant reduces selenium concentration by passing drainage water over iron filings. Better quality is produced by multiple passes over iron filings. The final output has a fixed quality per unit volume. Regional cooperation also reduces the variable cost of use of private sprinklers because the regional manager provides technical assistance to reduce labor costs.

Water from the treatment plant is disposed of in a water-receiving body which is the source of recreation and fishing for consumers in the area. Increased selenium concentration means decreased quality in this water body. The functional relationships defining yield, pollution, effects of selenium on fish and wildlife, and the consumers' equivalent variation are given in the Appendix B.

Producers respond to taxes on water and land by making changes in area of irrigated land, per acre applied irrigation water, and the share of the two technologies used on the irrigated land. In the case of regional cooperation, drainage water is sent through the treatment plant before disposal in a water-receiving body; the whole volume of drainage may not be treated.

Table 1 compares resource use for noncooperative and cooperative solutions as related to political weights, computed according to the algorithm above. For the cooperative solutions, the treated quantity is about the same for all weights but total drainage quantity is reduced as the consumer weight increases because of increased use of the sprinkler technology. Therefore, as the consumer weight is increased, a lower pollution level in the water receiving body is obtained. (The volume of water treated at the regional plant is actually slightly less for higher consumer weights because improved water utilization reduces the need for treatment.)

In the noncooperative solutions, drainage is also reduced as the consumer weight increases, but drainage is about a third higher than in the

Table 1. Resource Use for Noncooperative and Cooperative Solutions, as Related to Political Weights.

Consumer Weight	% Share, Tech 2 upsl.	% Share, Tech 2 downsl.	Water Use (ac/ft/acre) upsl.	Water Use (ac/ft/acre) downsl.	Drainage Quantity (ac/ft.)	Se Conc. (ppb)
			Noncooperative Solution			
.60	79	87	1.80	1.83	1173	22.14
.50	77	86	1.76	1.82	1300	23.54
.42	74	81	1.76	1.74	1410	25.64
.40	74	81	1.76	1.74	1410	25.64
.33	63	77	1.56	1.69	1517	26.44
0	58	67	1.58	2.00	1824	31.95
			Cooperative Solution			
.60	91	90	1.83	1.91	787	14.43
.50	91	88	1.82	1.88	987	15.43
.42	87	86	1.81	1.88	999	15.64
.40	87	86	1.81	1.88	999	15.64
.33	82	77	1.70	1.85	1020	22.55

corresponding cooperative case. Therefore, consumers must compare higher pollution with higher costs in choosing between noncooperative and cooperative solutions. Figure 4 compares the noncooperative production frontier to cooperative cases with corresponding weights.

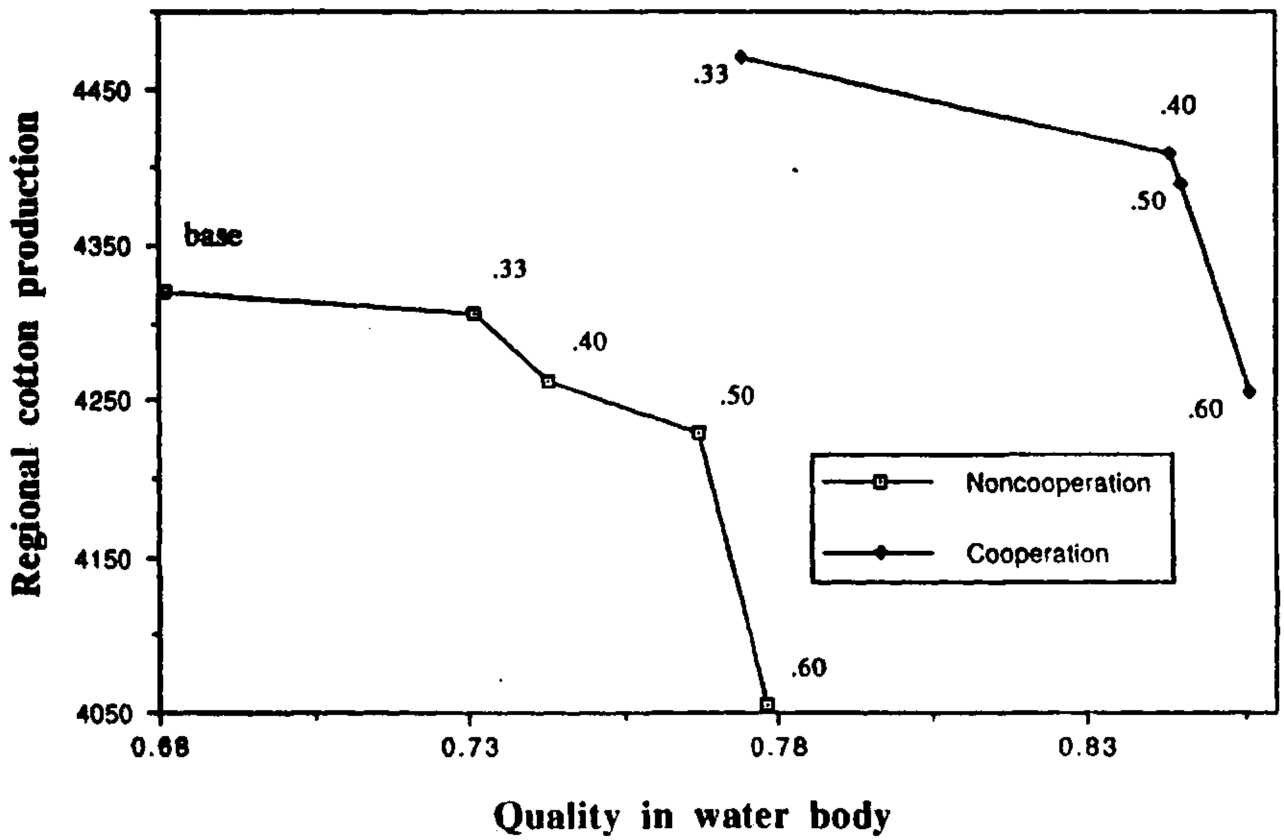
In both cooperative and noncooperative cases, the share of Technology 2 having improved water utilization increases for both types of producers with increased consumer weight. The share of Technology 2 is higher in the cooperative case because its variable costs are reduced by cooperation by 29%. Average water use per acre in the cooperative case is actually higher than in the noncooperative case, because better water quality can be achieved by the combination of reduced drainage and treatment. Net profits are increased in the cooperative solution compared to the noncooperative solution because of improved yield with the sprinkler technology and reduction in externality for the downslope producer.

Table 2 shows payoff values for the status quo, noncooperative and cooperative solutions computed according to the algorithm above for varying consumer political weights. An acceptable cooperative solution, where all parties are better off than at the status quo and at the noncooperative solution, is found for the consumer weight of .40. (This solution actually gives the same point on the production frontier as a weight of .42 but represents a different cost allocation.)

At this solution, each consumer has to pay about $3.60 per year for an improvement of about 16 ppb in selenium concentration, compared to a willingness to pay of about $5.90 for this change. Pigouvian taxes on land use paid by producers in the cooperative solution are about $14.70 per acre for upslope producers (compared to $54.20 in the noncooperative case) and $4.00 per acre for downslope producers (compared to $51 in the noncooperative case). Pigouvian tax rates per acre foot of water are $3.80

Fig. 4

Substitution between agricultural production and environmental quality in a regional setup with and without cooperation for various weights



$$Q = 1 - \frac{Se}{100}$$

Table 2. Comparison of Net Payoffs ($1000) for Status Quo Noncooperative, and Cooperative Solutions as Related to Political Weights.

Consumer Weight	Consumer EV	Producer Profits upslope	Producer Profits downslope
	Status Quo		
0	248	825	516
	Noncooperative Solution (NC)		
.60	284	657	422
.50	279	712	436
.42	271	714	441
.40	271	710	440
.33	268	708	443
	Cooperative Solution		
.60	265	799	495
.50	264	804	533
.42	269	837	542
.40	272	836	541
.33	253	835	542

Net Benefit of Cooperative Solution

Consumer weight	Consumers (compared to NC)	Producers upslope (compared to Status Quo)	Producers downslope (compared to Status Quo)
.60	-19	-26	-21
.50	-15	-21	+17
.42	- 2	+12	+26
.40	+ 1	+11	+25
.33	-15	+10	+26

Table 3. Payoffs ($), The Acceptable Cooperative Solution ($) Compared to Status Quo and Noncooperative Solution.

	Producers		Consumers
	upslope	downslope	
		Status Quo	
Gross Payoffs	825,465	515,987	248,528
		Noncooperative	
Gross Payoffs	823,998	521,003	271,414
Taxes Collected	113,118	81,075	
Net Payoffs	710,880	439,928	271,414
		Cooperative	
Gross Payoffs	889,789	573,110	307,914
Taxes Collected	27,105	6,910	
Cost Shares	27,092	27,092	36,122
Net Payoffs	835,592	541,327	271,792

for upslope producers (compared to $12.90 in the corresponding noncooperative solution) and $1.40 for downslope producers (compared to $11 per acre ft. in the noncooperative solution). (For comparison, the price of water is $60 per acre foot.) Because of increased efficiency in water use and lower tax rates, after paying cost shares the net income of upslope producers in the cooperative solution is increased by 17.5% compared to the noncooperative solution and by 1.2% compared to the status quo. For downslope producers net income is increased by 18.7% in the cooperative solution compared to the noncooperative solution and by 5% compared to the status quo. (See Table 3.)

The success of a negotiating process such as that described above is made more likely if an acceptable solution, as in this case, is shown to exist.

Conclusions

Externality problems (such as the irrigation problem studied here) may be alleviated by cooperative technology solutions. For such cases, the basic concepts presented and demonstrated in this paper are:

(i) Traditional economic solutions for externality problems (i.e. the Pigouvian tax) achieve noncooperative technology solutions, whereas technologies associated with cooperative solutions may be Pareto superior.

(ii) The concept of an acceptable cooperative solution is relevant for achieving a Pareto superior solution.

(iii) Resource allocation processes and procedures needed to achieve acceptable cooperative solutions can be designed based on economic and mechanism design principles.

For the case in this paper, this paper has proposed a sequential game process based on the Prisoners' Dilemma to locate an acceptable cooperative solution and corresponding political weights. Pigouvian taxes and cost allocation are economic tools used in the process. To indicate potential success of such a process, an algorithm to locate an acceptable solution was demonstrated.

An institution for implementation of such a process already exists in the irrigation externality case studied here -- namely the water district and the water district manager but greater responsibilities are proposed for the manager including mediation, information collection, computation of costs and taxes, management of cooperative technologies, and enforcement. Therefore, further consideration may need to be given to developing incentives for managers for good performance of these functions.

To apply the methods proposed here to real world situations, appropriate demographic, physical, and preference models are needed. Here, the required relationships were determined under the San Joaquin Valley Drainage Program (SJVDP). For other real settings, the development of such information and large scale computer models is also essential.

Even with potential gains for relevant parties and interest groups, actual acceptance of a cooperative solution in a given situation is a remaining question. Considering the Prisoner's Dilemma, indicated gains from cooperation may not always lead to cooperative outcomes. Behavioral research should also be undertaken to determine whether a cooperative game process such as that proposed here could actually result in finding an acceptable cooperative solution. The use of experimental games (Binger and Hoffman, 1987; Ostrom and Gardner, 1990) could be a useful tool to test actual acceptability.

The basic concepts in this paper also apply to more general public choice problems having potential cooperative technology solutions for which resource allocation, cost sharing, and political weights are important aspects. Generally in such cases, as demonstrated here, it may be possible for economists to help "engineer" solutions to public choice problems by applying mechanism design and other economic principles.

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Appendix A:

Technical Efficiency, Pareto Optimality, and Acceptability with Cooperation

As is well-known for the noncooperative case, a Pareto optimum solution is efficient. Below, efficiency is defined for the irrigation problem as a frontier in terms of water quality Q and agricultural production Y constrained by production relationships and resource constraints:

$$\max_{(\tau^i),Q,Y} \quad \lambda Q + (1-\lambda)Y$$

$$Y^u = Y^u(w^u;\tau^u)$$

$$Y^d = Y^d(w^d,\ kW^u;\ \tau^d).$$

$$Y = Y^u A^u + Y^d A^d$$

$$A^u + A^d \leq \bar{A}^u + \bar{A}^d \qquad \text{(A)}$$

$$W^u + W^d \leq \bar{W}^u + \bar{W}^d$$

$$S^u = \delta^u(\tau^u)\ W^u$$

$$S^d = \delta^d(\tau^d)\ (W^d + kW^u)$$

$$S = S^u + S^d$$

$$Q = 1 - \frac{S}{100}$$

where $w^i A^i = W$. For cooperative case additional constraints are:

$$W^{CS} \leq W^u + W^d$$

$$S^{CS} = f(S, W^{CS}; \tau^R)$$

$$Q = 1 - \frac{S^{CS}}{100}.$$

The production frontier is obtained by assuring the above for varying λ.

A Pareto optimum solution maximizes a weighted sum of payoffs subject to production constraints, with maximization over the same set of technologies and W^i, A^i. In the noncooperative case Pareto optimality is defined by (10). A Pareto optimum is efficient because a λ value and corresponding solution to (A) can be found correspond to a solution to (10) for any given $\{\alpha\}$.

In the cooperative case, Pareto optimality is similarly defined in terms of the objective function and constraints as in (10), but optimization occurs over cooperative as well as private technologies. Also, an additional feasibility constraint is required: joint costs should not exceed the total value of payoffs, i.e.

$$EV(S^{CS};S^{o}) + [p_f Y^u - F(\tau^u) - v'(\tau^u,\tau^R)w^u]A^u + [p_f Y^d - F(\tau^d) - v'(\tau^d,\tau^R)w^d]A^d$$
$$- JC(S^{CS},W^{CS};\tau^R) \geq 0. \qquad (A1)$$

Because this condition must be added to the production constraints present in the noncooperative problem (10) and there is no such requirement for technical efficiency, the correspondence between production efficiency and Pareto optimality is lost in the cooperative case. A cooperative solution will be feasible but not optimal for the technical efficiency problem (A). Also, a noncooperative solution to (10) will be feasible but not Pareto optimal for the cooperative problem since the noncooperative solution has zero joint costs.

Acceptability criteria for the cooperative problem can be imposed in the form of additional constraints on the Pareto optimality problem. Because of these additional constraints, an acceptable solution for the cooperative problem may not be a Pareto optimum. The constraints for acceptability are defined as follows.

Let $\pi^i(\alpha;\ CS)$ and $\pi^i(\alpha;\ NC)$ denote profit after Pigouvian taxes for upslope and downslope producers and C^c, C^u, C^d denote cost shares for consumers, upslope producers, and downslope producers which sum to the joint cost. For acceptability, profits for the cooperative case after cost sharing should be greater than profit in the noncooperative case:

$$\pi^i(\alpha;\ CS) - C^i \geq \pi^i(\alpha;\ NC). \qquad (A2)$$

For consumers in the cooperative solution, there should be a gain after paying cost shares compared to the noncooperative solution:

$$EV(S^{CS};\ S^{o}) - C^{c} \geq EV(S^{NC};\ S^{o}). \qquad (A3)$$

This condition says that water quality S^{CS} for the cooperative solution must be sufficiently improved compared to S^{NC} to offset the cost share paid by consumers in the cooperative case.

Rather than imposing (A2) and (A3) as additional constraints in the Pareto optimum problem, a weaker necessary condition for acceptability can be defined without specifying cost sharing rule. This necessary acceptability condition is obtained by adding the inequalities (A2) and (A3) (since cost shares must sum to joint costs):

$$\pi^{u}(\alpha;\ CS) + \pi^{d}(\alpha;\ CS) + EV(S^{CS};\ S^{o}) - JC(S^{CS},\ W^{CS};\ \tau^{R}) \geq \qquad (A4)$$
$$\pi^{u}(\alpha;\ NC) + \pi^{d}(\alpha;\ NC) + EV(S^{NC};\ S^{o}).$$

For acceptability, all players should also benefit compared to the status quo. Consumers will be better off than at the status quo if

$$EV(S^{CS};S^{o}) - C^{c} \geq EV(S^{o};S^{o}) = 0. \qquad (A5)$$

For producers, the following additional requirement, that there be positive benefits of cooperation compared to the status quo, should also hold:

$$\pi^{i}(\alpha;\ CS) - C^{i} > \pi^{i}_{o},\ i = u,d. \qquad (A6)$$

Adding the inequalities (A5) and (A6), another necessary condition for acceptability is

$$\pi^{u}(\alpha;CS) + \pi^{d}(\alpha;CS) + EV(S^{CS};\ S^{o}) - JC(S^{CS},\ W^{CS};\ \tau^{R}) \geq \pi^{u}_{o} + \pi^{d}_{o}. \qquad (A7)$$

However, because the externality between producers is alleviated in the noncooperative problem, joint profits in the noncooperative case will be greater than the sum of profits for the status quo. Also, $EV(S^{NC};\ S^{o})$ is greater than zero. Therefore, any solution satisfying the acceptability constraint (A4) will automatically satisfy (A7), so that (A7) does not need to be imposed if (A4) is a constraint. Also, note that (A1) is automatically satisfied by (A4) if producers have positive profits in the noncooperative case. Therefore, the constraint (A4) added to production constraints in the Pareto optimality problem (10) can be used to identify potential acceptable solutions without defining a specific cost-sharing rule.

The objective function in (17) is the weighted sum of payoffs minus joint costs. Compared to adding the constraint (A4) to the constraints in (10), the objective function in formulation (17) tends to give larger net benefits and hence is better to locate an accepable solution. The necessary condition (A4) can be satisfied by a solution to (17): since the noncooperative problem is feasible but not optimal for the cooperative problem (denoting the alternative solutions by subscripts NC and CS),

$$\alpha_c \, EV_{CS} + \alpha_u \, \pi^u_{CS} + \alpha_d \, \pi^d_{CS} - JC \geq \alpha_c \, EV_{NC} + \alpha_u \, \pi^u_{NC} + \alpha_d \, \pi^d_{NC}. \qquad (A8)$$

That is,

$$\alpha_c(EV_{CS} - EV_{NC}) + \alpha_u(\pi^u_{CS} - \pi^u_{NC}) + \alpha_d(\pi^d_{CS} - \pi^d_{NC}) \geq JC.$$

(A9)

Since $0 \leq \alpha_i \leq 1$, if the individual gains from cooperation are positive, then also

$$(EV_c - EV_{NC}) + (\pi^u_{CS} - \pi^u_{NC}) + (\pi^d_{CS} - \pi^d_{NC}) \geq JC.$$

Since (A4) is only necessary, but not sufficient for acceptability, the full set of acceptability conditions (A2), (A3), (A5), (A6) must be tested ex post, after defining a specific cost sharing rule. This process allows alternative cost sharing rules to be tested without resolving the cooperative optimization problem.

Appendix B:

Specification of Relationships for the Regional Model

Upslope (u) and downslope (d) producers grow the same single crop (cotton) with a limited amount of land and water. A crop-water production function for cotton was estimated using data from the west side of the San Joaquin Valley. Water supply is of a given quality (here, in terms of selenium) and two water use technologies are available [furrow (f) and sprinklers (s)]. A yield index for production on a per unit area basis for upslope and downslope producers is given by:

$$(RY^i)_f = .143 + .516w^i{}_f - .075(w^i{}_f)^2 \quad , i = u, d.$$

$$(RY^i)_s = .174 + .544w^i{}_s - .084(w^i{}_s)^2 \quad , i = u, d.$$

where $(RY^i)_j$ is the relative yield per acre for producer i with technology j(j=f,s). $w^i{}_k$ is the per acre amount of applied water by irrigation technology. Maximum per acre potential yield for producer i is MY^i; for simplicity, it is assumed to be independent of the water use technology. Yield per acre (Y^i) is then $(RY^i)_j$ times MY^i.

A portion of the irrigation water results in drainage which has quality (selenium) and quantity dimensions. For simplicity we assume a constant level of selenium in the drainage water for both producers. However, the upslope producer has a larger fraction of irrigation water which results in drainage. A fraction of the upslope producer's drainage moves laterally to produce the externality effect on the downslope producer. The summation of the two producers' drainage water creates regional drainage. This can be either disposed of directly into a water body or treated in a regional treatment facility to lower the level of selenium concentration before disposal in the water body. The original quality of water in the water-receiving body is initially better than both the untreated and treated drainage. (Treated drainage water could also be returned to the water supply system but this is not included in our analysis here.)

The final concentration in the water-receiving body after drainage water is introduced is:

$$S^1 = [VL \cdot S' + Q^R \cdot S^R]/[VL + Q^R]$$

where S' is the initial concentration in the water receiving body; VL is the volume of the water body; S^R is the quality of the drainage water disposed of the region; and Q^R is the volume of drainage water disposed from the region. S^1 denotes either the concentration of untreated drainage or that of final drainage after treatment in case of cooperation.

The estimated annual cost function for a regional treatment facility (Algal-Bacterial Selenium Removal System) is based only on quantity D' treated (Gerhardt and Oswald, 1990, pp. 215-220):

$$C = -11{,}552{,}000 + 3{,}593{,}700 \cdot \log D'$$

where C is annual total cost, and D' is the regional volume of drainage water to be treated ($D' \leq Q^R$). Quality of treated drainage is fixed at 15 ppb, achieved by passing a given quantity over iron fillings a number of times until this quality is achieved.

Consumers' benefit from improved water quality in the receiving water body are the sum of benefits from recreation and from health effects. The lower the concentration, the greater the consumer benefit.

$$EV = N \cdot \phi \cdot (100 - S^1)$$

where EV is total consumer benefits, N is the consumer population, ϕ is estimated benefit per unit change in water quality. For more details, see Loehman and Dinar (1990).

Variable	Description	Value(s)
MY^u	Maximum potential yield, upslope	1,100 lb/acre
MY^d	Maximum potential yield, downslope	1,000 lb/acre
β^u	Upslope drainage coefficient	.15
β^d	Downslope drainage coefficent	.10
δ_f	Furrow drainage coefficient	1.30
δ_s	Sprinkler drainage coefficient	1.15
k	Proportion of upslope drainage received on downslope fields	.90
P^w	Water supply cost	60$/AF
S'	Initial quality in water body	10 ppb
S^R	Quality of treated drainage	15ppb
	Initial quality of untreated drainage	35ppb
ϕ	Estimated benefit per consumer	
ψ	per ppb improvement	.365$/ppb
p	Cotton price	.75$/lb
v^u_f	Non-water variable cost of production upslope furrows	$416/A
v^d_f	Non-water variable cost of production downslope furrows	$427/A
v^u_s	Non-water variable cost of production upslope sprinklers	$401/A
v^d_s	Non-water variable cost of production downslope sprinklers	$415/A
F_f	Fixed cost for furrows	$20/A
F_s	Fixed cost for sprinklers, cooperative case	$98/A
F_s	Fixed cost for sprinkers, noncooperative case	$138/A
P^D	Cost of drainage pumping	15$/AF
$\bar{A}^u$	Land area upslope	2,500 acres
$\bar{A}^d$	Land area downslope	2,500 acres
$\bar{W}^u$	Water quota upslope	3,000AF/YR
$\bar{W}^d$	Water quota downslope	3,000AF/YR
N	Consumer population	10,000 people
VL	Volume of water receiving body	500 AF