AN ECONOMIC PERSPECTIVE ON THE ENVIRONMENTAL COSTS AND BENEFITS OF IRRIGATED AGRICULTURE

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ABSTRACT

A conceptual framework that depicts some of the private and public costs and benefits of irrigated agriculture is presented for use in identifying situations in which public policies might be implemented to generate a socially optimal use of resources in a competitive equilibrium. The framework is useful in describing the potential social gains or losses due to policies that motivate farmers to internalize the external costs or benefits of their activities. The model is demonstrated using the example of water quality issues pertaining to irrigation and drainage in California's San Joaquin Valley. The potential social costs of public policies designed to reduce the volume of subsurface drain water and selenium loads discharged into the San Joaquin River are examined using the conceptual framework.

INTRODUCTION

In many areas of the world, irrigated agriculture generates both private and public costs and benefits. Farmers have an economic incentive to maximize private net benefits, which are the returns they receive in excess of production costs. In competitive markets, private net benefits will be the same as public net benefits, provided that all costs and benefits are internalized in farm-level decisions. When some costs or benefits are external to farm-level decisions, the social optimum will not be achieved in a competitive equilibrium. In those cases, public policies may be required to motivate farmers to consider pertinent external costs or benefits.

Public policies must be chosen carefully to motivate the desired changes in farm-level decisions, without causing undesirable distortions in resource use or in the set of crops produced. Accurate information regarding external costs and benefits will assist public officials in identifying situations where public policies are required to generate a socially optimal use of resources, and in selecting appropriate policy instruments and parameter values. Useful information includes a conceptual framework that describes the nature of pertinent external costs and benefits, and empirical estimates of those costs and benefits.

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The goal of this paper is to present a conceptual framework for evaluating the external costs and benefits of irrigated agriculture, for use in examining public policies that may be implemented to generate a socially optimal use of resources in a competitive equilibrium. The framework is useful in describing the potential social gains or losses due to policies that motivate farmers to internalize the external costs or benefits of their activities. The model is demonstrated using the example of water quality issues pertaining to irrigation and drainage in California's San Joaquin Valley. The potential social costs of public policies designed to reduce the volume of subsurface drain water and selenium loads discharged into the San Joaquin River are examined using the conceptual framework.

CONCEPTUAL FRAMEWORK

In general, the private (farm-level) costs and benefits of irrigated agriculture are described by the prices paid and received by farmers in input and output markets. Market demand curves for farm products generate derived demand curves for farm inputs that describe the incremental values generated by employing additional units of inputs. For example, the farm-level incremental values of irrigation water are determined by the market value of the incremental output generated by delivering additional water. Farmers determine the profit-maximizing amount of water, per unit of land area, by comparing their expectation of incremental benefits with incremental costs. The farm-level incremental cost of irrigation water is constant when farmers face a flat-rate pricing structure.

It is easiest to describe the incremental costs and benefits of one variable input, such as irrigation water, while assuming that the use of other inputs is constant. A graph depicting the typical conceptual relationship between the incremental costs and benefits of irrigation water is presented in Figure 1. The farm-level profit-maximizing choice is denoted as W_F, where incremental cost is equal to the incremental benefit.

The farm-level value of a fixed input, such as land, is determined by summing the discounted present value of net returns that can be generated by keeping the input in production during an appropriate time horizon. For example, farmers expecting to earn \$600 ha^{-1} in net returns from cotton production, in perpetuity, should be willing to pay any price up to \$10,000 ha^{-1} for land if their discount rate is 6 percent. The incremental value of land may decline with farm size for an individual farmer if other resources, such as capital or management, are in limited supply. Variation in land quality will cause the aggregate incremental value curve to be downward sloping, as farmers employ the best land first, before extending production to lower quality land.

A graph depicting the typical conceptual relationship between the incremental costs and benefits of land in production is presented in Figure 2. The farm-level profit-maximizing choice is denoted as L_F, where incremental cost is equal to the incremental benefit. The incremental cost curve is shown as upward-sloping in this example to denote the situation in which land of a given quality is limited in supply. In such cases, farmers desiring additional land will face an upward-sloping supply curve. The incremental benefit curve is downward sloping to reflect diminishing returns to additional land, caused by declining land quality or by capital and management constraints.

In competitive markets in which producers and consumers have full information regarding prices and quantities, farm-level choices regarding fixed and variable inputs will be socially optimal, if all pertinent costs and benefits are included in the curves depicted in Figures 1 and 2. Farm-level decisions will not be socially optimal when input use or resource allocation decisions generate external costs or benefits that increase or reduce measures of social welfare, while not affecting farm-level net returns. Classic examples of agricultural externalities include the use of fertilizer and pesticides that degrade water quality in streams or aquifers receiving surface runoff from farm fields.

In arid regions, the volume of irrigation water delivered to farm fields must exceed crop water requirements to maintain salt balance. The excess water contributes to surface runoff and deep percolation that enter regional drains or shallow water tables. Agricultural drainage water containing salts, boron, or other elements may degrade water quality in receiving streams and aquifers. When this occurs, farm-level decisions regarding water use per unit of land area may not be socially optimal. Figure 3 depicts a situation in which the social incremental costs of irrigation lie above the private incremental costs. The vertical distance between the two curves, at any point, denotes the external incremental cost at that volume of water per hectare. When irrigation generates external costs, the socially optimal water volume, W_S, will be less than the farm-level profit-maximizing volume, W_F. In those cases, public policies that increase the farm-level cost of water may be appropriate to motivate farmers to reduce water use from W_F to W_S.

The external effects of land in agricultural production are often considered to be positive, rather than negative (Hodge, 1991). For example, farmland that is managed appropriately can provide wildlife habitat benefits that might not be available if the land is left idle or is developed for housing or industry. Similarly, farmland can provide scenic vistas of pastoral scenes that are enjoyed by residents of local towns and others traveling along nearby roads and highways. Farmland also generates watershed protection benefits and may be useful in protecting productive soil resources for future generations. These benefits are considered external to agricultural production decisions because they accrue to society, at large, rather than to individual farmers. Empirical estimates of amenity values from farmland support the conceptual notion of external benefits (Bergstrom et al., 1985; Kline and Wichelns, 1996; Ready et al., 1997).

Figure 4 depicts a situation in which the social incremental benefits of farmland lie above the private incremental benefits. The two curves are separated by a vertical distance that describes the external incremental benefits. When this occurs, the socially optimal area of land in agriculture, L_S, will be greater than the farm-level profit-maximizing area, L_F. Public policies that increase the farm-level benefits from farming or reduce the costs of keeping land in production may be appropriate to encourage farmers to cultivate additional land, increasing the area in production from L_F to L_S.

Public policies that encourage the retention of agricultural land include special tax assessment programs that enable farmers to pay taxes according to farm values, rather than values that reflect development potential. Farmers are required to keep their land in agriculture for a specified number of years, in exchange for the reduced tax assessment (Aiken, 1989). Many states and some local governments also purchase the development rights to farmland, so that farmers may benefit financially from development values, while keeping their land in agriculture. These programs are often funded by bond issues that are approved in statewide referenda, reflecting public support for agricultural land preservation programs (Kline and Wichelns, 1994). Such support is also strong in Europe, where public appreciation of agriculture's role in generating and maintaining rural landscapes has led to the use of management agreements and covenants with farmers for the purpose of preserving rural landscapes (Whittaker, et al., 1991).

The conceptual framework described in Figures 3 and 4 depicts a situation in which some of the variable inputs used in irrigated agriculture may generate negative externalities, while the land in production may generate positive external benefits. The social net benefits of agricultural production can likely be enhanced by designing public policies that address these issues, provided that the policies recognize the sources of external costs and benefits. For example, policies intended to reduce the external costs of selected variable inputs will be more efficient if they are designed to address the use of those variable inputs, directly, with minimal impact on the use of complementary inputs that may generate external benefits. The potential social gains and losses of policy alternatives are demonstrated by using this conceptual framework to examine irrigation and drainage issues in California's San Joaquin Valley.

AN IRRIGATION AND DRAINAGE EXAMPLE

Much of the subsurface drain water collected beneath farmland on the west side of California's San Joaquin Valley contains selenium, boron, and other elements that occur naturally in local soils and are leached from the profile during irrigation and drainage activities (Letey et al., 1986; Deverel and Gallanthine, 1988; Gilliom, 1991). The U.S. Environmental Protection Agency has established a national water quality criterion for selenium of 5 parts per billion (ppb), when measured as a 5-day moving average concentration. Selenium concentrations in farm-level drainage systems vary geographically within the region, ranging from less than 10 ppb to 4,000 ppb (Deverel et al., 1984). Drain water concentrations at individual drainage systems are relatively consistent, over time, and are correlated with drain water salinity (Deverel, et al., 1989).

The California Regional Water Quality Control Board for the Central Valley Region has adopted a Basin Plan Amendment designed to achieve the national selenium concentration standard, over time. That amendment includes a set of monthly and annual selenium load targets that are expected to generate acceptable selenium concentrations in the near term, while farm-level and regional efforts are implemented, over time, to achieve the national water quality standard.

The Regional Water Quality Control Board has also established a 2-ppb selenium water quality objective for sloughs and ditches in a wetland habitat located between an agricultural production area and the San Joaquin River. As a result, it became necessary to remove agricultural drainage water from wetland channels, as selenium concentrations in drainage water are often in the range of 20 to 100 ppb (Deverel et al., 1984; Presser and Barnes, 1985). Seven irrigation and drainage districts in the region have formed a regional drainage authority to construct and operate drainage facilities, and to coordinate efforts to achieve the selenium load targets. The group has constructed a new channel that carries drainage water from all seven districts around the wetland area to an existing portion of the San Luis Drain, which carries the water to a tributary of the San Joaquin River. This program, which is known locally as the Grassland Bypass Project, began operating in September of 1996.

The monthly and annual selenium load targets are substantially lower than estimates of historical discharges. As a result, farmers and districts have had to implement aggressive programs to motivate farm-level improvements in irrigation practices that will reduce surface runoff and deep percolation, and to increase the blending and re-use of drainage water with fresh water supplies. Innovations in district policies have included tiered water pricing, low-interest loans for purchasing new irrigation systems, and restrictions regarding surface runoff discharged into drainage ditches. Farmers have responded by replacing traditional surface irrigation methods with improved furrow methods, gated pipe, and sprinkler systems. They have also increased the labor and management components of irrigation activities.

District efforts to motivate farm-level improvements in water management are consistent with the incremental cost and benefit framework shown in Figure 3. Charging higher prices for irrigation water raises the incremental cost curve, motivating farmers to reduce water deliveries from the original W_F, in the direction of W_S. Policies that restrict farm-level surface runoff or drain water volume will also raise the incremental cost curve, as farmers must recycle their drainage water or improve water management to reduce the volume of drainage water generated. These activities raise the implicit cost of water deliveries, even if the explicit price of irrigation water remains the same.

The average volume of water delivered per hectare in the drainage problem area has declined as a result of farm-level and district efforts to reduce drain water volume and selenium loads (Wichelns and Cone, 1992a and 1992b; Wichelns, et al., 1996). However, despite these efforts and the observed reductions in water deliveries, drain water volumes and selenium loads have not been reduced proportionally. It appears that exogenous forces including rainfall and subsurface flows of shallow groundwater into the drainage problem area may contribute significantly to the volume of drain water collected in local drainage systems. As a result, selenium load targets have been exceeded in many months since the Grassland Bypass Project was started. However, negative impacts of selenium concentrations in excess of water quality objectives have not yet been observed.

THE ROLE OF UNCERTAINTY IN POLICY CHOICES

Efforts to reduce water deliveries from the farm-level optimum, W_F, to the social optimum, W_S (Figure 3), have increased the costs of farm-level and district water management. These costs may be justified, from an aggregate efficiency perspective, if the social optimum is, indeed, W_S. However, if scientific information regarding the potential impacts of selenium on aquatic wildlife in the Grassland Area and the San Joaquin River is not yet complete, public officials may not know with certainty the true effects of selenium in those environments. As a result, the selenium load targets may not be truly optimal, and the costs involved in reducing drain water volume and selenium loads to achieve those targets may represent a social loss.

Conceptually, when the potential environmental effects of a constituent are uncertain, the expected incremental costs of an activity that generates that constituent or discharges it into the environment will diverge from the true incremental costs. For example, if the potential effects of selenium are over-estimated, the true social incremental costs of water deliveries will be less than the expected social incremental costs (Figure 5). Regulations or voluntary efforts that reduce water deliveries from W_F to $W_S{}^e$ will generate social costs in the form of unnecessary expenditures on water management and reductions in output values. The size of the social loss is a function of the relative slopes of the incremental cost and benefit curves. The net social loss in Figure 5 is shown as the shaded area below the incremental benefit curve and above the true social incremental cost curve.

Social losses can also be imposed by policies directed toward inputs not directly responsible for generating an externality. For example, there is much discussion in the San Joaquin Valley regarding land retirement as a policy alternative for reducing drain water volume and selenium loads. Several state and federal agencies have allocated either staff time or program funds in recent years to encourage farmers to retire farmland. The premise motivating this effort is that a smaller volume of subsurface drain water will be generated in the region if a smaller land area is farmed. Unfortunately, the physical relationships that generate drain water volume are not yet understood sufficiently to predict with accuracy the potential reductions in drain water volume and selenium loads that might be accomplished by land retirement.

A land retirement program may generate social losses if it is not successful in reducing drain water volume and selenium loads, or if the environmental effects of selenium are less costly than expected. As shown in Figure 6, the socially optimal area in production, L_S, exceeds the area chosen by farmers, L_F, in cases where the public derives external benefits from farmland. A land retirement program that reduces the land in production to a land area such as L_R will generate a net social loss described by the shaded area in Figure 6. That area represents the potential net social benefits that could be gained by expanding the land area in production from L_R to L_S. The direct costs of implementing a land retirement program, such as the funds required to purchase land and to administer the program, would increase the net social loss.

SUMMARY

Public policies may be appropriate for motivating farmers to modify their profit-maximizing decisions regarding the use of fixed or variable inputs when those decisions generate external costs or benefits. Classic examples of agricultural externalities include the use of fertilizer and pesticides that can reduce water quality in streams and aquifers. The generation of subsurface drain water may also involve an externality if chemicals or naturally occurring constituents in the drain water degrade wildlife habitat in receiving areas. Positive externalities from agriculture include the provision of wildlife habitat, scenic views, and watershed protection in areas that might be developed for other purposes.

The conceptual framework presented in this paper can be used by public officials to analyze the potential social gains and losses of policies designed to achieve socially optimal levels of agricultural activities. Appropriate policy alternatives and parameter values can be determined by comparing incremental cost and benefit information from both the farm-level and social perspectives. This task is particularly important when information regarding the incremental costs and benefits of agricultural activities is uncertain or incomplete, as some policy alternatives will be more effective than others in maximizing the likelihood that social goals will be achieved in those situations. Viewed from another perspective, the social losses that may result from policy implementation when incremental costs and benefits are uncertain will vary among policy alternatives.

The usefulness of this conceptual framework has been demonstrated by examining policy alternatives for reducing drain water volume and selenium loads on the west side of California's San Joaquin Valley. Policies designed to reduce water use by modifying the price of irrigation water may be appropriate in situations where excessive deep percolation generates incremental external costs in excess of incremental benefits. However, policies to reduce the area of land in production may generate social losses in the form of reduced output and reductions in the environmental amenities provided by agricultural land. The likelihood that land retirement will generate social losses is enhanced by the lack of information regarding the effects of such a program on drain water volume and selenium loads, and uncertainty regarding the impact of selenium on receiving waters in the region.

ACKNOWLEDGMENTS

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Figure 1. Incremental costs and benefits of irrigation water

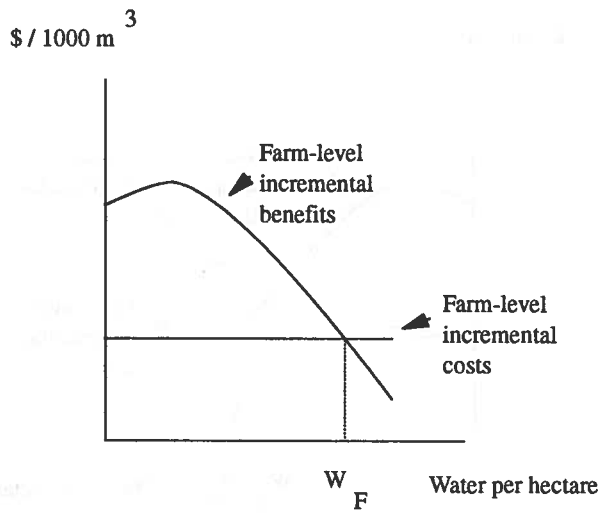


Figure 2. Incremental costs and benefits of agricultural land

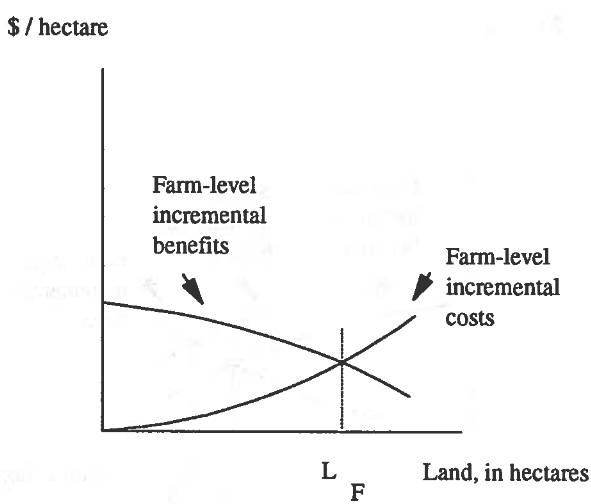


Figure 3. Farm-level and social costs and benefits of irrigation

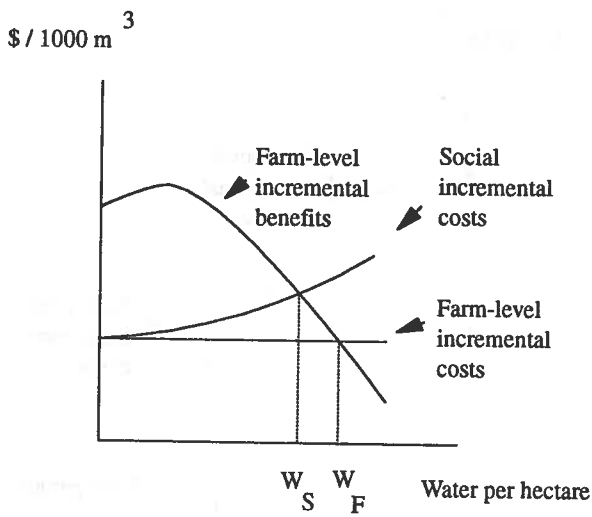


Figure 4. Farm-level and social costs and benefits of agricultural land

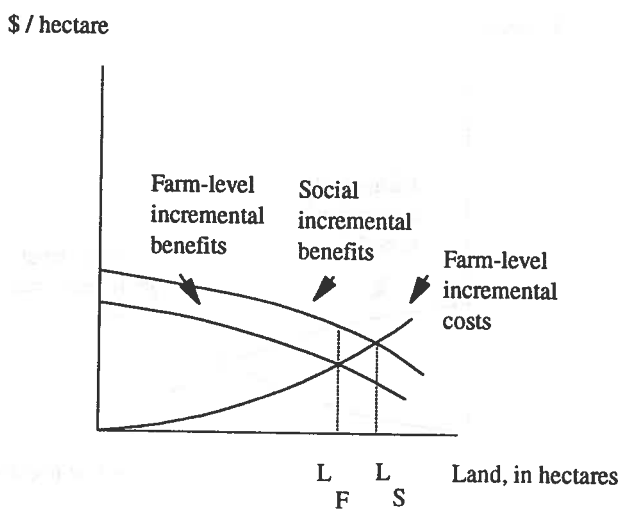


Figure 5. Expected and true social incremental costs

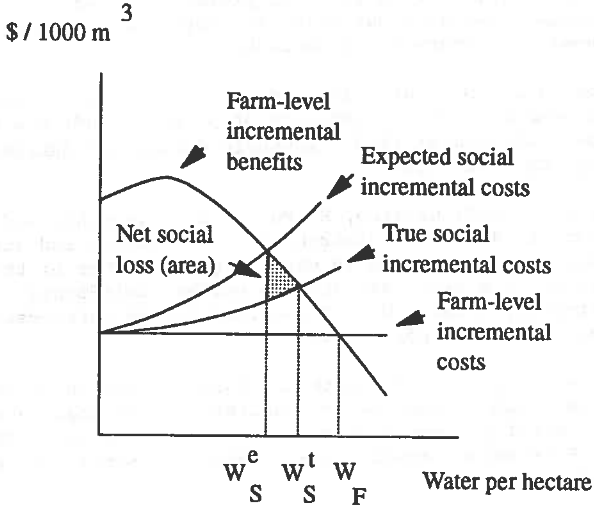
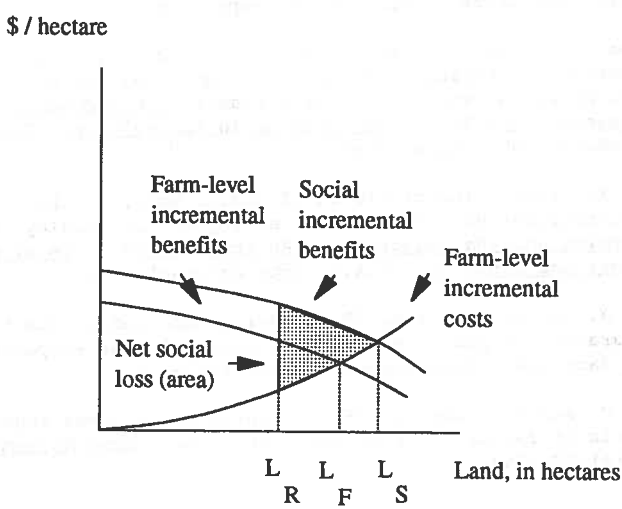


Figure 6. The potential net social cost of a land retirement program



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