Inter-American Development Bank

Sustainable Development Department

The Use of Subsidies to Achieve Efficient Resource Allocation in Upland Watersheds

Darrell L. Hueth

Environment Division

Working Paper Series ENV 1 — March 1995

Darrell L. Hueth is a professor in the Department of Agricultural and Resource Economics, University of Maryland, College Park, MD 20740, USA.

The author is grateful for helpful comments and guidance on this work from numerous sources but is particularly indebted to William J. Vaughan from the Inter-American Development Bank and Brent Hueth at the University of Maryland. Jeff Vaughan read the several drafts of this paper with great care and his numerous suggestions and comments significantly improved the manuscript. The section on least cost subsidies in this paper is attributable to Brent Hueth. Thanks are also extended to Sergio Ardila, Ricardo Quiroga, Mario Niklitschek, Raul Tuazon, Glen Westley, Luis Zavaleta of the IDB and Juan Novara of the Fundacion Mediterranea in Cordoba, Argentina.

Environment Division
Sustainable Development Department
Inter-American Development Bank
1300 New York Avenue N.W.
Washington, D.C. 20577

CONTENTS

Introduction

The Inter-American Development Bank (IDB), the International Bank for Reconstruction and Development (World Bank), and other international organizations are currently using a number of mechanisms to improve environmental quality, promote sustainable development, and increase incomes in rural areas of Latin America. The IDB recently had its capital fund increased by 40 percent, chiefly to finance additional environmental and social programs. A significant portion of these new funds is expected to go to projects to improve resource allocation in upland watersheds. For example, the IDB currently (1995) is considering approximately US $300 million in loans to improve watershed management in six Latin American and Caribbean countries .

Many of these projects focus on reducing erosion in upland watersheds by changing the agronomic and agroforestry practices of small growers. Erosion is considered one of the most important impediments to achieving sustainable production in developing countries. The negative impacts of erosion have been well documented (Southgate 1988; Anderson and Thampapillai 1990; Kaimowitz 1992) and it is hoped that changing the management practices of small landholders and promoting reforestation projects can significantly reduce the offsite costs, and in many cases, increase farm income as well. In the past, direct intervention and incentives have been used to induce growers to adopt proposed management practices.

Governments have employed subsidies for many purposes, including income redistribution. More frequently, and more justifiably from the standpoint of economics, they have been employed to achieve a more efficient allocation of resources by either inducing growers to alter production decisions to reflect offsite impacts, or promoting the adoption of more profitable production technologies.

This paper evaluates the use of subsidies to achieve efficient resource utilization. It is increasingly recognized that efficient management of resources in agriculture requires a systems approach and that focusing on a single input or crop can lead to privately and socially inefficient decisions (Heimlich and Ogg 1982, Board of Agriculture 1994). Indeed, in many cases the management practices used to control erosion are also used to improve water quality, therefore, much of the discussion will also be applicable to water quality improvement projects. In the context of this evaluation the possibilities for using other mechanisms will also be explored. The paper provides guidance regarding the conditions under which subsidies can be expected to produce desired results.

The paper begins with a discussion of the nature of erosion and methods of estimating rates of erosion. The second section presents a short review of the literature on onsite and offsite erosion damage assessment (which concludes that in tropical regions, it is easier at present to identify onsite productivity losses than offsite damages). The next section presents an evaluation of the economic arguments for government intervention, followed by a discussion of possible alternatives to subsidies (such as direct intervention, moral suasion, taxes, and marketable pollution permits) to achieve more efficient resource use.

An evaluation of the efficiency properties of subsidies finds that they are similar to those of taxes in adjusting for offsite impacts, but have drawbacks associated with entry incentives and financial considerations. Nevertheless, carefully designed subsidy mechanisms which are targeted to environmentally sensitive areas and exploit differing producer response characteristics, may be useful and politically feasible, second best incentive mechanisms. Some of these mechanisms are presented for consideration.

Finally, the the paper explores possibilities for government intervention in the form of technology development and information transfer. Government expenditures are found to be most justifiable in this case. The same subsidy mechanisms proposed to adjust for offsite impacts can be used with greater justification to accelerate the rate of adoption of more profitable and environmentally enhancing technologies. Technology development and technology transfer present possibilities for improvements in environmental quality and in grower profits, i.e., a win-win situation.

Sources and Nature of Erosion

Erosion is a natural geological phenomenon. The collision of tectonic plates and consequent growth of mountain ranges either along coastal regions (the Andes) or inland (the Himalayas), combined with rainfall produces erosion independent of human activity. Given the observed dramatic consequences of erosion, it is surprising how little is known about the rates of erosion, the fate of eroded soil, and the impacts of alternative land management practices on erosion rates and productivity losses in developing countries.

As explained by Crosson (1983) two methods are used to estimate rates of soil erosion: either some form of the universal soil loss equation (USLE) (See for example Lal et al. 1991) or sediment delivery ratios (SDRs). The USLE was developed for use in the midwestern United States and has been the chief method used to estimate erosion rates in developed countries. This method uses land characteristics to predict soil delivered from a parcel, usually an acre, to the site of initial deposition in a stream.[1] The difficulties associated with adopting these models for use in upland watersheds are well know (Lal 1990) and have led some soil scientists to adopt alternative approaches to modeling soil erosion in tropical regions.

In developing countries, rates of erosion are usually estimated using SDRs. These ratios, which vary depending on the size of the watershed, infer erosion rates upstream from the sediment content of rivers downstream. In practice, they have produced highly variable estimates of erosion rates. For example, de Janvry and Garcia (1992) point out that one study of the erosion rates for river basins in Mexico produced an estimate of 2.7 tons per hectare per year, while another produced an estimate of 46.9 tons per year for the same region. Also, Crosson (1983) points out that studies using SDRs for the four major river basins of India suggest that the erosion rate for these basins is 34 billion tons per year, while agricultural scientists have independently estimated erosion from Indian cropland to be 6 billion tons per year.

Despite the paucity of information concerning erosion rates in developing countries, and the fact that geologic erosion rates in tropical regions are several orders of magnitude greater than in temperate regions under optimal management, there is general agreement that onsite and offsite negative external impacts from erosion due to deforestation and agronomic practices are great. Thus, in developing countries, particularly in small watersheds, there is agreement that intervention to reduce erosion rates can be justified. Nevertheless, as emphasized by Crosson (1983), eroded soil is not necessarily lost to agricultural production since it may be deposited downstream. Indeed, in some cases the productivity of the soil may be enhanced since it may be transported from steep unproductive sites in the mountains to productive sites on the plains.

[1] In the United States the USLE will frequently only predict the amount of soil lost from a parcel and hence may simply be delivered to a neighboring farmer. Additional modeling is necessary, as can be found in Gianessi et al. (1985), to estimate the soil sediment delivered to the streamside.

Damages Arising from Erosion

The cutting of native forests and land clearing activities increases the rate of erosion through the elimination of soil binding understory and ground cover. The most important onsite damage is loss of soil productivity caused by reduced soil depth and loss of soil nutrients.[2] Crosson (1983) argues that aggregate productivity losses are much less in temperate regions with large watersheds than in tropical regions. In tropical regions the steepness of the hillsides being cleared and the fragility of the soils combine to increase the likelihood of reduced productivity of eroded soils. These speculations are supported by several studies. Magrath and Arens (1989) find, for example, that in Java between 70 percent and 90 percent of the estimated damages occur onsite. Likewise, de Janvry et. al. (1993) find that in a proposed agroeconomic project for the Dominican Republic, 80 per cent of the benefits from erosion reduction would accrue to private growers through increased productivity.

Deforestation in tropical regions also causes onsite losses of biodiversity of plant and animal species and may have other, less understood, negative ecological impacts. For example, the close relationship of upland forests to the hydrologic cycle in these regions may have an impact on the frequency and magnitude of tropical rainfall. Ecological changes may occur onsite and offsite. Deforestation changes the species composition at the site, and by increasing the rate of erosion, may also change the ecology downstream. This is particularly true if the runoff carries large amounts of pesticides and fertilizers. These ecological impacts are just beginning to be investigated and are expected to play a greater role in future project evaluations.[3]

Reforestation to a single species forest plantation will not replace biodiversity loss and moreover may not substantially reduce water erosion in forest ecosystems (Magrath and Doolette 1990). It is the presence of vegetative cover of the understory that reduces surface erosion. Thus, some highly profitable reforestation projects in upland watersheds using a single fast maturing species may not make a significant contribution to erosion reduction and can greatly alter the ecosystem. As yet, little research has been conducted to analyze the tradeoffs presented by these alternatives.

There are also cases of significant direct offsite downstream damages from erosion. Increased sedimentation increases the wear and tear on the equipment of downstream irrigators and industrial users of river water, reduces the value of rivers for recreational purposes, and sediment borne nutrients and pesticides can reduce fish populations. In addition, deforestation increases the rate of streamflow during rainy seasons (increasing chances of flooding) and reduces the rate of recharge to basin aquifers. The best documented cases of downstream damage in developing countries are losses of production of hydroelectric power due to reservoir sedimentation and increased dredging costs (Southgate and Macke 1989, Veloz et al. 1985, Crosson, 1983). Steep slopes and high rates of rainfall in tropical regions result in much shorter reservoir lifetimes relative to reservoirs in temperate regions. Since the ratio of reservoir capacity to sediment load is much lower in tropical regions than temperate regions, tropical reservoirs incur earlier production losses from siltation and have relatively shorter productive lives.[4]

---

[2] Estimates of costs of reduced agricultural productivity attributable to erosion in developing regions can be found in Magrath and Doolette (1990), Bishop and Allen (1989), Magrath and Arens (1989), and de Janvry et al. (1993). Estimated onsite damages in the United States can be found in Walker (1982) and Walker and Young (1986), and offsite damages in Clark et al. (1985).

[3] For a review of this literature see Aylward and Barbier (1992).

[4] Crosson (1983) for example cites the case of the multimillion dollar lower Anchicaya reservoir in Colombia which had a useful life of only seven years.

Two questions arise regarding the possibilities for generating downstream benefits through reforestation projects or other upland watershed management projects. First, to what extent can the rate of river sedimentation and offsite damages be reduced by increasing the cover in upland watersheds through watershed management projects? And second, are there other more cost effective methods available?

Existing research does not allow a conclusive answer to the first question. Most of the studies which have estimated effects on sedimentation of changing watershed management practices have used some form of the USLE to estimate the changes in deposition at the site, and then combined these estimates with estimated SDRs to infer reduced sediment loads, and hence, reduced downstream damages. Given the variability in estimated SDRs noted above, and the problems with using the USLE in tropical regions, it is difficult to have much confidence in the estimated reductions in damages using this methodology. The existence of offsite damage from erosion in tropical regions is indisputable. However, at present, the degree to which this sedimentation is a result of human activity is not well known. It is therefore difficult to predict the quantitative downstream impacts of proposed watershed projects that focus on changing management practices.[5]

The possibilities for generating benefits offsite appear to depend critically on the size of the watershed. For smaller watersheds the linkage between management practices and sedimentation is much easier to identify, and possibilities for changing the volume of sediment carried in the river are greater. For larger watersheds the opportunities are fewer. Pearce (1986) has estimated that the time required to simply flush existing sediment from these systems could be 40 years. The marginal impact of reducing erosion is likely to be small under these conditions for any reasonable discount rate. Thus, changing management practices cannot be expected to yield major benefits downstream.

On the second question of alternatives, Southgate and Macke (1989) suggest that there may exist modifications in the design of hydroelectric systems that are highly cost effective for erosion management in tropical regions. They cite recent changes in the design of water resource development in Ecuador to illustrate the expanded policy options available. Current options under consideration include constructing more flexible reservoirs that can be periodically flushed, constructing larger reservoirs further downstream, and the use of check dams in more easily managed microwatersheds. Changing farm practices may not be the least cost means of reducing downstream impacts.

To summarize, the problems in measuring downstream damages, the lack of a clear linkage between alternative management practices and downstream sediment loads, and the possible availability of other more cost effective solutions to reduce sediment loads, suggest that the justification for watershed management projects in developing countries, at present, will have to based largely on onsite benefits.

Economic Justification for Public Intervention

Arguments for public intervention in watershed management decisions are based on market failure. Several reasons have been used to explain market inefficiencies. For instance, farmers do not take downstream impacts into consideration when making their production and land use decisions, and they may not consider the impact of erosive practices today on their future earnings. Farmers who lack secure land ownership do not take soil depletion sufficiently into account. Credit markets do not exist in some rural areas, and where they do exist,

[5] Studies estimating the impacts of soil conservation programs in the United States have similar shortcomings (Ribaudo 1989).

they operate inefficiently. And finally, technology development and farm management information are public goods which will be underprovided by the private sector. Each of these cases will be considered in turn below.

Negative Downstream Externalities

Theoretically, where there are negative impacts unaccounted for by decisionmakers ("externalities") policies need to be adopted to internalize them. A strong case can be made for public intervention in situations where significant downstream impacts can be identified. In addition, it is suspected that as knowledge of ecological relationships in upland watersheds improves, the negative impacts on these systems will be increasingly important as a justification for intervention. As indicated above, however, existing knowledge about the technical and economic relationships in these systems does not provide a firm basis for intervention. Additional systems oriented research is needed to guide policy for small watershed management.

Onsite Productivity Impacts

The theoretical justification for public intervention in the case of onsite productivity impacts of erosion is less clear. As McConnell (1983) has shown, a rational farmer with secure tenure will take the foregone loss of future profits (user costs) into consideration when making current land use decisions. This, of course, presumes that farmers are aware of the negative productivity impacts of their land use decisions. However, there is a question of the degree to which productivity decreases are recognized by growers. The loss of 20 tons of topsoil on an acre of land is equivalent to about one-seventh of an inch of soil is not likely to be noticed physically by the grower (Crosson 1983). Moreover, given the variability of agricultural yields caused by weather and other factors, it may be difficult for a grower to recognize a decline in productivity resulting from erosion. If growers cannot perceive these negative impacts it is also likely that prospective land buyers will not observe them. Thus, the effect of some erosive management practices may not be incorporated into land prices, and market failure may exist.

In tropical regions, however, rates of erosion are much greater than in temperate regions and hence growers are more likely to observe the adverse productivity impacts of their decisions. This speculation is supported by Gould et al. (1989) whose research found that growers on steep slopes have a greater awareness of soil erosion problems. There is additional empirical evidence that where erosion is evident markets do reflect soil loss conditions. In a study conducted in New South Wales, Australia, King and Sinden (1994) found that current soil productivity had a positive impact on land prices and highly eroded lands sold for less, all other things being equal. Also, Palmquist and Danielson (1989) found erosive characteristics of land to be a significant determinant of land values. In tropical regions one would expect the eroded condition of land to be rather obvious and where land markets exist, these impacts to be recognized.

Mining of the land for agricultural production can be rational from the point of view of the grower and does not itself justify pubic intervention on efficiency grounds. The "optimal" depletion of land, however, assumes that there are secure land tenure, efficient credit markets, and efficient land markets. It also assumes that growers know and use the most profitable production system available. These conditions are not frequently met in developing countries. When efficient markets do exist, intervention can be justified on the basis of intergenerational equity and sustainability considerations. Equity considerations are, however, outside the usual scope of project and policy evaluation work. Furthermore, research has shown that technical progress has made it possible to increase yield per acre of crops on eroded land (Walker and Young 1986) and thus that production can be economically sustainable in the presence of erosion.

Land Tenure

Insecure land tenure and undeveloped land markets are widely acknowledged as causes of land degradation in the developing world. Under these conditions growers have little incentive to account for land degradation. In tropical regions, land may be used as a common property resource by farmers. It has been recognized that common property resources are not necessarily used inefficiently by the occupants. That is, there is evidence that suggests that where peasant farmers have occupied an area over a long time period, institutions can be developed that promote efficient land use even though the rights to the land are held in common (Ostrom 1990). Farmers have been shown to recognize that if they abuse the land, their neighbors are likely to do so as well, and hence the entire community will experience losses. Under these conditions growers have often been found to have internalized the negative externality effects. However, these conditions (symmetrical externalities) are much more likely to be encountered in lowland tropical forests than in upland watersheds.

In the case of recent migrations to upland watersheds, perhaps induced by agricultural modernization in the valleys, there has not been sufficient time for these institutions to develop, externalities are not likely to be symmetrical, and the land is more appropriately treated as an open access, rather than a common property resource (de Janvry and Garcia, 1993). Open access resources are characterized by greater than optimal levels of exploitation and use. Farmers who do not have title to the land ,are not likely to adjust their current management decisions to reflect impacts on future losses of profits, or the future sale price of the land. Moreover, there is empirical evidence that indicates significant overexploitation of natural resource systems in other developing regions (López 1993).

The lack of clear tenure and transferability of property rights can also result in inefficiency in production when it is characterized by risk and producers are highly risk averse. Under competitive conditions with transferable property rights, land would pass into the hands of those more willing to undertake the risks. This cannot happen when property rights are not assigned. In upland watersheds the lack of clear rights of growers to use and transfer property leads to inefficient rates of erosion and thus provides a justification for government intervention.

Credit Markets

Imperfections in the market for farm credit also provide a rationale for intervention in the form of subsidized credit to small farmers in upland watersheds. Capital market imperfections in the agricultural sector, arising chiefly from the existence of asymmetric information and the attendant moral hazard and adverse selection problems, have been well documented (see Calomiris and Himmelberg 1993).[6] When banks do not have experience with the evaluation of loans for the agriculture sector, and do not have a basis to evaluate the management capabilities of prospective borrowers, they will charge higher interest rates and restrict capital inflows to rural areas.[7] Thus, growers are not able to borrow at the market rates of interest available to other sectors. That is, there is likely to be discrimination in the informal or formal credit markets.

---

[6] Asymmetric information occurs when growers have knowledge about their management and production capabilities different from what bankers have. In this case bankers may select less efficient growers (adverse selection) for loans and growers may adopt more risky practices after receiving the loan than they would have without the loan (moral hazard).

[7] It must be recognized, however, that agriculture is an inherently risky sector, and rates of interest would be expected to be higher in this sector. Hhence observed higher interest rates are not prima facie evidence of capital market failure.

The resolution of capital market imperfections is a complex task that is highly dependent on the characteristics of local institutions. Perhaps the most obvious mechanism available is directed government credit. However, governments may not be able to screen growers any better than private bankers. Moreover, other sectors of the economy, in particular small scale urban enterprises, also lack access to credit markets.

There are transactions costs associated with mechanisms designed to treat the problems of moral hazard and adverse selection which have precluded the development of private credit markets in rural areas, and the benefits may not justify these costs. For example, there is considerable production risk from insect damage and lack of rainfall in United States agriculture, but the private market does not provide insurance for these perils. Studies have clearly shown that problems of moral hazard and adverse selection are important in this setting, but as yet, there is little agreement on the design of an efficient government insurance program to remedy this market failure (Hueth and Furtan 1994). It has proven to be a much more difficult task than anticipated. The design of an efficient government supported credit market is also likely to be difficult.

In summary, the task of resolving problems stemming from a lack of access to capital markets in developing countries is not best treated within the context of a watershed management project. Specific projects which are focused directly on the possibilities for designing mechanisms to improve overall credit market performance are preferable.

Technology Development and Information Transfer

Watershed projects can be justified on the basis of the public goods characteristics of information. The results of applied agricultural research and knowledge of new agronomic practices are difficult to appropriate by the private sector and will thus be undersupplied. Government technology development can be justified without consideration of negative externality reductions if the net present values of increased producer profits and consumer gains exceed the costs of these programs.[8] Moreover, investments that increase the rate of adoption of these programs can yield positive net social benefits.

Increasingly, in developing and developed countries alike, the focus of technology development and transfer for erosion reduction has shifted from an emphasis on structures and physical barriers, to the development and introduction of sustainable agronomic and agroforestry production technologies (Kaimowitz 1992; Magrath and Doolette 1990). The use of technologies such as minimum till, intercropping, green fertilizers, and multiple use forestry production is knowledge intensive and many international programs are assisting in the development and promotion of these technologies. Most countries now have an extension service responsible for providing these educational services. In addition, in many cases these new technologies result in new products with undeveloped markets. Hence, public expenditures on marketing programs may be needed to achieve profitable levels of production.

Most watershed management projects contain both applied research and extension components. In agriculture, particularly in sustainable agriculture, the line between research and extension has become more blurred as more research is done on farms. Research and extension expenditures which may directly benefit the producing

---

[8] Conceptually there is no reason why some programs developed for producers might not have negative environmental impacts. For example in some watersheds no till programs may yield small external benefits from sediment reduction. But the increased complexity of the resulting weed, insect, and pest management problems can increase pesticide use, and hence, the net effect may be negative. In what follows, however, it will be assumed that a purpose of the watershed programs is to improve environmental quality and projects will focus on practices that improve the environment.

sector in this context are not subsidies if properly undertaken. They are public expenditures on public goods and there is conceptually an optimal rate of investment in these activities. Of course, over or under investment can occur. But, public benefits from this investment in conservation technology include not only the producer and consumer gains from market oriented outputs, but also nonmarket environmental gains. Thus, the rate of return to a technology development and transfer project estimated using only producer profits and consumer gains will be a lower bound estimate.

Summary

Offsite externalities from agricultural production can justify government intervention, but determining the optimal level of intervention is more difficult in developing countries than in developed countries, and the design of efficient mechanisms is a greater challenge. Existing research in developing countries does not provide conclusive empirical evidence of downstream benefits from intervention in farmer decisions upstream. Without question, limited property rights and nonexistent credit markets cause inefficient land use decisions and excessive future productivity losses. The most obvious means of correcting for lack of secure land tenure is to assign property rights, but this may not be feasible in many developing countries at present. Investigations of how to improve credit market performance are warranted. This is likely to prove a difficult task, however. Hence, at present, watershed management programs that develop and transfer technologies which are currently more profitable, reduce future soil productivity losses, and perhaps reduce environmental damage downstream, are the most likely means to produce social gains.

Subsidies and Other Mechanisms for Efficient Resource Allocation

The purpose of this section is to assess the effectiveness of subsidies as a policy option available for the resolution of market failure problems in upland watersheds, and their potential role in technology development and adoption. Initially, however, alternative mechanisms for the resolution of these problems are discussed. Policy options will be assessed with regard to economic efficiency, political viability, government enforcement costs and other budgetary impacts. Equity or income distribution considerations will be highlighted where relevant. The alternative policies evaluated are moral suasion, direct regulation, markets in pollution permits, pollution taxes or taxes based on estimated pollution, and subsidies.[9] The discussion in this section presumes significant downstream environmental impacts of current upstream management practices. As discussed above, these impacts have yet to be widely documented, but this view is sufficiently broadly accepted to warrant conceptual treatment.

Moral Suasion

Moral suasion is defined as a set of noncoercive government activities designed to encourage the private internalization of environmental externalities and the reduction of environmental damages. They include public education programs for television and radio, as well as brochures and other written materials. This approach appeals to an environmental ethic or teaches that there is a moral imperative to improve environmental quality. The approach seeks voluntary actions on the part of consumers and producers to achieve improvements.

[9] A discussion of policy options using similar criteria for controlling externalities relating to agricultural chemicals can be found in Abler and Shortle (1991).

Funding to increase environmental awareness in developing countries has increased dramatically in recent years. In many countries funds are available for developing elementary and secondary school educational materials in addition to information for the general public.

The economic efficiency of these programs is difficult to assess and specific project evaluation studies that focused on them were not encountered during the preparation of this paper. However, some comments are possible. Numerous studies that have used contingent valuation to estimate environmental benefits have found that willingness to pay for improvements depends strongly on the information available to households (Bergstrom et al. 1990). That is, if consumers are made aware of the health and safety hazards posed by contaminants, they have shown a willingness to pay for projects that reduce levels of emissions. Moreover, given an increased awareness of the costs they are bearing, they show a greater propensity to bring pressure on governments to force producers to reduce emissions levels. In most cases, however, consumer groups recognize that they will realize direct benefit from reduced emissions. That is, in most cases the environment is presented as a public good whose improvement (for instance, improved air and water quality) will benefit citizens directly.

This is not, however, generally the case with agricultural producers in watersheds. As discussed above, if producers do not own the land and there are no efficient land markets, they cannot gain from reducing erosion rates, and have little incentive to reduce downstream impacts. Hence the moral imperative for the producers to change their behavior is not likely to be great. In some cases farmers are observed to take pride in being referred to as "stewards of the land" and may be inclined to reduce environmental damage by, for instance, taking care to use only the minimum amount of pesticides necessary to suppress a pest population. But, farmers are most inclined to be stewards of the land they own. Moral suasion alone is not expected to be cost effective in reducing environmental damages in watershed settings, particularly when these producers are low income farmers who do not have secure land tenure. When production is necessary to sustain the essentials of life for the household, concern for the ecology of the area will be of secondary importance, regardless of how highly esteemed it is.

However, if the definition of moral suasion is broadened to include the delivery of information on sustainable agricultural programs, it can play an important role in internalizing externalities. In upland watersheds there are cases where all growers within a watershed can benefit if they agree to adopt a soil conservation technology. This also presents the government with opportunities for institution building. These institutions may use the moral suasion arguments to achieve efficient exploitation of open access resources and to produce environmental amenities.

Direct Regulation

Direct regulation cannot be expected to produce perfectly efficient erosion control. In addition to the static losses resulting from the lack of knowledge of the optimal level of intervention, there are dynamic losses attributable to the failure to promote the development and adoption of more efficient technologies through time. Still, direct intervention can be an attractive second best policy. Requiring barrier strips along streams, for example, can be a highly effective means of reducing runoff and is enforceable in most settings. Or, simply banning the use of a particular pesticide can likewise produce improvements in welfare. Direct controls can be less costly to implement than taxes, particularly where pollution is stochastic as it is in most watersheds, necessitating the continual adjustment of tax levels in response to changes in natural conditions.

In developing countries, it is difficult to generalize about the potential for the use of direct intervention, or imposed technologies, on producers since the capability to enforce such standards or practices varies widely across and within countries. In rural areas where the government, in fact, does not have a physical presence, regulation or intervention is impossible. It is illegal to cut trees in many tropical forests where observed deforestation rates are high. Timber companies in these areas buy from all sellers of logs without questioning where or how the logs were harvested, and indigenous peoples cut trees wherever they find them unprotected.

The enforcement of standards on erosion runoff would be even more difficult, and it would be complicated by the problem of establishing the source of the runoff. It may often be the case that management practices farther removed from the stream could be the source of the sediment arriving at streamside, but it would be difficult to establish a physical basis for responsibility. Moreover, the usual method of enforcing standards is to levy fines on growers exceeding them. Such fines would not be collectable in most developing countries.

Nevertheless, in some cases governments in developing countries have more constitutional power over management of natural resources than their counterparts in developed countries, and may therefore be able to employ mandated standards more effectively. In any case, enforcement costs need to be included in any economic evaluation of a proposed mandated standard or practice, as they do for other instruments.

Tradable Pollution Permits

The use of tradable pollution permits as a mechanism to achieve a given ambient environmental standard has gained great popularity in recent years. As yet, this mechanism does not appear to have been used in watershed management, but would seem to hold some promise. For it to be useful, it is necessary to have established a functional relationship between management practices and erosion or water quality downstream. Given the relationship between reaches of a watershed, it is conceptually possible to grant marketable pollution permits to upstream growers and allow downstream growers or others adversely affected to bid for these rights. In practice this approach usually presumes that the upstream growers have the right to pollute. That is, "historic" property rights are granted to the polluter.[10] Measurement, monitoring, and enforcement of these contracts between individual growers would, however, be a serious problem in developing countries.

A more likely alternative is the establishment of a contract between grower and community organizations.. For instance, in response to an observed decline in valley aquifer levels, a group of Colombian coffee growers purchased an entire small watershed from small farmers solely for the purpose of enhancing recharge to the basin aquifer used by the coffee growers.[11] Thus, where producer organizations have been formed in upland watersheds, and adversely affected growers downstream are likewise organized, it may be possible to establish a contract between these organizations. Although previous water contracts in Latin America, as in Chile for example, have focused on water quantity, presumably payments for water delivered could be made conditional on quality characteristics. Upstream growers would agree to reduce erosion through alternative management practices and would be compensated by downstream growers for doing so. The existence of local organizations provides the mechanism for enforcement of the contract. Possibilities for such institutional arrangements to internalize externalities merit further consideration.

[10] As was pointed out by Glenn Westley, however, there is no reason that permits could not be assigned to downstream parties or some split allocation between upstream and downstream growers.

[11] Information provided to the author on a trip to the Center for Tropical Agriculture in Palmira, Colombia.

Taxes

Pigouvian taxes which internalize the negative external effects of a production activity have been the most desirable policy choice of economists for resolving environmental problems. Pigouvian taxes levied on the use of the externality producing residual, or on a practice assuming a fixed proportion technology, have been shown to be statically and dynamically efficient, and further, can produce revenue to support enforcement activities. That is, Pigouvian taxes achieve economically efficient levels of pollution during any production period and provide incentives to growers to search for more efficient production systems which allow them to avoid the tax payments. Moreover, tax revenues provide a source of income for the administration of the system.

Nevertheless, as Barthold (1994) has documented, Pigouvian taxes have been seldom used in practice. Barthold points out that there are difficulties in the administration of a tax that has to be levied on a residual of production or on the "use" of an input. The application of pesticides on a hillside may have a negative impact on fish and bird populations, for example, but it is impossible to know when or how a grower uses these chemicals (growers frequently buy chemicals for use over several years). As a result, economists recommend, as a second best solution, the levying of taxes on the production of agrichemicals or the retail sale of the chemicals rather than farmer applications. Similar recommendations may also be relevant in developing countries, but it should be observed that these taxes no longer have the textbook properties of Pigouvian taxes.

Also, Barthold argues that economists are not sufficiently sensitive to the issue of who pays. Politicians like to be viewed as providing benefits for their constituencies and holding down costs. Taxes impose a cost on people and the environmental benefits are most often not immediately observable. In a welfare theoretic context, even thought the gains exceed the losses, and thus there is a potential Pareto improvement (i.e., the gainers could compensate the losers), if the gainers cannot be clearly identified, and losers (taxpayers) are a loud and noisy lot, few politicians are likely to support the tax proposal. Politicians are in search of Pareto improvements, that is, cases where everyone can be made better off. This may mean that the only politically feasible solutions are second best ones. This is particularly true in the case of poor people living in watersheds in developing countries where taxation is not politically feasible.

An additional limitation on the use of Pigouvian taxes is the stochastic nature of the externalities associated with watershed management, due to weather, and the lack of information regarding the technical capabilities of individual growers. Shortle and Dunn (1986) have investigated the conditions under which it is possible to use taxes on management practices, or alternatively on estimated runoff, to achieve Pareto efficiency. They have shown that in the most general case of multiple producers differentiated by management capabilities and attitudes toward risk aversion, the government agency will not typically possess sufficient information to set efficient tax incentives based either directly on the management practice or on estimated runoff. They have also shown, however, that under more restrictive conditions (risk neutrality and a representative producer) incentive based mechanisms will outperform direct controls on management practices or the setting of runoff standards.

A number of simulation models have been developed by the United States and other countries (see Setia and Osborn 1989 and Arch 1987) which model runoff under alternative management practices. Shortle and Dunn (1986) have suggested that these models could be used to estimate runoffs to set targeted taxes on either estimated runoffs or management practices assuming some average level of management capability. The setting of a tax on runoff would require that the management agency provide the grower with the estimated runoff schedule in addition to the tax schedule. A linear additive damage function would be sufficient to justify the efficiency of this mechanism applied to estimated runoffs. Alternatively, taxes based on model predictions could be used to achieve a given amount of runoff if information regarding the damage function is not available.

A shortcoming of this approach is that only known technologies are subject to modeling activities, and thus, there is little incentive for the agency or the grower to explore more efficient technologies. Also, the development of simulation models for upland watersheds is in its infancy and their usefulness for this purpose is in the distant future. Moreover, a tax, as stated previously, is always subject to the limitation of politically feasibility. Although taxes based on estimated emission have been used successfully in industrial sectors of some countries, and warrant consideration in agricultural sectors, they are not likely to be feasible in upland watersheds populated by large numbers of small farmers. For the larger scale commercial agricultural sector, they could be a feasible alternative.

Subsidies

Subsides have been widely used in the developed and developing world as a mechanism to obtain adoption of alternative management practices and more efficient resource use. Subsidies have been provided in many forms for many purposes. Kaimowitz (1992), in a review of eighteen watershed management projects in Central America and the Caribbean, found that subsidies used included food, wage payments, provision of inputs (including capital inputs), directed credit, prizes for competitions, and permits to use public forest resources.[12] Subsides have been used extensively for the construction of terraces, canals and other structural systems and, less commonly, to promote adoption of alternative cropping systems.

These subsidies are usually justified by the expected reductions of downstream offsite damages resulting from adoption of less erosive production technologies. However, at times, subsidies are viewed as an incentive to transfer information about the increased profitability or reduced risk of a new technology. Insufficient attention has been given to these distinctly different roles of subsidies in the policy process: that is, the use of subsidies for the correction of negative externalities, as opposed to the use of subsides as an incentive to promote the adoption of a more profitable, and perhaps more sustainable, technology. The latter is largely a public goods and optimal – investment – in – technology – transfer justification. A review of the theoretical and applied literature on this subject suggests that there is greater justification for subsidies of the latter type than the former.

Efficient Design of Subsidies

In this section we explore possibilities for the use of subsidies rather than taxes to promote the adoption of technologies which improve environmental quality but are not necessarily more profitable for growers. A subsequent section considers the possibilities for promotion of alternative technologies which are expected to be more profitable for growers, and additionally, yield environmental benefits.

The conditions under which there is a symmetrical relationship between Pigouvian taxes and subsidies to internalize negative externalities has been well established in the literature (Baumol and Oates 1993; Carlson et al. 1993). Assuming zero agency transactions costs and restricted entry, appropriately designed subsidies can achieve the same efficient level of pollution as Pigouvian taxes. The selection of one or the other can be viewed as simply a matter of alternative assignments of property rights. With taxes it is assumed that the

---

[12] Interestingly, however, Kaimowitz (1992) notes that he did not encounter any literature which has investigated the effectiveness of alternative forms of subsidization in achieving adoption. Nor did this author.

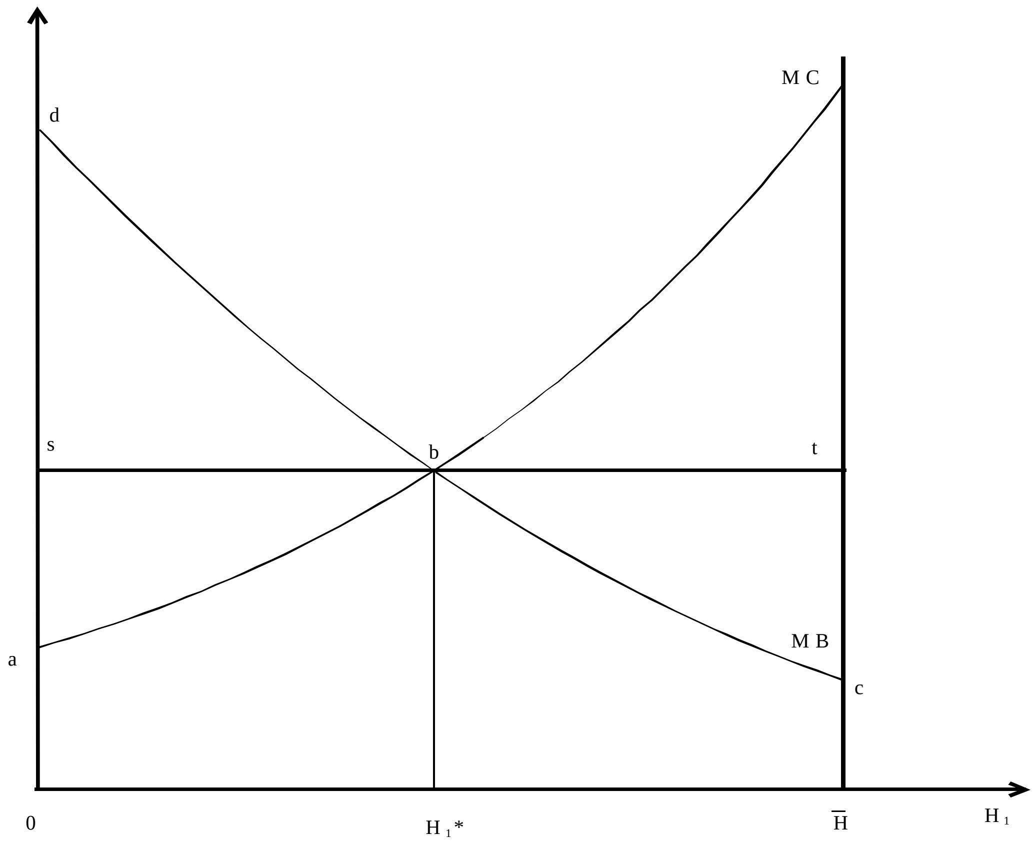


Figure 1: The Symmetry of Taxes and Subsidies

polluter does not have the right to pollute the environment and must pay to do so. With subsidies it is assumed the polluter has a right to pollute and must be compensated for emissions reductions.

This is illustrated in the context of watershed management practices in Figure 1 where two alternative management practices are assumed, one which is highly erosive and another which is significantly less so. There are $\bar{\mathbf{H}}$ hectares under cultivation by a large number of small producers in the watershed each with an equal number of hectares which, without loss of generality, are assumed equal to one. Each hectare is assumed to contribute equally to environmental damage when under cultivation. The curve **MC** represents the marginal opportunity costs of adopting the new technology arranged in order of increasing opportunity costs from left to right. Opportunity costs for producers will vary due to management capabilities, household characteristics, attitudes toward risk, off-farm employment opportunities, capital goods available, and other reasons. Sloping downward from left to right is the social marginal benefit function (**MB**) of adoption, that is, the marginal benefits of converting hectares from the conventional technology to the alternative technology. As shown in the Appendix this curve is the negative of the marginal damage function of runoff. If growers do not have secure land tenure the marginal benefit function could also be interpreted as including the marginal gain in foregone future profits resulting from adoption.

The socially optimal number of hectares transferred to the new technology is given by $\mathbf{H_1^*}$ where the marginal benefit from adopting is equal to the marginal cost of adoption. Suppose a tax, **t** , is imposed on each hectare that uses the old technology. Farmers who have an opportunity cost of adopting the new technology greater than the tax, will prefer to pay the tax rather than shift to the new technology. Those whose opportunity cost of adoption is less than the tax will prefer to change technologies. Thus $\mathbf{H_1^*}$ hectares are transferred to the new technology and $\mathbf{\bar{H} - H_1^*}$ remain in the conventional technology. The agency receives tax revenues of area $\mathbf{H_1^* bt\bar{H}}$ and total environmental damages are reduced by area $\mathbf{OdbH_1^*}$.

Now suppose a subsidy of **s** is offered for each hectare transferred to the new technology. Moving from left to right, producers will convert hectares to the new technology up to the point where producers are encountered who have a marginal cost of adoption greater than the subsidy. Hence, again H_1^* hectares are transferred to the new technology and total damages are reduced by area $\mathbf{OdbH_1^*}$. The difference is that now the government is paying the producers area $0sbH_1^*$ rather than receiving tax revenues. Thus, taxes and subsidies produce the same efficient outcome, but the government now has to make annual outlays of area $\mathbf{OsbH_1^*}$ to maintain this acreage in production using the improved technology. Producers are earning rents (i.e., earnings in excess of what growers would be willing to accept to adopt the technology) of area **asb**. It is the existence of these rents and their implications for resource use over time that has caused most economists to abandon their position of indifference with regard to taxes and subsidies as policy measures.

To illustrate the problem that can arise, consider the situation presented in Figure 2. In this figure it is assumed that the existence of rents in the short run attracts colonizers, who have zero opportunity costs of adoption, from the lowlands and urban areas to the upland watershed. These colonizers bring $\mathbf{HN = \hat{H} - \bar{H}}$ additional hectares into cultivation. The new marginal cost of adoption curve ($\mathbf{MC_1}$) is shifted rightward. As demonstrated in the Appendix, the additional hectares under cultivation in the watershed shift the marginal benefit curve upward from $\mathbf{MB_1}$ to $\mathbf{MB_2}$. If the subsidy **s** is maintained, acreage adopted increases from $\mathbf{H_1^*}$ to $\mathbf{H_1^{**}}$. That is, hectares using the alternative technology are increased. Total runoff and damages, however, can increase even though more growers are using the conservation technology (reductions in damages through adoption are now area $0edH_1^{**}$). That is, there are two impacts of the subsidy on total damages given sufficient time for new entry in the watershed, the adoption effect and the entry effect. As shown in the Appendix, the adoption effect will be negative (it will reduce damages). The entry effect will be positive, (it will increase damages).

Thus, the net effect is unclear: the existence of new entrants implies it is possible that total environmental damages from land use in the watershed may be increased. In addition, budgetary outlays have increased by area $\mathbf{H_1^* bcH_1^{**}}$ and there are increased rents to be sought by new potential colonizers.

This analysis suggests that when there exist potential colonizers with low opportunity costs of adoption, a situation not uncommon in most developing countries, subsidies have limitations as a mechanism to correct for negative externalities. Of course, one possibility is to offer the subsidy only to existing growers. This, however, may not be politically feasible. More importantly, in this context, the subsidy would have to be offered in perpetuity since if it were eliminated growers would have an incentive to return to the old technology.

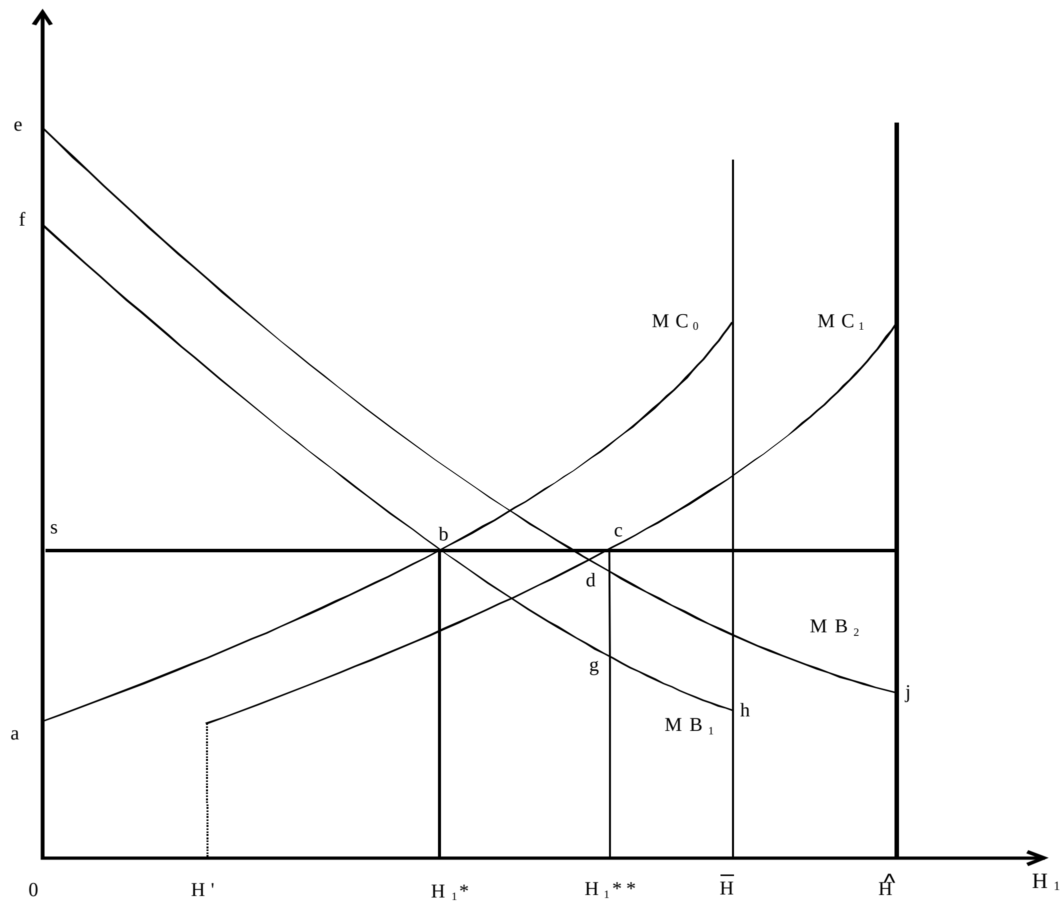


Figure 2: The Effect of Subsidies on Entry

Thus, there exists a serious financing problem with this proposed solution. Finally, the government is paying more than is necessary to achieve an efficient level of adoption. That is, the rents of area **asb** in Figure 1 are the excess of what the government is paying over what is necessary to achieve adoption of $\mathbf{H_1^*}$ hectares. Existing producers would be willing to accept area $\mathbf{0abH_1^*}$ to transfer these acres to the new technology. It would be desirable to use a mechanism for granting subsidies which is cost effective, that is, one that pays producers only the minimum amount necessary to achieve adoption of the new technology. One such mechanism is presented below. First, however, the use of in-kind subsidies and the possibilities for targeting subsidies are discussed.

In-Kind Subsidies

In-kind subsidies have been used mainly to promote the establishment of conservation structures, rather than practices, and given the increasing focus on the development of sustainable practices, are less likely to be used in the future. The experience with in-kind subsidies is mixed, but more negative than positive. Kaimowitz (1992) cites cases where once payments in food were initiated it was politically impossible to suspend them, and other cases where maintenance of structures by farmers who were paid food for work largely stopped once food payments stopped. He also cites spectacular failures of gifts of trees from public nurseries in El Salvador.

On the other hand, Doolette and Magrath (1990, p. 30) cite a case in the Philippines where gifts of breeding cattle to obtain adoption of contour hedgerows were extremely effective. In the latter case there was a strong financial incentive for the growers to maintain the hedgerow.

As discussed above, the lack of availability of credit in small watersheds has been identified as a critical problem in obtaining adoption of improved technologies. In addition, lack of grower information about the profitability of the technology is often an impediment to adoption. To the degree that in-kind subsidies alleviate the credit market problem and enhance adoption of technologies shown to be profitable and to improve the environment, they might be justified. But, growers should clearly understand the conditional nature of the grant; that is, they must adopt the technology. Given the bias of this type of mechanism toward structures, and the demonstrated lack of success, in-kind subsidies should be carefully scrutinized.

The employment of farmers and farm families for food or wages is troublesome. First, in many cases in developing countries people migrate to the small watersheds because of lack of employment opportunities in the urban areas. Subsidized employment in these projects raises the opportunity cost of accepting jobs in the urban areas as development occurs.[13] Secondly, in developing countries as in developed countries, there is an increasing trend for small growers to work in neighboring communities and farm part time. A project which requires their employment eliminates the possibility of hiring cheaper labor for the project work and means that the grower would be unable to continuing his employment. The desire of the project administrator to have the project "succeed" makes the creation of labor market distortions likely. Finally, there is the risk that once the employment phase of the project is completed, the grower will abandon the project to return to conventional production methods. Again, careful analysis of the profitability of the new technology must precede implementation. Payment in-kind is not recommended.

Targeting

Hectares within a watershed can differ greatly with regard to their technical pollution producing capability. It has been recognized that greater cost effectiveness can be obtained if funds are targeted to those hectares that are more erosive or contribute most to environmental contamination or where the net marginal benefits of damage reductions are the greatest.[14] Initially, targeted subsides were used chiefly for building on farm structures but there has been an increasing trend to provide "incentive payments" for the adoption of improved management practices. The work thus far in the United States has focused on achieving a particular runoff standard or soil loss standard as opposed to attempting to use a damage function approach. Setia and Osborn (1989), for example, using soil loss, agricultural production, and market simulation models generate a least cost frontier for achieving various levels of soil loss, and then compare the costs of achieving an accepted soil loss tolerance standard using nontargeted and targeted mechanisms. They found that savings from targeting could be significant, as high as 44 percent.

---

[13] Mario Niklitschek points out that this problem is exacerbated in many Latin American countries by the presence of government created segmented labor markets and high wage taxes in the formal urban sector where productivity may be higher than in informal rural sector.

[14] "At present, targeting is moving more toward justifications based on offsite benefits, particularly water quality," personal communication, Tim Osborn, United States Department of Agriculture, June 7, 1994. Also, entire programs can be viewed as "targeted" such as the Water Quality Incentive Program, and the Colorado Salinity Control Program. Furthermore, the Conservation Reserve Program used are environmental benefit index to rank bids for inclusion in the program.

A particular example (Table 1, page 98) in their paper, however, points to one of the practical problems in using subsides associated with management practices. Their farm management model suggested that the use of straight row planting of a corn/corn rotation with no tillage would save the grower 67 dollars per unit area but this practice was not observed to be the growers' practice. A host of reasons are advanced by the authors as to why growers may not be profit maximizing, most of which deal with the lack of information and experience of the growers with the system. There is obviously also the possibility that the model developed from experimental field data has not been calibrated sufficiently well to the particular region, or that additional research is needed before moving forward. In developing countries this is likely to be even more of a problem. Growing regions are extremely diverse and greater attention must be paid to calibration, field validation of models, and the farm financial analysis of proposed technologies.

Other concerns which have been raised about targeting are the informational needs regarding technical relationships onsite, and offsite and the political acceptability of unequal payments to growers in the same regions for adoption of the same practice. It is not possible to generalize regarding these concerns. Data availability and political conditions will vary greatly among countries and regions.

The use of the targeting mechanism assumes symmetric information between growers and the management authority. In fact, growers may vary greatly in their technical capabilities, financial resources, and other characteristics that are unknown to the government. These informational asymmetries are an additional source of inefficiency in the targeting which has been practiced thus far. The most cost effective adoption incentive mechanism should pay each grower the marginal opportunity cost of adopting an improved technology up to the number of hectares desired for participation in the program or until a particular runoff standard is achieved. The following section describes a mechanism that could achieve this objective and could be used effectively to transfer more profitable and environmentally enhancing technologies.

Least Cost Subsidy Mechanisms

A more general notion of an optimal resource allocation will not only include targeting subsidies to those hectares that provide the greatest environmental benefit, but will also recognize the variability across producers of the marginal opportunity cost of adoption, or of producers' reservation values for adoption. Optimality will then require that in addition to considering the potential environmental benefit from adoption on a particular producer's hectares, the price required to induce adoption also be considered. In this setting the government can be viewed as a monopsonist (sole buyer) purchasing adoption hectares where the productivity (onsite and/or offsite damage reduction) of an adoption hectare varies across producers, and where the reservation value for adoption is unobservable and also varies. The problem for the government is then one of setting an optimal adoption hectare/payment schedule for producers contingent on the characteristics of their hectares that achieves an optimal allocation of resources subject to the constraint that the reservation value of each producer is unknown to the government.

An optimal adoption hectare/payment schedule for the **ith** producer consists of a set $\mathbf{T^i = \{(s_1, a_1), (s_2, a_2), ..., (s_n, a_n)\}}$, where $(\mathbf{s_k}, \mathbf{a_k})$ represents an agreement between the government and the **ith** producer for the producer to adopt some pre-specified technology for a given period of time on $\mathbf{a_k}$ hectares for $\mathbf{s_k}$ dollars. **T** is indexed by **i** because the contracts are contingent on the level of benefits from adoption on **i**'s hectares. To actually compute $\mathbf{T^i}$ it is assumed that the cost to the **ith** producer of adopting the alternative technology on a hectare can be represented by a function, $\mathbf{C(?_i, a)}$, where $\mathbf{?_i}$ is single parameter known by the **ith** producer, but unobservable to the government. Furthermore, it must be possible to represent the government's a priori beliefs on the distribution of **?** by a probability distribution function, **F(?)**, defined over some interval, $\mathbf{? \ 0\ [\underline{?}, \bar{?}]}$.

Given this information, $\mathbf{T^i}$ can be computed where ($\mathbf{s_k}$, $\mathbf{a_k}$) represents the element intended for a producer with $\mathbf{? = ?_k}$, i.e., a type **k** producer, and where each producer has incentive to select the contract intended for him. The government cannot simply offer ($\mathbf{s_k}$, $\mathbf{a_k}$) to a type k producer because a priori the government does not know the producer's type.

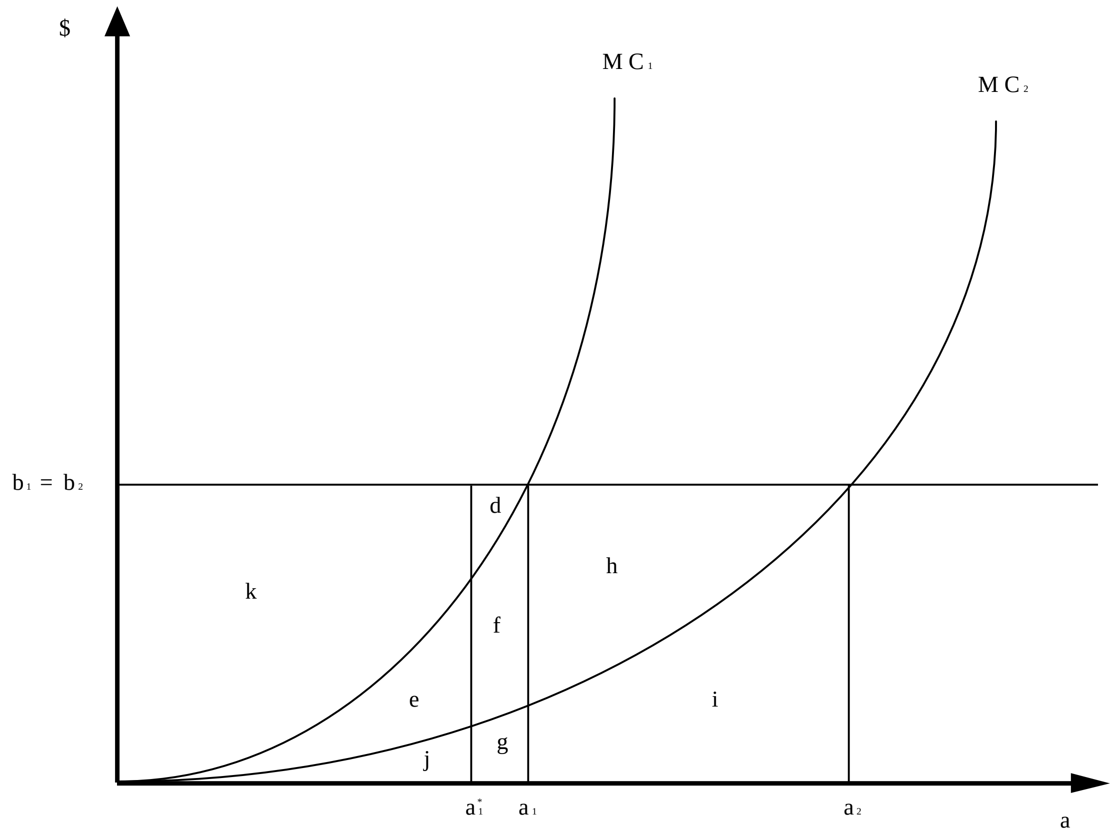


Figure 3: Optimal Subsidies with Asymmetric Information

To gain some intuition on how $\mathbf{T^i}$ is determined consider the situation depicted in Figure 3, where two producers have marginal adoption cost functions $\mathbf{MC_i = \partial C(?_i, a)/\partial a}$. It is assumed that adoption of the alternative technology on each of the producers' hectares results in a constant marginal benefit of **b** per hectare. If the government knows $\mathbf{?_i}$, the first best allocation of resources can be achieved with the set of contracts given by $\mathbf{T = \{(e + f + j + g, a_1), (j + g + i, a_2)\}}$, where the first contract is intended for producer 1, and the second for producer 2. Each producer adopts on the efficient level of hectares, and both producers are left with zero surplus.

Now suppose the government knows that **?** can take on two possible values **{?$_1$, ?$_2$}**, but is uncertain about which **?** is relevant for each of the producers. That is, both producers could be of type 1, both of type 2, or one producer type 1 and the other type 2. Note that if each producer is allowed to choose from one of the above contracts both types will always select the first contract. This is because a type 1 producer earns negative surplus under the second contract, while a type 2 producer earns positive surplus under the first. If the government offers an alternative set of contracts $\mathbf{T^* = \{(e + j, a_1^*), (e + j + g + i, a_2)\}}$, then a type 2 producer is given a surplus of **e** and is indifferent between the two contracts (it is assumed that the government can always resolve a tie as it chooses), and a type 1 producer has all of his surplus extracted under the first contract. When there is one producer of each type net benefits under the initial set of contracts are given by **2(k + d)** and net benefits under the alternative set of contracts are given by **(2k + d + h + f)**. By offering a contract for a type 1 producer with $\mathbf{a_1^* < a_1}$ the government loses d on a type 1 producer, but gains **(h + f)** on a type 2 producer who no longer has incentive to select the wrong contract.

Clearly for small movements to the left of $\mathbf{a_1}$**, h + f** will be larger than **d**, and hence the government can always gain from a set of contracts which recognizes the existing informational asymmetry. In some cases the government may not have the resources to reach the full second best optimum, and may instead wish to reach some target level of, say, total hectares in the program. This simply requires the imposition of an additional constraint in the optimization that $\mathbf{S_i\ a_i}$ **$ A**, where **A** is the target. Alternatively, the government might face a budget constraint, $\mathbf{S_i\ s_i}$ **# S**.

The analytic solution to problems like the one above are attained by appealing to the revelation principle which allows us to solve for the optimal allocation in a general mechanism, called a direct revelation mechanism, which can mimic the outcome of any specific mechanism (Fudenberg and Tirole 1992). Once the optimal allocation of adoption hectares and payments is determined the task still remains to design a specific mechanism which might achieve that allocation. It is always possible to use an adoption hectare/payment schedule such as the one mentioned above, but other instruments may also be able to implement the optimal allocation. One such instrument that might be useful in the context of a watershed management projects is an auction. That is, producers could submit bids for the number of hectares on which they wish to adopt the new technology, and the compensation they would require to do so. These bids could then be ranked according to the characteristics of the producers' hectares, and the per hectare payment. The exact way these bids would be ranked, and the rules of the auction (sealed bid, maximum allowed per hectare subsidy, etc.) would have to be set such that the optimal allocation is achieved. One advantage of the auction instrument is that the exact functional forms of C(.,.) and F(.) do not have to be known. That is, correct computation of the optimal set of adoption hectare/payment schedules for each producer requires correct specification of C(.,.) and F(.). In an auction, the optimal set of rules will depend on the assumed properties of C(.,.) and F(.), but they will be more robust to misspecification of the exact functional forms.

Two informational issues that may limit the potential success of such a mechanism deserve mentioning. First, field experience is lacking in the operation of such a program. Without such experience, unforseen problems would surely be encountered. Second, the informational requirements for producers may be greater under an auction mechanism than under a standard subsidy mechanism. Producers would have to evaluate the potential profitability of the alternative technology and then formulate a bid, taking into account the likelihood of being outbid by their neighbors. However, producers must also make some evaluation of the relative profitability of the alternative technology when deciding whether to participate in a standard subsidy program, so it is not clear that the additional informational requirement of producers would be significantly greater. Furthermore, the basic notion of asking producers to bid against each other for the right to participate in a technology transfer program seems reasonable, and worthy of consideration.

It should be noted that the mechanisms discussed in this section create only minimal rents in the watershed. However, if the technology is not more profitable than the current practice, the subsidy would have to be paid indefinitely. When the technology is more profitable and environmentally enhancing the subsidy program does not need to be repeated. The following section provides the rationale for subsidies under these conditions.

Technology and Information Transfer

This section assumes that there are opportunities for investment in the development and transfer of conservation technologies that are more profitable for growers. Because knowledge is a public good, it will be undersupplied by the private sector. Hence, there is an economic justification for investment in and dissemination of technological information in developing countries. Further, the more rapidly hectares can be shifted from less profitable to more profitable technologies, the greater the social economic benefits.

The private rate of adoption may be less than socially optimal for a number of reasons. First, growers' perceived marginal costs of adopting, as shown in Figure 1, may be significantly greater than the true costs of adopting. Second, growers may regard the alternative technologies as being more risky than they are in reality. Third, research has shown that growers with little wealth and low incomes have lower rates of adoption than more wealthy growers (Amacher and Hyde 1993). With less wealth they are generally expected to be more risk averse and unlikely to adopt risky technologies. Finally, the increase in profits may be small, but the environmental benefits may be large. In this case, growers will have little incentive to adopt conservation technologies, but the social gains from adoption are large. Thus, investments in technology transfer programs, such as demonstration projects or direct per hectare incentive payments for adoption, may yield a positive net social rate of return.

Thus, the most defensible case for subsidies is for the transfer of profitable technologies to growers who lack experience using them. In addition to the incentive payments, most of the sustainable technologies will likely require an intensive extension program to insure their success. This is particularly true for innovative agroforestry systems currently being developed. If these technologies have negative cash flows initially and credit markets do not exist, credit could be extended and repayment required. Alternatively, one time up front subsidies contingent on adoption might be justified.

Subsidies should be transitional, the project should be carefully monitored to insure compliance, and subsidies should be designed to keep rent-seeking behavior to a minimum. A major difficulty in using subsidies, such as suggested here, however, is the uncertainty surrounding the profitability of the proposed technology. The yields and market values of various crops, as well as rotations and cultural practices, vary widely from area to area and thus the true profitability of the practice will not be known with certainty until tried. This strongly suggests the argument that these subsidies should be offered to existing growers on a one-time basis. If the practice is profitable growers will continue to use it.[15] If not they will simply return to the traditional technology. There will be failures. Developing countries, perhaps in conjunction with international regional research centers, should reduce this uncertainty to a minimum through applied research programs before subsidized watershed programs are approved.

---

[15] Empirical support for this argument is found in Amacher and Hyde (1993) who found growers in Pakistani villages willing to adopt reforestation projects without large subsidies.

A number of models have been developed in recent years for the financial and environmental analysis of farm management options. The Inter-American Development Bank ,for example, has produced the FARMSIM model that can be used for this purpose. In addition there are models discussed in Arch (1987) Heimich and Ogg (1982) and, most recently, spreadsheet programs (such as Planetor developed by the Center for Farm Financial Management in1994) have been developed to evaluate farm management options.

There appears to be considerable scope for extension and institution building projects. Grower associations and community organizations can provide self-enforcement mechanisms for treating the problems of-asymmetric information in the delivery of farm credit, can internalize externality problems associated with common property resources, can serve as an information delivery mechanism for production technologies, and can possibly serve to negotiate contracts for pollution reduction with other grower groups.

Conclusions and Recommendations

This review of published and unpublished literature and interviews with researchers in a number of Latin American countries and the United States has reached the following conclusions regarding the use of subsidies in watershed development projects.

! Existing research has not established a sufficiently strong relationship between land use practices in upland watersheds and downstream sedimentation damages, at this time, to justify subsidy programs in most watersheds. Moreover, the literature suggests that there are alternative methods of reducing sedimentation damages which are more cost effective.

! There is increasing recognition of the importance of ecological impacts as negative externalities relating to land use practices. These may be onsite ecological impacts (reduced biodiversity), impacts on the hydrological cycle, and impacts on local fisheries populations. Also, there may be downstream impacts such as reduced recharge to aquifers and impacts on human health. These ecological considerations will increasingly be used as a justification for public intervention.

! If production practices exist which result in environmental benefits, but which are not more profitable for producers, there is a justification for corrective action, but not in the form of subsidies as currently practiced. Subsidies in this context would have to be continued in perpetuity and thus would place a significant financial burden on the government. In addition, rent-seeking behavior by growers and prospective growers would likely cause significant economic losses. Alternative mechanisms which are recommended as corrective action in this case include: direct intervention (i.e. mandated management practices), the establishment of markets in pollution permits, and the use of Pigouvian pollution taxes in areas where it is politically and administratively feasible. Second best solutions such as taxes on the sale of pesticides should also be considered.

! Subsidies should be restricted to one-time transitional use mechanisms to achieve adoption of profitable and environmentally improving management practices. Ggrowers may not have adopted such proven profitable practices on their own because of insufficient cash flows, small increases in profitability, inadequate development of rural credit markets, lack of familiarity and experiences with new production technologies, and inaccurate perceptions of the true production costs and risks associated with these technologies. But, watershed management projects should require careful economic evaluation of alternative technologies prior to their approval.

- Cost effective subsidy programs should be designed and implemented. These programs should be targeted, should minimize rent-seeking behavior and bring the largest number of hectares possible into the program for the budget available. Experience suggests subsidy programs should focus more on improved vegetative and agro-forestry management practices and less on structural projects. The design of least cost subsidy mechanisms discussed in this paper should be considered for use on an experimental basis.

- The true cost and returns information regarding technologies which are transferred from experimental projects to the field will not be known until implemented. Hence, occasionally, it is anticipated that new technologies will not be economically feasible once the subsidy is terminated. Every effort must be made to minimize these experiences by using linear programming and/or spreadsheet models to evaluate proposed technologies.

- Greater efforts should be made to search for opportunities to create local institutions that can enhance the economic well-being of local growers and improve environmental quality. Extension efforts in this area could have a high rate of return.

Although the relationship between changing management practices in upland watersheds and reducing damages in downstream areas in tropical areas has not been shown to be sufficiently strong at this time to provide justification for most watershed projects, future research may strengthen this relationship. Moreover, increased economic development may increase the demand for reduced sediment loads downstream and hence increase the benefits from changing management practices.

Colonization and production on fragile land in upland watersheds is likely to continue for some time in Latin America, and the prospects for the development of more profitable and sustainable technologies is good. However, upland watershed projects should be viewed in the broader context of the economic development of the country, and as such, should take care not to create permanent distortions through the use of subsidies which impede this development process. Undoubtedly, there will exist cases in the future where increasing employment opportunities in urban areas and subsequent migration from the watershed will result in the most efficient use of resources.

References

Abler, David G. and James S. Shortle. "The Political Economy of Water Quality Protection from Agricultural Chemicals," Northeastern Journal of Agricultural Resource Economics, April 1991. pp.53-60.

Amacher, Gregory S., William F. Hyde, and Mohammed Rafiq. "Local Adoption of New Forestry Technologies: An Example from Pakistan's Northwest Frontier Province," World Development, Vol. 21, No. 3, 1993. pp. 445-453.

Anderson, J.R., and J. Thampapillai. Soil Conservation in Developing Countries: Project and Policy Intervention. Washington, D.C.: World Bank, 1990. PRS8.

Arch, A.M.J. "Farm-Level Studies of Soil Conservation Economics: Models for Quantifying Costs and Benefits of Soil Conservation in Cropping Regions of Australia," Occasional Paper No. 16, La Trobe University, Bundoora, Australia. 1987.

Aylward, B., and E. Barbier. "Valuing Environmental Functions in Developing Countries," Biodiversity and Conservation 1 (1992): 34-50.

Barthold, Thomas A. "Issues in the Design of Environmental Excise Taxes," Journal of Economic Perspectives 8.1 (1994): pp. 133-151.

Baumol W.J., and W.E. Oates. The Theory of Environmental Policy: Cambridge University Press, 1993.

Bergstrom, J.C., Stoll J.R., and A. Randall. "The Impact of Information on Environmental Commodity Valuation Decisions," American Journal of Agricultural Economics 72.3 (Aug. 1990): 614-21.

Bishop, Joshua and Jennifer Allen. The On-Site Costs of Soil Erosion in Mali: World Bank, Policy Planning and Research Staff, Nov. 1989. Environment Working Paper, No. 21.

Board of Agriculture. Soil and Water Quality: An Agenda for Agriculture. Washington, D.C.: National Research Council, National Academy Press, 1993.

Calomiris, Charles W. and Charles P. Himmelberg. "Directed Credit Programs for Agriculture and Industry: Arguments from Theory and Fact," Annual Bank Conference on Development Economics. Washington, D.C.: World Bank, May 1993.

Carlson, G.A., Zilberman, D. and Miranowski J.A. Agricultural and Environmental Resource Economics. New York: Oxford University Press, 1993.

Center for Financial Management. Planetor: An Environmental and Economic Analysis Computer Program, University of Minnesota Cooperative Extension Service, 1994.

Crosson, Pierre. Soil Erosion in Developing Countries: Amounts, Consequences and Policies: Center for Resource Policy Studies, School of Natural Resources, College of Agriculture and Life Sciences, University of Wisconsin, Madison, Nov. 1983. Working Paper No. 21.

de Janvry A., Sadoulet, E. and Santos B. Project Appraisal for Sustainable Rural Development: Notes for IFAD's Operational Guidelines. Prepared for the Inter-American Development Bank, 1993.

de Janvry, Alain and Raul Garcia. Rural Poverty and Environmental Degradation in Latin America: International Fund for Agricultural Development, 5 June 1992. Staff Working Paper 1.

Doolette, J.B. and W.B. Magrath. Watershed Development in Asia: Strategies and Technologies. Washington, D.C.: World Bank, 1990. World Bank Technical Paper, No. 127.

Duda, A.M. and R.J. Johnson. "Cost-effective Targeting of Agricultural Nonpoint-source Pollution Controls," Journal of Soil and Water Conservation Jan.-Feb. 1985, pp. 108-111.

Foster, George R. "Major Development in Prediction of Soil Erosion by Water," in Soil Management for Sustainability by R. Lal and F.J. Pierce (eds.) Soil and Water Conservation soc. Amex, Iowa, USA.

Fudenberg, D. and J. Tirole. Game Theory. Boston: MIT Press, 1992.

Gianessi, L.P. A National Data Base of Nonurban Nonpoint Source Discharges and their Effect on the Nation's Water Quality. Washington, D.C.: Resources for the Future, 1985.

Gould, Brian W., Saupe, William E. and Richard M. Klemme. "Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion," Land Economics, Vol. 65, No. 2, May 1989. pp. 167-182.

Heimlich Ralph E. and Clayton W. Ogg. "Evaluation of Soil-Erosion and Pesticide-Exposure Control Strategies," J. of Environmental Economics and Management 9, 1982. pp. 279-288.

Hueth D.L. and Furtan W.H. Economics of Agricultural Crop Insurance: Theory and Evidence. Boston: Klewer, 1994.

Kaimowitz, D. La Experiencia de Centro America y la Republica Dominicana con Proyectos de Inversion que Buscan Sostenibilidad en las Laderas. Washington, D.C.: Instituto Interamericano de Cooperacion para la Agricultura, 1992.

King, D.A., and J.A. Sinden. "Price Formation in Farm Land Markets," Land Economics 70.1 (Feb. 1994): 38-52.

Lal, Rattan. Soil Erosion in the Tropics: Principles and Management. New York, McGraw Hill. 1990.

Lopez, R. Resource Degradation, Community Controls and Agricultural Productivity in Tropical Areas. Department of Agricultural and Resource Economics, University of Maryland, Sept. 1993.

Magrath, W.B., and P. Arens. The Cost of Soil Erosion in Java: A National Resource Accounting Approach. Washington, D.C.: World Bank, 1989. Environment Department Working Paper No. 18.

Magrath, William B. and John B. Doolette. Strategic Issues for Watershed Development in Asia.: World Bank, Policy Planning and Research Staff, May 1990.

McConnell, K.E. "An Economic Model of Soil Conservation," American Journal of Agricultural Economics 65 (1983): 83-89.

Ostrom, E. Governing the Commons: the Evolution of Institutions for Collective Action. New York: Cambridge University Press, 1990.

Palmquist, R.B., and L.E. Danielson. "A Hedonic Study of the Effects of Erosion Control and Drainage on Farmland Values," American Journal of Agricultural Economics 71 (1989): 55-62.

Pearce, Andrew J. "Erosion and Sedimentation," Paper Prepared for the Workshop on Ecological Principles for Watershed Management. East-West Center Honolulu, 9 Apr. 1986.

Pulley, Robert V. Making the Poor Creditworthy: A Case Study of the Integrated Rural Development Program in India. World Bank Discussion Paper No. 58, 1989.

Ribaudo, Marc O. Water Quality Benefits from the Conservation Reserve Program. USDA/ERS, Feb. 1989. Agricultural Economic Report No. 606.

Setia, Parveen P. and Tim C. Osborn. "Targeting Soil Conservation Incentive Payments," North Central Journal of Agricultural Economics (Jan. 1989): pp. 95-103.

Shortle, J. and J. Dunn. "The Relative Efficiency of Agricultural Source Water Pollution Control Policies," American Journal of Agricultural Economics 68.3 (1986): 668-677.

Southgate, D. and R. Macke. "The Downstream Benefits of Soil Conservation in Third World Hydroelectric Watersheds," Land Economics 65.1 (1989): 38-48.

Southgate, Douglas. The Economics of Land Degradation in the Third World. World Bank, Policy Planning and Research Staff, May 1988.

Veloz, A., Southgate D., F. Hitzhusen, et al. "The Economics of Erosion Control in a Sub-Tropical Watershed: A Dominican Case," Land Economics 61.2 (1985): 145-155.

Walker, D.J. and D.L. Young. "The Effect of Technical Progress on Erosion Damage and Economic Incentives for Soil Conservation," Land Economics 62.1 (1986): 83-93.

Walker, David J. "A Damage Function to Evaluate Erosion Control Economics," American Journal of Agricultural Economics (Nov. 1982): pp. 690-698.

Appendix

The purposes of this appendix is to present the derivation of the marginal benefit function found in Figure 2 of the text, and to establish the result that subsidies for adoption of improved watershed management practices can lead to increased total damages in the watershed when entry is possible.

Let total environmental damages in the watershed be given by $\mathbf{D = D(r)}$ where $\mathbf{r}$ is the total runoff in the watershed. It is presumed that $\mathbf{\partial D/\partial r = D' > 0}$ **and** $\mathbf{\partial D^2/r^2 = D'' > 0}$. That is, total damage is increasing at an increasing rate in runoff. Figure A.1 presents a typical damage function.

Assume that there are two technologies available for agricultural production in the watershed, a conventional technology and an alternative technology. Assume also that the new technology produces runoff at a constant rate a_1 per hectare, that the conventional technology produces runoff at a rate a_0 per hectare and that $\mathbf{a_1 < a_0}$. Total runoff in the watershed is then give by $\mathbf{r = a_0H_0 + a_1H_1}$, where $\mathbf{H_0}$ and $\mathbf{H_1}$ are the total hectares under production in the watershed under the conventional and new technologies respectively. Suppose there are initially $\mathbf{\bar{H}}$ hectares under production in the watershed. Then, $\mathbf{\bar{H} = H_0 + H_1}$, $\mathbf{r = a_0(\bar{H} - H_1) + a_1H_1}$ and by substitution total damages as a function of hectares in the alternative technology are given by:

(1) $$\mathbf{D = D(r) = D(a_0(\bar{H} - H_1) + a_1H_1)}.$$

The marginal damages **(MD)** of increasing hectares in the alternative technology (or decreasing hectares in the conventional technology) are given by

(2) $$MD = \frac{\partial D}{\partial H_1} = \frac{\partial D}{\partial r}\frac{\partial r}{\partial H_1} = D'(\alpha_1 - \alpha_0) < 0$$

Total damages are decreasing at a decreasing rate. That is, $\mathbf{\partial D^2/H_1^2 = D''(a_1 - a_0)^2 > 0}$. And, the marginal benefits of shifting a hectare to the alternative technology are defined as $\mathbf{MB = - MD}$.

These relationships are shown in figure A.2 for two alternative levels of hectares under cultivation in the watershed $\bar{H}$ and $\hat{H}$ where $\mathbf{\hat{H} > \bar{H}}$. Note that differentiating equation (1) with respect to $\mathbf{\bar{H}}$ obtains $\mathbf{a_0D'}$ which is positive. That is, the total damage function in figure A.1 shifts up with an increase in hectares under cultivation. Also note that differentiating equation (2) with respect to $\mathbf{\bar{H}}$ yields $\mathbf{D''(a_1 - a_0)a_0}$ which is less than zero and thus the marginal benefit function also shifts upward. Total damages associated with a particular level of adoption of the new technology $\mathbf{H_1^*}$ given $\mathbf{\bar{H}}$ hectares under cultivation can be measured directly in figure A.2 by the total damage function $\mathbf{D(H_1^*|\bar{H})}$ or by the distance **0g** - area $\mathbf{0abH_1^*}$, i.e., the amount of damages when all hectares use the conventional technology minus the reduction in damages resulting from shifting $\mathbf{H_1^*}$ hectares into the alternative technology.

We now consider the effect of increasing the subsidy rate s on damages. Suppose there are initially **I** growers in the watershed. Each grower $\mathbf{i \in I}$ will adopt the alternative technology only if $\mathbf{p_1^i - p_0^i > 0}$, where $\mathbf{p_j^i}$ is the profit of the **ith** producer using the **jth** technology and **s** is the level of subsidy offered. Profits here are broadly defined to include off-farm income of family members as well as net returns from farm production activities. Now let $\mathbf{d_i}$ be and indicator variable for adoption. That is, $\mathbf{d_i = 1}$ for producers who have adopted and $\mathbf{d_i = 0}$

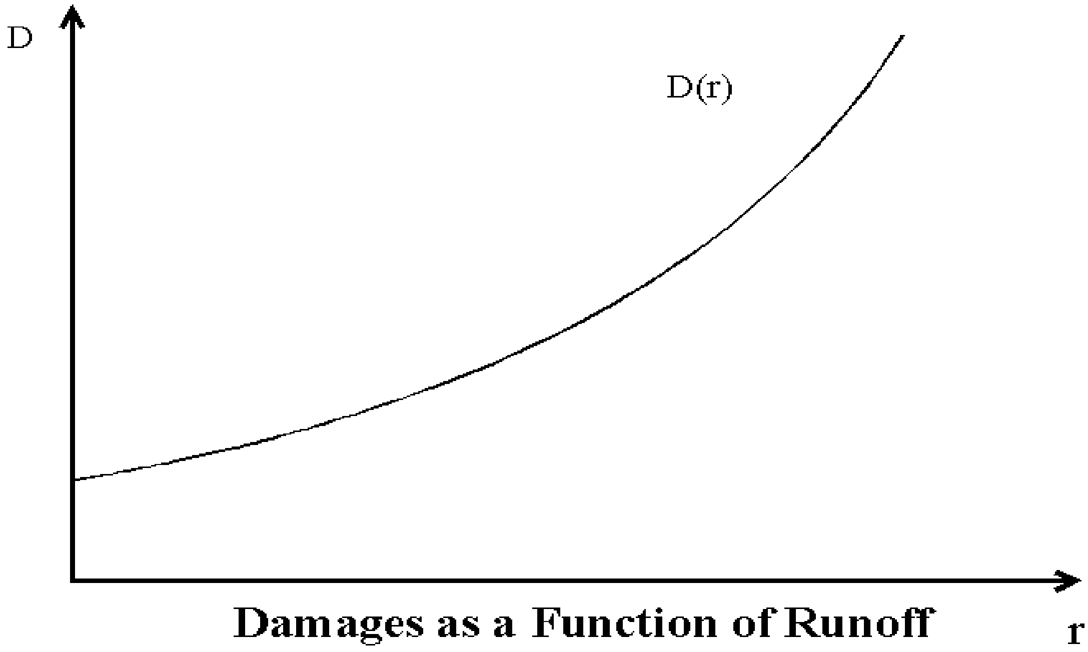
for those who have not. The total number of hectares using the new technology is thus given by $\mathbf{H_1} = \mathbf{j}\ *_i$ under the one hectare per producer assumption. This sum clearly depends on the level of the subsidy s. Let $\mathbf{H_1 = H_1(s)}$ be a differentiable approximation to this relationship.

Suppose also there are **J** potential growers not initially operating in the watershed who have reservation values or opportunity costs of $\mathbf{?_j}$, and let $\mathbf{?_j}$ be an indicator variable associated with these growers. Growers will enter according to $\mathbf{p_1^j + s > ?_j}$ and the number of new entrants will be given by $\mathbf{j}\ ?_j$. Clearly again, this number is increasing in the subsidy level. Let $\mathbf{\bar{H} = \bar{H}(s)}$ be a differentiable function approximating this entry relationship. Then the change in damages with respect to a change in the subsidy is given by:

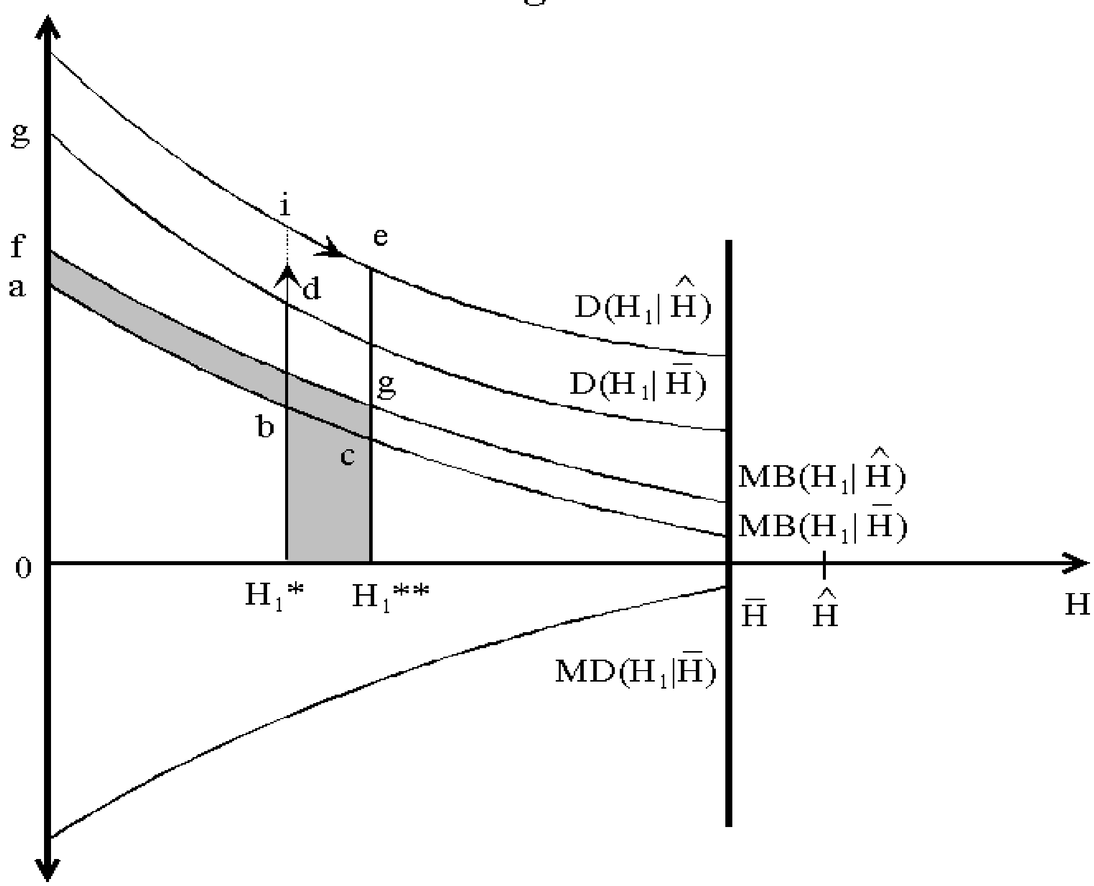
(3) $$\frac{\partial D}{\partial s} = (\alpha_1 - \alpha_0) DN \frac{\partial H_1}{\partial s} + \alpha_0 DN \frac{\partial \bar{H}}{\partial s}$$

which is of indeterminate sign since the first term of the right-hand side of (3) is negative and the second term is positive. That is, since both hectares under the new technology and the total number of hectares under cultivation in the watershed increase with the subsidy, the effect on total damages cannot be determined. It is possible that the additional damages caused by the increase in hectares under cultivation in the watershed more that outweigh the reduced damages occasioned by the increased in adoption of the alternative technology.

This possibility can be seen in figure A.2 where hectares under cultivation are increased from $\mathbf{\bar{H}}$ to $\mathbf{\hat{H}}$ and hectares under cultivation with the new technology is increased from $\mathbf{H_1^*}$ to $\mathbf{H_1^{**}}$. The total reduction in damages resulting from adoption of the alternative technology is given by area $\mathbf{0fgH_1^{**}}$. Initially total damage reduction was area $\mathbf{0abH_1^*}$. Thus, increased entry and increased adoption increases the damage reduction by the shaded area in figure A.2. Total damages, however, are shown to increase from $\mathbf{H_1^*d}$ to $\mathbf{H_1^{**}e}$. The change in damages can be thought of as moving first from **d** to **i,** increasing damages as additional hectares are brought into cultivation, and then a movement from **i** to **e** as damages are reduced through adoption. The net change may be positive or negative.



Damages as a Function of Runoff
Figure A.1



Damages as a Function of Hectares Adopted
Figure A.2