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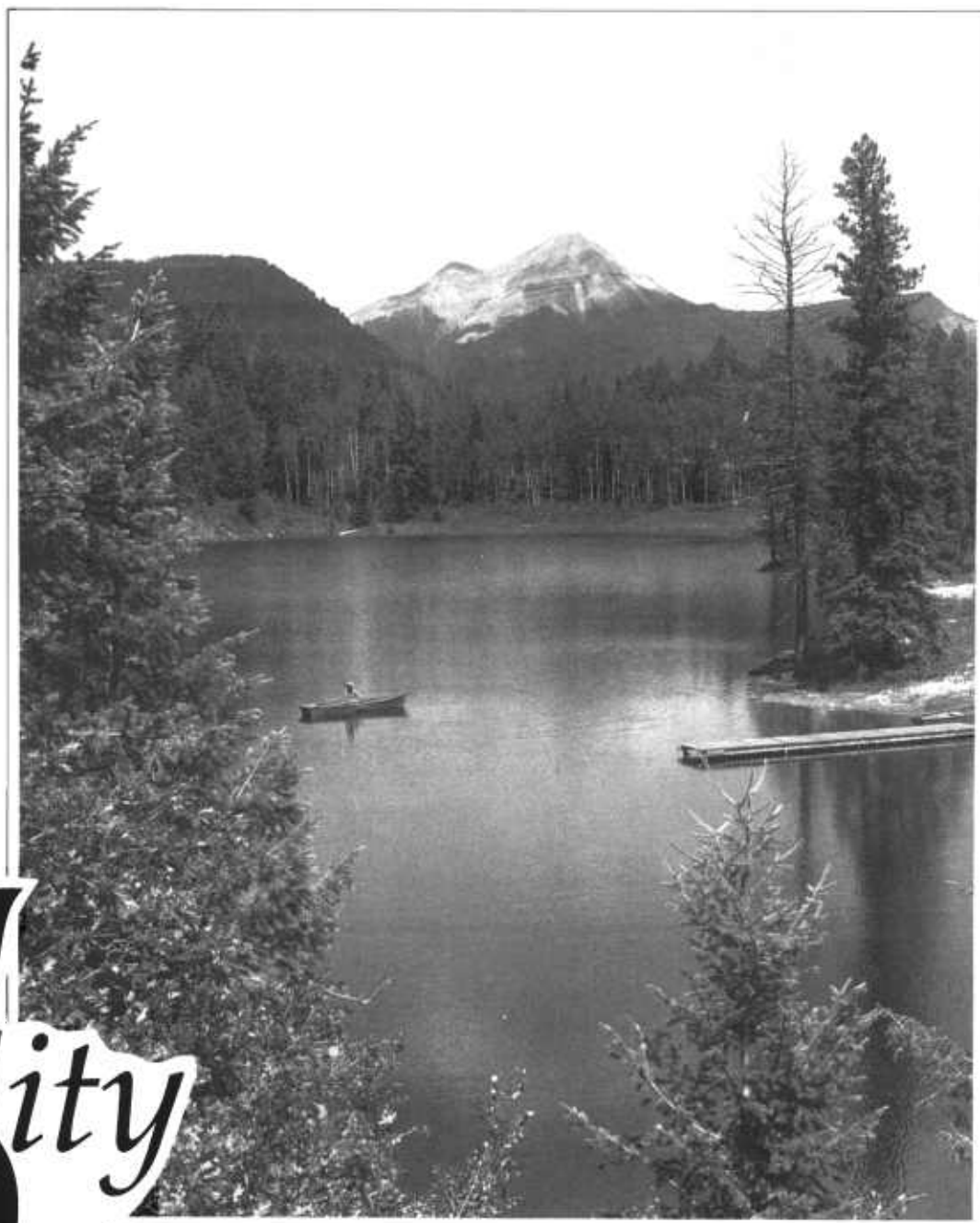
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# Optimal Cost-Sharing Programs To Reduce Agricultural Pollution

Arun S. Malik and Robbin A. Shoemaker



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**Optimal Cost-Sharing Programs To Reduce Agricultural Pollution.** By Arun S. Malik and Robbin A. Shoemaker, Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Technical Bulletin Number 1820.

### **Abstract**

Pollution from agriculture depends on the agricultural practices or technologies farmers use. Policy instruments, such as government cost-sharing programs, can reduce the costs of adopting less-polluting practices. This report examines the problem of designing economically efficient cost-sharing programs. Farmers' decisions to adopt less-polluting technologies are based on the profitability of their farms' existing technology, compared with new technologies. A benchmark solution to the pollution problem serves as a reference against which to compare the optimal cost-sharing policy with imperfect targeting of land. The optimal input subsidy scheme depends on the pollution being managed, costs associated with the participation constraint, and the social cost of public funds.

**Keywords:** cost-sharing, technology adoption, resource quality, technology policy

## Contents

	<i>Page</i>
Summary .....	v
Introduction .....	1
Technology, Land Quality, and Farm Production Behavior .....	2
Profitability and Land Quality .....	3
Real Profits .....	5
Agricultural Pollution Levels Depend on Technology and Chemical Use .....	6
A Benchmark Solution .....	6
Optimal Cost Sharing With Imperfect Targeting .....	8
Land-Use Targeting .....	10
Cost-Sharing Policy .....	11
The Importance of Targeting .....	13
Uniform Subsidy Rate .....	13
Eliminating Land-Use Controls .....	14
Conclusions .....	14
References .....	16
Appendix .....	17

## Summary

Pollution from agriculture depends on the agricultural practices or technologies farmers use. For example, the use of agricultural chemicals may harm ground water if more chemicals are used than are necessary for plant growth or maintenance. Agricultural practices can be employed that provide a more accurate account of nutrient and pesticide requirements and ensure against excessive applications of agricultural chemicals. Policy instruments, such as government cost-sharing programs, can reduce the costs of adopting less-polluting practices. This report provides a technical examination of the issues surrounding the design of economically efficient cost-sharing programs.

We develop a model of technology adoption in which farmers' adoption decisions are based on the relative profitability of their farms' existing technology and a new, less-polluting technology. Profitability of each technology depends on land quality, which varies over the farm. A benchmark solution to the pollution problem serves as a reference against which to compare the optimal cost-sharing policy with imperfect targeting of land. Policymakers must determine the optimal subsidy rates to encourage enough producers to voluntarily adopt less-polluting practices to achieve the goal of reduced agricultural pollution.

Several conclusions can be drawn from our analysis. First, the optimal input subsidy scheme depends on the nature of the pollution being managed. In some cases, it might be optimal to subsidize just one input, whereas in others it might be optimal to subsidize several. For example, cost sharing the investment in a manure waste pit and the use of manure-nitrogen crediting would encourage the use of two complementary practices. When several inputs are subsidized, efficiency gains can be made by varying subsidy rates across inputs.

Second, optimal cost-sharing programs are the second-best economic incentive for farmers to adopt less-polluting agricultural practices. The best economic incentive is a tax on the polluting input that varies with technology and land quality. For example, policymakers may elect to tax the use of nitrogen fertilizers or certain pesticides that are used on soils highly vulnerable to chemical leaching. A cost-sharing program cannot duplicate the incentives provided by such a tax. Regardless of the inputs subsidized, cost sharing imposes costs on the public because it requires the use of public funds. The overall economic viability of such a program is determined by weighing the costs of these public expenditures against the benefits the public receives in reduced agricultural pollution.

Third, the ability to target land eligible for cost sharing, via land-use controls, and identifying the most environmentally vulnerable land helps to moderate the welfare costs of cost-sharing programs. For example, restricting the lowest quality land allowed in production counters the incentive to bring previously idle land into cultivation because of lower input costs. Similarly, specifying the quality of land at which farmers switch from the old technology to the less-polluting technology enables policymakers to extend or contract use of the less-polluting technology relative to the producer's profit-maximizing choice.

# Optimal Cost-Sharing Programs To Reduce Agricultural Pollution

Arun S. Malik  
Robbin A. Shoemaker

## Introduction

Nonpoint source water pollution, of which agriculture is among the major contributors, is now considered a principal cause of impaired water quality (U.S. Environmental Protection Agency). Surface and ground waters may be contaminated by agricultural chemicals, such as fertilizers and pesticides, that leach into aquifers or are carried by runoff into water bodies. Surface water is also impaired when agricultural practices increase soil erosion. Several trends have elevated the severity of water pollution from agriculture over the past few decades. Between 1964 and 1982, the use of nitrogen and phosphate fertilizers nearly doubled (USDA, 1992), while pesticide use more than doubled (Osteen and Szmedra). There have also been increases in concentrated livestock, dairy, and poultry operations, and in the quantity of irrigated farmland.

The level of pollution from agricultural activity depends in part on the agricultural practices or technologies used. Soil erosion can be controlled by using alternative tillage practices. Pollution due to agricultural chemicals can be reduced by modifying the manner in which the chemicals are applied or by adopting less chemical-intensive practices.

A variety of regulatory instruments may encourage use of less-polluting practices. For example, a per-acre tax could be imposed on environmentally harmful practices, a tax could be levied on chemical inputs, or harmful practices or chemicals could be banned. Although some chemical bans have been imposed, regulatory approaches to reducing agricultural pollution have generally been shunned. Emphasis has been placed instead on voluntary means of inducing adoption, such as education and technical assistance programs. These have been supplemented by cost-sharing programs, such as the Agricultural Conservation Program (ACP). Under these programs, a State or Federal agency offers to defray some or all of the costs associated with less-polluting practices. While the ACP has always provided aid to farmers for land improvements, the program has more recently eased the financial burden of meeting the conservation compliance provision of the 1985 farm legislation.<sup>1</sup> States have also begun to use cost-sharing programs to promote adoption of practices that reduce pollution of surface and ground waters in vulnerable areas. The 1990 farm legislation expanded the ACP to emphasize the promotion of water quality-enhancing practices at the Federal level through the Agricultural Water Quality Protection Program (USDA, 1991). Under these State and Federal programs, farmers are free to choose whether to adopt the cost-shared practices based on their relative benefits and costs.

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<sup>1</sup> This provision required farmers to use practices approved by the Soil Conservation Service in order to receive benefits such as deficiency payments.

This report examines the problem of designing economically efficient cost-sharing programs.<sup>2</sup> Although these programs resemble the pollution subsidy schemes discussed in the literature, they differ in some important respects.<sup>3</sup> The typical pollution subsidy provides firms a per-unit payment for reducing pollution below its current level. As emphasized in the literature, this scheme assumes the current or benchmark level of pollution can be properly established (Kamien and others), and that pollution can be readily measured. Although this is generally true for point sources of pollution, it is not true for nonpoint sources, such as agricultural activity (Shortle and Dunn). At best, pollution generated by agricultural activity can be estimated using physical process models. These models use information on agricultural practices, together with information on geologic, hydrologic, and meteorologic variables to generate estimates of pollution loadings into ground or surface waters (DeCoursey). Given the costs of developing and using these models, typical subsidy schemes are ill suited for controlling agricultural pollution.

Physical process models play a more limited role in cost-sharing programs. They may be used to determine the scale and nature of the program, in terms of the practices that need to be adopted and the acreage that needs to be targeted to achieve some pollution goal. But implementation of the programs centers on promoting adoption of the appropriate practices. In this paper, a dichotomous model of technology adoption is developed along the lines of Caswell and Zilberman. Farmers' adoption decisions are based on the relative profitability of their farms' existing technology and a new, less-polluting one. Profitability of each technology depends on land quality, which varies over the farm. The regulator's problem is to determine the optimal subsidy rates that induce a level of adoption sufficient to achieve some exogenous pollution goal. Given the voluntary nature of cost-sharing programs, a participation constraint is included in the regulator's problem to ensure that the farmer finds it profitable to participate in the program and adopt the less-polluting technology on the requisite acreage.

## Technology, Land Quality, and Farm Production Behavior

Two technologies are represented by the per-acre production functions  $f^i(x^i; a)$ ,  $i = A, B$ , where  $x^i$  is a vector of inputs and  $a$  is the quality of the particular acre of land. Both production functions are increasing and strictly concave in  $x^i$  and  $a$ . Without loss of generality, land quality is restricted to take on values between zero and one,  $a \in [0, 1]$ . Distribution of land quality over the entire farm is given by the density function  $g(a)$ . For analytical convenience, lowest quality land is assumed to be unproductive:  $f^i(x^i; 0) = 0$ ,  $i = A, B$ .

The farm employs three types of inputs: a chemical input  $x_1$ , a nonpolluting variable input  $x_2^i$ , and a fixed capital input  $x_3^i$ . For both technologies, the variable inputs  $x_1$  and  $x_2^i$  are assumed to be gross substitutes. As the superscript on  $x_2^i$  and  $x_3^i$  suggests, nonpolluting and fixed inputs need not be the same for the two technologies.<sup>4</sup> To simplify notation later on, the units of the fixed inputs are chosen so that  $x_3^i = 1$

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<sup>2</sup> Previous work on cost-sharing programs has been primarily empirical and positive in nature, examining the determinants of adoption of alternative agricultural practices. See, for example, Lichtenberg, Strand, and Lessley and the references cited therein. Madariaga discusses some of the drawbacks of existing cost-sharing programs from a normative perspective.

<sup>3</sup> The literature on pollution subsidies includes work by Kamien and others, Porter, and Polinsky.

<sup>4</sup> For instance, the fixed inputs could represent different irrigation technologies, such as center pivot sprinklers versus gated pipes (see Negri and Hanchar).



( $i = A, B$ ), thus  $x^i = \{x_1, x_2, 1\}$ . The inputs have market prices  $w^i = \{w_1, w_2, w_3\}$ . In the presence of input subsidies (or taxes), the costs faced by the producer  $c^i = \{c_1^i, c_2^i, c_3^i\}$  differ from the market prices:  $c_j^i \neq w_j^i$ . With the exception of the benchmark problem, only the new, less-polluting technology B is subsidized.

### Profitability and Land Quality

For a given technology, the producer's profit-maximization problem for each unit of land is:

$$\max_{x_1, x_2^i} p f^i(x^i; a) - c^i x^i. \quad (1)$$

Let  $\pi^i(p, c^i; a)$  denote the profit function defined by equation 1 and let  $\hat{x}_j^i = \hat{x}_j^i(p, c^i; a)$ ,  $j = 1, 2$ , denote the variable input demands. We assume the demands are such that own-price effects dominate the cross-price effect:

$$\frac{\partial \hat{x}_j^i}{\partial c_j^i} > \frac{\partial \hat{x}_j^i}{\partial c_k^i}, \quad j = 1, 2, \quad j \neq k, \quad i = A, B, \quad \forall a. \quad (2)$$

We also assume that demand for the chemical input is decreasing in land quality, that is,  $\partial \hat{x}_1^i / \partial a < 0$ .

For both technologies, profits are increasing in land quality, that is,  $\pi_a^i = p f_a^i > 0$ . We assume the existing technology ( $i = A$ ) is consistently more profitable than the new one ( $i = B$ ) in the absence of cost sharing,  $c^i \equiv w^i$ :

$$\pi^A(p, w^A; a) > \pi^B(p, w^B; a), \quad \forall a. \quad (3)$$

At the other extreme, with full cost sharing,  $c^B \equiv 0$ , the new technology is consistently more profitable:  $\pi^A(p, w^A; a) < \pi^B(p, 0; a)$ ,  $\forall a$ .

For some intermediate levels of cost sharing, the new technology is assumed to be more profitable on low-quality land than it is on higher quality land. Let  $C^B$  denote the set of values of  $c^B$  for which this is true. Thus, the following relationships hold for  $c^B \in C^B$ :

$$\pi^B(p, c^B; a) \begin{matrix} > \\ < \end{matrix} \pi^A(p, w^A; a) \quad \text{as} \quad a \begin{matrix} < \\ > \end{matrix} a^*, \quad (4)$$

where  $a^* = a^*(p, w^A, c^B)$  is the unique level of land quality at which profits are equal for the two technologies. Accordingly,  $a^*$  is the land quality at which a profit-maximizing producer would choose to switch from technology B to technology A.

The assumption that the less-polluting technology is more profitable on low-quality land is consistent with our earlier assumption that demand for the chemical input is decreasing in land quality. The latter implies more chemicals are applied to low-quality land than to higher quality land. Hence, the policymaker would likely target low-quality land.<sup>5</sup> The policymaker does this by promoting a less-polluting technology that is more profitable on low-quality land.<sup>6</sup> Correspondingly, if demand for the chemical input were increasing in land quality, the policymaker would likely target higher quality land, by promoting a less-polluting technology that is more profitable.<sup>7</sup>

Given  $f^i(x^i; 0) = 0$  and the fixed cost  $c^i$ , profits are negative for some range of land qualities. Let  $a^i = a^i(p, c^i)$  denote the land quality at which the producer breaks even,  $\pi^i = 0$ . Given equation 4, for  $c^B \in C^B$ , this land quality must be lower for the new technology than the existing one:  $a^B < a^A$ . Implicitly differentiating the identity  $\pi^i(p, c^i; a^i) = 0$  we also find:

$$\frac{\partial a^i}{\partial c_j^i} = \frac{\hat{x}_j^i(\bullet; a^i)}{\pi_a^i(\bullet; a^i)} > 0, \quad i = A, B, \quad j = 1, 2, 3. \quad (5)$$

Thus, consistent with intuition, lower quality land is brought into production when input costs fall.

Figure 1 illustrates the relationship between land quality and profits for the two technologies for  $c^B \in C^B$ . Consistent with the assumptions made above, the new technology is relatively more profitable than the old technology on low-quality land. Even with this technology, however, land of lower quality than  $a^B$  is left idle because it yields negative returns. The old technology, on the other hand, is relatively more profitable than the new technology on higher quality land.

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<sup>5</sup> This assumes that higher quality land is not inherently more polluting (for example, has higher leaching potential) than low-quality land. As noted in the section on pollution and technology choice, we assume pollution from agricultural activity does not directly depend on land quality.

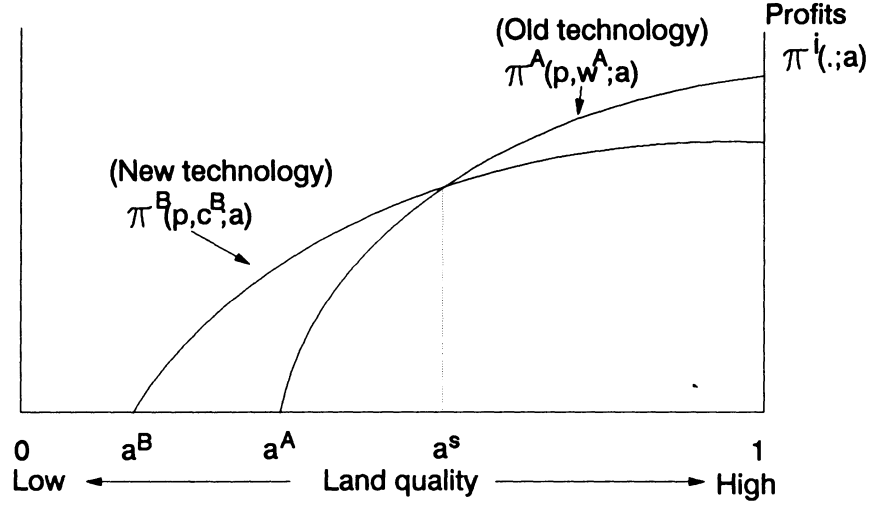
<sup>6</sup> If the less-polluting technology were more profitable on higher quality land, then a cost-sharing program that induced farmers to adopt it on low-quality land would also make it profitable for them to adopt it on higher quality land. Hence, in the absence of controls on the land that could be cultivated with the less-polluting technology, the technology would be adopted over the entire farm.

<sup>7</sup> For a more detailed discussion of these issues, see Caswell and Shoemaker.

Figure 1

**Relationship between land quality and profits**

*In this figure, the new (less-polluting) technology is more profitable than the old technology on low-quality land. Conversely, the old technology is more profitable than the new technology on higher quality land. Land of quality less than  $a^B$  is idled because it yields negative returns.*

**Real Profits**

For later use, it is convenient to define a real profit function  $\tilde{\pi}^i(p, c^i; a)$  that gives profits net of subsidies (or taxes):

$$\tilde{\pi}^i(p, c^i; a) \equiv pf^i(\hat{x}^i; a) - w''\hat{x}^i, \quad (6)$$

where  $\hat{x}^i = \{\hat{x}_1^i, \hat{x}_2^i, 1\}$  is the solution to equation 1. Since the producer equates the effective cost,  $c_j^i$ , of each variable input to the value of its marginal product, the derivatives of the real profit function with respect to the  $c_j^i$  can be written as:

$$\frac{\partial \tilde{\pi}^i}{\partial c_1^i} = [c_1^i - w_1] \frac{\partial \hat{x}_1^i}{\partial c_1^i} + [c_2^i - w_2^B] \frac{\partial \hat{x}_2^i}{\partial c_1^i}, \quad (7)$$

$$\frac{\partial \tilde{\pi}^i}{\partial c_2^i} = [c_1^i - w_1] \frac{\partial \hat{x}_1^i}{\partial c_2^i} + [c_2^i - w_2^B] \frac{\partial \hat{x}_2^i}{\partial c_2^i}, \quad (8)$$

$$\frac{\partial \pi^i}{\partial c_3^i} = 0. \quad (9)$$

As indicated by equation 9, marginal changes in the cost of the fixed input ( $c_3^i$ ) have no effect on real profits since they do not affect input choice. Changes in the costs of the variable inputs do have an effect, however, as indicated by equations 7 and 8.

### Agricultural Pollution Levels Depend on Technology and Chemical Use<sup>8</sup>

The relationship among the level of pollution generated by agricultural activity, the technology employed, and chemical use is captured by the per-acre pollution functions  $z^i(x_1)$ . If the pollution being regulated is soil erosion,  $z^i$  does not depend on  $x_1$ ,  $dz^i/dx_1 = 0$ . If the pollution being regulated is related to chemical use (for example, nitrogen pollution from fertilizer use),  $z^i$  is an increasing function of  $x_1$ ,  $dz^i/dx_1 > 0$ . For simplicity, we assume no pollution is generated from idle land. The less polluting nature of the new technology is captured by the assumption  $z^B(\hat{x}_1^B) < z^A(\hat{x}_1^A)$ ,  $\forall a$  when  $c^i \equiv w^i$  ( $i = A, B$ ); in other words, the new technology generates less pollution than the existing one when the producer faces the market prices of inputs.

### A Benchmark Solution

As a reference against which to compare cost-sharing policies, we first specify and analyze a benchmark problem. The problem is one where policymakers have a complete set of policy instruments at their disposal and can perfectly target each instrument. Policymakers are assumed to be able to *costlessly* dictate: (i) the input prices the producer faces, with the prices varying by technology and land quality, if necessary; and (ii) the type of land that is cultivated and the technology with which this is done.

The first of these two tasks is accomplished by specifying input cost schedules  $c_i^j(a)$ ,  $i = A, B$ . The second is accomplished by prescribing the lowest quality land allowed in production,  $a_m$ , together with the specific land quality at which producers switch from using technology B to technology A.<sup>9</sup> This land quality is termed the "switching" land quality and is denoted  $\alpha$ . Here,  $a_m$  is the counterpart to  $a^B$ , the lowest quality land the producer would cultivate based on a profit-maximizing objective. Similarly,  $\alpha$  is the counterpart to  $a^A$ , the land quality at which it is most profitable for the producer to switch from technology B to technology A.

The policymakers' objective in choosing the above policy instruments is to maximize aggregate real profits subject to a constraint on total pollution generated:

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<sup>8</sup> For simplicity, we assume pollution does not directly depend on land quality. Results presented below are unchanged if pollution is a decreasing function of land quality. If pollution is an increasing function of land quality, results could change. See the following footnote.

<sup>9</sup> Given our assumptions, it is always optimal to cultivate the highest quality land. Therefore, we do not include as a decision variable the highest quality land allowed in production. If pollution were an increasing function of land quality, such a variable would be needed.

$$\max_{a_m, \alpha, c_j^i(a)} \int_{a_m}^{\alpha} \tilde{\pi}^B(p, c^B; a) g(a) da + \int_{\alpha}^1 \tilde{\pi}^A(p, c^A; a) g(a) da \quad (10)$$

subject to:

$$\bar{z} \geq \int_{a_m}^{\alpha} z^B(\hat{x}_1^B) g(a) da + \int_{\alpha}^1 z^A(\hat{x}_1^A) g(a) da. \quad (11)$$

The two terms in the objective function represent aggregate real profits from land cultivated using technologies B and A, respectively, while the terms in the constraint represent pollution from these two types of land. The solution to the problem differs from the first-best solution only to the extent that the pollution goal is exogenously specified.

Assuming an interior solution, the first-order conditions for the benchmark problem are:

$$\tilde{\pi}^B(\bullet; a_m) = \mu z^B(\hat{x}_1^B(\bullet; a_m)), \quad (12)$$

$$\tilde{\pi}^B(\bullet; \alpha) - \tilde{\pi}^A(\bullet; \alpha) = \mu [z^B(\hat{x}_1^B(\bullet; \alpha)) - z^A(\hat{x}_1^A(\bullet; \alpha))], \quad (13)$$

and

$$\frac{\partial \tilde{\pi}^i(\bullet; a)}{\partial c_j^i} = \mu \frac{dz^i(\hat{x}_1^i)}{dx_1^i} \frac{\partial \hat{x}_1^i(\bullet; a)}{\partial c_j^i}, \quad i = A, B, \quad j = 1, 2, \quad (14)$$

where  $\mu \geq 0$  is the Lagrange multiplier associated with the pollution constraint. Notice the absence of a condition for  $c_3^i$ . At the margin, the cost of the fixed input does not affect either real profits or the level of pollution.

All three first-order conditions are easily interpreted. Condition 12 implies that low-quality land should be brought into production until real profits from the last unit of land equal the cost of the pollution generated from that land. This differs from the decision rule the producer would employ in the absence of land-use targeting, which would be to bring land into production until gross profits fell to zero.

Condition 13 indicates that  $\alpha$ , the switching land quality, should be chosen so that the difference in real profits for the two technologies is equal to the difference in the cost of the pollution associated with them. In the absence of land-use targeting, the producer would simply set  $\alpha$  equal to  $a^*$ , the land quality at which gross profits are equal for the two technologies.

The last condition, 14, calls for the  $c_j^i$  to be chosen so that, for each land quality, the change in real profits

from increasing input costs is equal to the change in pollution costs. If the pollution being regulated is not a function of chemical use,  $dz^j/dx_1 = 0$ , condition 13 reduces to the requirement that the  $c_1^j$  be chosen so marginal profits are zero. Using equations 7 and 8, we can verify this simply requires setting  $c_1^j(a) = w_1^j$ ,  $\forall a$ . Thus, if there are no externalities associated with variable input use, policymakers do not have to alter input prices; they only have to impose the land-use controls embodied in  $a_m$  and  $\alpha$ .

When the pollution being regulated depends on chemical use,  $dz^j/dx_1 > 0$ , land-use controls alone are insufficient. Using equations 7 and 8, one can verify that now a tax of  $c_1^j(a) - w_1 = \mu dz^j/dx_1$  must be imposed on the chemical input for condition 14 to hold.<sup>10</sup> This is a familiar solution to the externality problem. Note, however, that the tax varies across technologies and land qualities: the magnitude of  $dz^j/dx_1$  depends on the technology employed and on land quality, given the inverse relationship between chemical use and land quality.

### Optimal Cost Sharing With Imperfect Targeting

In terms of practical application, the benchmark problem and its solution are unrealistic. They assume policymakers are able to tax the chemical input and, more important, are able to vary the tax depending on technology and land quality. Not only does this call for considerable political power on the policymakers' part, but it also requires close monitoring of the farm's input use. The benchmark problem further assumes the producer will accept the tax imposed by policymakers, regardless of profitability; the tax is, in effect, assumed to be unavoidable.

A distinguishing and important characteristic of cost-sharing programs is their voluntary nature: farmers need not participate in the programs if they perceive the costs to outweigh the benefits. Another characteristic is that inputs can only be subsidized and not taxed (virtually by definition), and subsidies are typically restricted to inputs used with the alternative, less-polluting technology. Furthermore, the subsidies can vary with land quality only to the extent that subsidies can be targeted for production on some subset of the farm's land. In terms of the benchmark problem, this form of targeting is equivalent to dictating the land on which technology B is used by specifying  $a_m$  and  $\alpha$ . Further tailoring the subsidies to depend on the quality of land in production is impractical, given the close monitoring it would require of input use by land quality.

In this section, we examine the design of an optimal cost-sharing program, given the above institutional and technical constraints. Policymakers now have a restricted range of policy instruments at their disposal and can target the instruments imperfectly at best. In particular, policymakers can now employ only subsidies and not taxes, and can subsidize only inputs used with the new technology. Although the unit subsidies must be constant for all land cultivated with the new technology, the subsidies are allowed to vary across inputs. Policymakers are still allowed to determine the land cultivated with the new technology by specifying  $\alpha$  and  $a_m$ . Existing cost-sharing programs frequently do target the land on which alternative practices are cost-shared. The policymaker's objective is to maximize some measure of net social benefits. These now consist of the real profits from production minus the opportunity cost of providing subsidies. The maximization is carried out subject to pollution constraint 11, and a constraint that ensures that the farmer finds it profitable to participate in the cost-sharing program.

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<sup>10</sup> For both  $x_1$  and  $x_2$ , condition 14 then reduces to  $c_1^j - w_1 = \mu(dz^j/dx_1^j)$ . A subsidy to the nonpolluting input is not required because it does not enter the pollution functions  $z^j$ .

Formally, the policymaker's problem is to:

$$\begin{aligned} \max_{a_m, \alpha, c_j^B} & \left[ \int_{a_m}^{\alpha} \bar{\pi}^B(p, c^B; a) g(a) da + \int_{\alpha}^1 \pi^A(p, w^A; a) g(a) da \right] \\ & - \beta \int_{a_m}^{\alpha} [\pi^B(p, c^B; a) - \bar{\pi}^B(p, c^B; a)] g(a) da \end{aligned} \quad (15)$$

subject to condition 11 and:

$$\int_{a_m}^{\alpha} \pi^B(p, c^B; a) g(a) da \geq \int_{a^A}^{\alpha} \pi^A(p, w^A; a) g(a) da, \quad (16)$$

$$w_j^B \geq c_j^B \geq 0, \quad j = 1, 2, 3. \quad (17)$$

Since only technology B inputs are subsidized, the first term in equation 15 represents the farm's aggregate real profits. The second term represents the social costs of raising cost-share funds. The parameter  $\beta$  is the marginal social cost of public funds.<sup>11</sup> It is multiplied by total subsidy payments, which are given by the difference between gross and real profits for technology B.

Equation 16 is the participation constraint, which ensures that the producer finds it profitable to take part in the cost-sharing program. The left-hand side (LHS) gives the aggregate profits from land cultivated with technology B under the cost-sharing program, while the right-hand side (RHS) gives the profits forgone by participating in the program. In general,  $a_m \neq a^A$ ; thus the total amount of land under cultivation will differ for the two scenarios. The last set of constraints, 17, ensures that inputs are subsidized and not taxed ( $w_j^B \geq c_j^B$ ), and that the subsidies do not become positive inducements to use inputs ( $c_j^B \geq 0$ ).

Letting  $\mu \geq 0$ ,  $\lambda \geq 0$ , and  $\gamma_j \geq 0$  denote the Lagrange multipliers for constraints 11, 16, and 17, respectively, the first-order conditions for the policymaker's problem can be written as:

$$\bar{\pi}^B(\cdot; a_m) + \lambda \pi^B(\cdot; a_m) + \beta [\bar{\pi}^B(\cdot; a_m) - \pi^B(\cdot; a_m)] = \mu z^B(\hat{x}_1^B(\cdot; a_m)), \quad (18)$$

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<sup>11</sup> Because public funds are raised using distorting taxes, the social opportunity cost of \$1 of government spending is greater than \$1. Estimates suggest that the marginal social cost of public funds ( $\beta$ ) is likely to be between \$1.20 and \$1.50. For a discussion of the importance of these opportunity costs in the context of farm programs, see Alston and Hurd (1990).

$$[\bar{\pi}^B(\bullet; \alpha) - \pi^A(\bullet; \alpha)] + \lambda [\pi^B(\bullet; \alpha) - \pi^A(\bullet; \alpha)] \quad (19)$$

$$+ \beta [\bar{\pi}^B(\bullet; \alpha) - \pi^B(\bullet; \alpha)] = \mu [z^B(\hat{x}_1^B(\bullet; \alpha)) - z^A(\hat{x}_1^A(\bullet; \alpha))],$$

$$(1 + \beta) \int_{a_m}^{\alpha} \frac{\partial \bar{\pi}^B}{\partial c_j^B} g(a) da - \mu \int_{a_m}^{\alpha} \frac{dz^B}{dx_1^B} \frac{\partial \hat{x}_1^B}{\partial c_j^B} g(a) da \quad (20)$$

$$- (\lambda - \beta) \int_{a_m}^{\alpha} \hat{x}_j^B g(a) da - \gamma_j \leq 0, \quad i = A, B, \quad j = 1, 2,$$

$$- (\lambda - \beta) \int_{a_m}^{\alpha} g(a) da - \gamma_3 \leq 0, \quad i = A, B; \quad (21)$$

along with the complementary slackness conditions:

$$\gamma_j (w_j^B - c_j^B) = 0, \quad c_j^B \left( \frac{\partial \mathcal{L}}{\partial c_j^B} \right) = 0, \quad j = 1, 2, 3, \quad (22)$$

where  $\mathcal{L}$  denotes the Lagrangian for the policymaker's problem.

### Land-Use Targeting

The condition for  $a_m$  in equation 18 is similar in form to that for the benchmark problem equation 12, except that the LHS expression for the social gains from cultivating an additional unit of land has extra terms. As before, cultivating more land (that is, lowering  $a_m$ ) yields direct social benefits (the first term on the LHS). But it now also yields indirect benefits by increasing farm profits under cost sharing, thereby reducing the stringency of the participation constraint (the second term). It also directly imposes costs now by increasing the socially costly subsidy payments that policymakers must make (the third term).

We can establish the following proposition from equation 18:

**Proposition 1.** *Under an optimal cost-sharing policy, the minimum land quality control is binding,  $a_m > a^B$ : in the absence of the control, the producer would bring more land into production than is socially optimal.*

This result underscores the need for land-use targeting. In the absence of the control  $a_m$ , not only would more land be cultivated than is socially optimal, but more land would be cultivated than in the absence of the cost-sharing program. From equation 5, we know lower quality land is brought into production as costs fall. Since the cost-sharing program lowers input costs for technology B, it would induce the producer to cultivate land that was previously left idle,  $a^B(p, c^B) < a^B(p, w^B)$ .



The condition for the optimal value of  $\alpha$  in equation 19 differs from the corresponding benchmark condition 13 in a similar manner. As before, the RHS of equation 19 gives the difference in the cost of pollution generated by the two technologies, and the first term on the LHS gives the difference in real profits. The second term on the LHS gives the effect of increasing  $\alpha$  on the stringency of the participation constraint. The last term captures the higher subsidy costs associated with increasing  $\alpha$  and the land devoted to technology B. Because technology B is less polluting than technology A, we would expect  $\alpha$  to be greater than  $a^*$  at an optimum. In other words, we would expect the socially optimal land quality at which the farm should switch from technology B to technology A ( $\alpha$ ) to be higher than the profit-maximizing land quality ( $a^*$ ). As the following proposition reveals, this is true in some cases:

**Proposition 2.** *If  $a_m < a^*$  and the participation constraint is binding ( $\lambda > 0$ ), the socially optimal switching land quality is higher than the profit-maximizing one:  $\alpha > a^*$ .*

If  $a_m < a^*$ , the producer will earn higher profits under the cost-sharing program than in its absence if  $\alpha$  were smaller than  $a^*$ . But then the participation constraint would not be binding. (As shown below, it is almost always binding.) Therefore,  $\alpha$  must be greater than  $a^*$ . On the other hand, if  $a_m > a^*$ , policymakers may need to set  $\alpha \leq a^*$  to compensate the farm for the profits it forgoes on land of quality  $[a^*, a_m]$  when the farm participates in the program.

### Cost-Sharing Policy

To determine the structure of the optimal cost-sharing policy, it is instructive to first examine the case where the pollution being regulated is not a function of chemical use and then examine the case where it is. For the first case, the benchmark solution calls for policymakers to impose the land-use controls embodied in  $\alpha$  and  $a_m$ . No subsidies or taxes are needed. This solution is infeasible under a cost-sharing program since the farm must be given an incentive to participate in the program. Given equation 3, the farm will adopt technology B only if it is subsidized. The relevant question now is: what inputs should be subsidized? As the following proposition indicates, the answer depends on the stringency of the participation constraint.

**Proposition 3.** *When the pollution being controlled is not a function of chemical use, the optimal cost-sharing policy has the following structure:*

- (i) *If  $\lambda = \beta$  (that is, if the shadow cost of the participation constraint is equal to the marginal social cost of funds), only the fixed input is subsidized:  $c_j^B = w_j^B, j = 1, 2; 0 \leq c_3^B < w_3^B$ .*
- (ii) *If  $\lambda > \beta$ , the fixed input is fully subsidized, and both variable inputs are at least partially subsidized:  $0 \leq c_j^B < w_j^B, j = 1, 2; c_3^B = 0$ .*

Note the possibility of  $\lambda$  being smaller than  $\beta$  is omitted. As shown in the appendix,  $\lambda < \beta$  cannot hold when pollution is independent of chemical use. Because subsidies do not yield any social benefits in this case (other than securing participation), the marginal social cost of funds ( $\beta$ ) is a lower bound on the shadow cost of the participation constraint ( $\lambda$ ).

Proposition 3 can be easily explained. Subsidies are provided only to ensure the farm's participation in the cost-sharing program. If the participation constraint is not very stringent ( $\lambda = \beta$ ), policymakers minimize social costs by only subsidizing the fixed input. This is equivalent to providing a lump-sum subsidy. The only social costs incurred are those associated with raising cost-share funds. The firm's input choices are not distorted since it continues to face the market prices for its variable inputs.

If the participation constraint is sufficiently stringent ( $\lambda > \beta$ ), the variable inputs also have to be

subsidized to secure the farm's participation. But policymakers would first subsidize the fixed input fully, and only then subsidize the variable inputs. By subsidizing both variable inputs, rather than giving a larger subsidy to just one input, the aggregate distortion in the firm's input choices is minimized.

The rate at which the variable inputs are subsidized follows an inverse elasticity rule similar to that for an optimal commodity tax (Atkinson and Stiglitz). Let:

$$\epsilon_{jk} = \frac{\frac{\partial \int_{a_n}^{\alpha} \hat{x}_j^B g(a) da}{\partial c_k^B}}{\frac{\int_{a_n}^{\alpha} \hat{x}_j^B g(a) da}{c_k^B}}, \quad j, k = 1, 2, \quad (23)$$

denote the price elasticity of total demand for the  $j^{\text{th}}$  input used with technology B. Then, using equations 7 and 8, the first-order conditions for the variable input costs can be arranged to give:

$$\frac{(c_1^B - w_1)/c_1^B}{(c_2^B - w_2^B)/c_2^B} = \frac{\epsilon_{22} - \epsilon_{12}}{\epsilon_{11} - \epsilon_{21}}. \quad (24)$$

The LHS of this equation represents the ratio of the unit subsidy for each input, expressed as a proportion of input cost. The numerator on the RHS can be interpreted as the aggregate elasticity of input demands with respect to the cost of the nonpolluting input. Similarly, the denominator gives the elasticity with respect to the cost of the chemical input. Thus, equation 24 implies that a proportionally larger subsidy should be given to the input with the lower aggregate price elasticity of demand.

Let us now turn to the case where the pollution being regulated is a function of chemical use. Recall that in this case the benchmark solution calls for policymakers to tax the chemical input, in addition to imposing the land-use controls. Under a cost-sharing program, taxing the chemical input is out of the question since only subsidies can be provided. The issue of interest, once again, is the structure of the optimal cost-sharing scheme. As the following proposition reveals, the structure differs substantially from the optimal scheme when the pollution being regulated is not a function of chemical use.

**Proposition 4.** *When the pollution being regulated is a function of chemical use, the optimal cost-sharing scheme has the following structure:*

- (i) *If  $\lambda < \beta$ , only the nonpolluting input is subsidized:  $c_1^B = w_1$ ,  $0 \leq c_2^B < w_2^B$ ,  $c_3^B = w_3^B$ .*
- (ii) *If  $\lambda = \beta$ , both the nonpolluting and fixed inputs are subsidized, but the chemical input is not:  $c_1^B = w_1$ ,  $0 \leq c_2^B < w_2^B$ ,  $0 \leq c_3^B < w_3^B$ .*
- (iii) *If  $\lambda > \beta$ , the fixed input is fully subsidized, the nonpolluting input is at least partially subsidized, and the chemical input may also be subsidized:  $0 \leq c_1^B \leq w_1$ ,  $0 \leq c_2^B < w_2^B$ ,  $c_3^B = 0$ .*

Unlike in the case where pollution is not a function of chemical use,  $\lambda < \beta$  may hold at an optimum.

Subsidizing the nonpolluting input now yields social benefits because it lowers chemical use. Hence, the (net) social costs associated with providing a subsidy ( $\lambda$ ) may be smaller than the marginal social cost of funds ( $\beta$ ). In fact, the participation constraint may not even be binding ( $\lambda = 0$ ).

As part (i) of the proposition indicates, if the participation constraint is not very stringent,  $\lambda < \beta$ , policymakers simply subsidize the nonpolluting input until the costs of doing so equal the benefits of reduced pollution from chemical use. Subsidizing the fixed input is no longer desirable because there are no direct social benefits from doing so.

If  $\lambda = \beta$ , however, the fixed input is subsidized. This is true even if the nonpolluting input is not fully subsidized because the subsidies to the nonpolluting input are invariably distorting, despite the benefits they yield in terms of reduced chemical use. At some point, the costs of further subsidizing the nonpolluting input outweigh the benefits in terms of reduced chemical use.

If the participation constraint is sufficiently stringent,  $\lambda > \beta$ , policymakers may find it optimal to subsidize the chemical input even though this increases chemical use. In this case, the fixed input would first be fully subsidized, but the nonpolluting input may not be. The added distortion from further subsidizing the nonpolluting input would be balanced against the pollution cost and distortion introduced by subsidizing the chemical input.

## The Importance of Targeting

Although the cost-sharing program examined above employs only imperfect targeting, the degree of targeting assumed is still fairly high. Policymakers are assumed to be able to: (i) vary subsidies across inputs, and (ii) specify the land cultivated using technology B. In this section we briefly consider the consequences of eliminating each of these two forms of targeting.

### Uniform Subsidy Rate

Varying subsidy rates across inputs may be administratively cumbersome. Hence, policymakers may choose simply to defray some fraction of total input costs. Let  $k \in [0,1]$  denote this fraction. The farm then faces unit input costs  $c_j^B = (1-k)w_j^B$ ,  $j = 1,2,3$ . The structure of the policymaker's problem changes to the extent that the three cost variables  $c_j^B$  are replaced by a single variable  $k$ , and the last set of constraints (17) is replaced by the single constraint  $0 \leq k \leq 1$ . Substituting  $(1-k)w_j^B$  for  $c_j^B$  in equations 11, 15, and 16, and assuming an interior solution<sup>12</sup> ( $0 < k < 1$ ), the first-order condition for  $k$  can be written as:

$$\begin{aligned}
 - (1 + \beta) \sum_{j=1}^2 w_j^B \int_{a_n}^a \frac{\partial \pi^B}{\partial c_j^B} g(a) da &+ \mu \int_{a_n}^a \frac{\partial z^B}{\partial x_1^B} \left[ w_1 \frac{\partial x_1^B}{\partial c_1^B} + w_2 \frac{\partial x_1^B}{\partial c_2^B} \right] g(a) da \\
 &+ (\lambda - \beta) \sum_{j=1}^3 w_j^B \int_{a_n}^a x_j^B g(a) da = 0.
 \end{aligned} \tag{25}$$

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<sup>12</sup> Given equation 3,  $k = 0$  cannot be optimal because the participation constraint would not hold;  $k = 1$  can be optimal, but it would imply that full-cost sharing is required.

Substituting from equations 7 and 8, it can be verified that the first term above is negative, given the assumed dominance of own-price effects (equation 2). Similarly, the second term is either negative or zero, depending on whether or not pollution is a function of chemical use. In either case, the third term in equation 25 must be positive, which implies  $\lambda > \beta$  at an optimum (that is, the shadow value of the participation constraint is always higher than the marginal social cost of funds). Thus, with a uniform subsidy rate, a cost-sharing program invariably introduces production distortions. This is not true when subsidies are allowed to vary across inputs, since  $\lambda \leq \beta$  may well hold at an optimum.

### Eliminating Land-Use Controls

We have implicitly assumed that policymakers are able to issue and enforce the land-use controls  $a_m$  and  $\alpha$ . Existing cost-sharing programs frequently do target land on which less-polluting practices should be employed. In principle, these controls could be enforced by making subsidy payments contingent on compliance. In some cases, however, policymakers may be unable to issue land-use controls or effectively enforce them.

The effect of removing land-use controls from the policymaker's set of policy instruments is best illustrated by eliminating  $\alpha$  as one of the decision variables in the policymaker's problem of the previous section. This alters the structure of the problem only to the extent that  $\alpha$  is replaced by  $a^*$ , the land quality at which the producer would choose to switch from technology B to technology A. This change, however, complicates the first-order conditions for the problem considerably. For example, the first-order condition for  $c_3^B$ , the cost of the fixed input, becomes

$$\begin{aligned}
 & -(\lambda - \beta) \int_{a_m}^{a^*} g(a) da + [\bar{\pi}^B(\cdot; a^*) - \pi^A(\cdot; a^*)] g(a^*) \frac{\partial a^*}{\partial c_3^B} \\
 & - \beta [\pi^B(\cdot; a^*) - \bar{\pi}^B(\cdot; a^*)] g(a^*) \frac{\partial a^*}{\partial c_3^B} - \mu [z^B - z^A] g(a^*) \frac{\partial a^*}{\partial c_3^B} - \gamma_3 \leq 0.
 \end{aligned} \tag{26}$$

In choosing  $c_3^B$ , policymakers now take into account its effect on the switching land quality  $a^*$ , and the associated components of benefits and costs. As a result, the simple rules presented in propositions 2 and 3 no longer hold. Specifically, it is no longer true that the fixed input is always fully subsidized when  $\lambda > \beta$ .<sup>13</sup> In effect, removing  $\alpha$  as a policy instrument moves policymakers even further away from a first-best solution.

### Conclusions

Cost-sharing programs have become an important policy instrument for promoting adoption of less-polluting agricultural practices. In this report, we examined the problem of designing cost-sharing programs that maximize a measure of net social benefits while achieving an exogenously specified pollution goal. We found the optimal input subsidy scheme depends on the nature of the pollution being managed,

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<sup>13</sup> As can be verified by differentiating equation 4, when it holds as an equality,  $\partial a^* / \partial c_3^B < 0$ . Hence, the second and third terms in equation 26 are unambiguously positive. Therefore, equation 26 can hold as an equality even when  $\lambda > \beta$ , which implies that a non-zero value of  $c_3^B$  can be optimal.

the relative magnitude of the start value of the participation constraint ( $\lambda$ ), and the social cost of public funds ( $\beta$ ). In some cases, it might be optimal to subsidize just one input, whereas in others it might be optimal to subsidize several. Subsidizing fixed inputs is not always optimal even though it is equivalent to providing a lump-sum transfer.

When several inputs are subsidized, gains can be made by varying subsidy rates; the optimal rates are unlikely to be the same across inputs. In the simple setting where the pollution being regulated is not a function of chemical use, the optimal subsidy rates for the variable inputs follow an inverse elasticity rule similar to that for optimal commodity taxation: a larger subsidy should be given to the input with the lower aggregate price elasticity of demand.

The second-best nature of the optimal cost-sharing policies deserves emphasis. As the solution to the benchmark problem indicates, the first-best economic incentive is a corrective tax on the polluting input that varies with technology and land quality. A cost-sharing program cannot duplicate the incentives provided by such a tax. Regardless of the inputs subsidized, cost sharing imposes welfare costs, given the social opportunity cost of public funds ( $\beta$ ). It imposes additional welfare costs when variable inputs are subsidized by driving a wedge between the market prices of inputs and the prices producers face.

The ability to target land eligible for cost sharing, via the land-use controls  $a_m$  and  $\alpha$ , provides an important means of moderating these welfare costs. Restricting the lowest quality land allowed in production ( $a_m$ ) counters the incentive to bring previously idle land into cultivation because of lower input costs.<sup>14</sup> Similarly, specifying the switching land quality ( $\alpha$ ) enables policymakers to extend or contract use of the less-polluting technology relative to the producer's profit-maximizing choice.

The model we used to obtain these results can be extended or modified in a number of ways. For instance, we assume policymakers maximize some measure of net social benefits. In practice, policymakers may have the narrower objective of minimizing subsidy outlays. This change would not qualitatively affect our results, since minimizing subsidy outlays is closely related to minimizing production distortions. Conversely, we assumed the producer has the narrow objective of maximizing profits. In practice, the producer may attach some value to being "environmentally conscious" and mitigating pollution from agricultural activities. This could be accommodated in the model by adding a positive term to the LHS of the participation constraint, making it less stringent. This would not affect our qualitative results, although it would reduce the shadow cost of the participation constraint.

The effects of other extensions are more difficult to predict. For example, we assumed no uncertainty about the productivity of the new, less-polluting technology. Allowing for such uncertainty, along with risk-averse behavior on the producer's part, would clearly enhance the model's realism. Allowing pollution to depend on land quality, as well as on other land characteristics, would also be valuable. Incorporating commodity programs in the model and analyzing their interaction with cost-sharing programs would allow for a more comprehensive set of conclusions regarding the design of agricultural policy.

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<sup>14</sup> This incentive is conceptually identical to the longrun asymmetry between subsidies and taxes for pollution control: subsidies can induce entries or forestall exits that would not have occurred with the optimal tax. See Madariaga, and Lichtenberg and others.

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## Appendix

**Proof of Proposition 1.** The result can be established by contradiction. Suppose  $a_m \leq a^B$ . Then, because profits are increasing in land quality and some subsidies must be offered for the participation constraint to hold,  $\bar{\pi}^B(\cdot; a_m) < \pi^B(\cdot; a_m) \leq \pi^B(\cdot; a^B) = 0$ . It follows that the first term on the LHS of equation 18 is negative and the second term is nonpositive. The last term on the LHS is negative, since  $\pi^B > \bar{\pi}^B$  in the presence of subsidies. Thus, the LHS of equation 18 has a negative sign. But the equality in equation 18 cannot hold then because the RHS is unambiguously nonnegative.

**Proof of Proposition 2.** From Proposition 1, we know  $a_m > a^B$ , hence the farm makes profits on the lowest quality land allowed in production. Since profits are increasing in land quality, it follows that all land cultivated using technology B yields profits. If  $a_m < a^A$ , then by participating in the cost-sharing program the farm earns additional profits from land of quality  $a \in [a_m, a^A]$ . Now suppose  $\alpha \leq a^A$ . Then, given equation 4, we know  $\pi^B > \pi^A$  for all  $a \in [a^A, \alpha]$ . Thus, the farm's profits are unambiguously higher when it participates in the cost-sharing program. Hence, the participation constraint 16 cannot be binding, which violates the premise that the constraint is binding. (As discussed it is almost always binding.) Hence,  $\alpha > a^A$  must hold when  $a_m < a^A$ .

**Proof of Proposition 3.** Note that the second term in equation 20 vanishes when pollution is not a function of chemical use. (i)  $\lambda = \beta$ . We show, by contradiction, that  $c_j^B = w_j^B$ ,  $j = 1, 2$ , must hold at an optimum. Suppose  $c_1^B < w_1$ , so  $\gamma_1 = 0$ . Then for condition 20 to hold for  $j = 1$ , the first term must be nonpositive. Using equation 7, we can see this requires the nonpolluting input to be subsidized,  $c_2^B < w_2^B$ . Thus,  $\gamma_2$  must equal zero, and for  $j = 2$  the first term in equation 20 also must be nonpositive. Thus, the first term in equation 20 must be nonpositive for both inputs ( $j = 1, 2$ ). It follows that the sum of the first terms must be nonpositive, or, using equations 7 and 8,

$$(c_1^B - w_1) \int_{a_m}^{\alpha} \left[ \frac{\partial x_1^B}{\partial c_1^B} + \frac{\partial x_1^B}{\partial c_2^B} \right] g(a) da + (c_2^B - w_2^B) \int_{a_m}^{\alpha} \left[ \frac{\partial x_2^B}{\partial c_2^B} + \frac{\partial x_2^B}{\partial c_1^B} \right] g(a) da \leq 0. \quad (\text{A-1})$$

But this inequality cannot hold, given the assumption in equation 2 regarding the dominance of own-price effects. Therefore, we can rule out  $c_1^B < w_1$ . An analogous argument can be used to rule out  $c_2^B < w_2^B$ . Hence,  $c_j^B = w_j^B$ ,  $j = 1, 2$ , at an optimum. Now since neither variable input is subsidized, the fixed input must be subsidized (given equation 3, the participation constraint would not hold otherwise). Clearly, condition 21 does hold when  $\gamma_3 = 0$ . (ii)  $\lambda > \beta$ . In this case, condition 21, together with the second complementary slackness condition in 21, imply the fixed input is fully subsidized,  $c_3^B = 0$ . We now show by contradiction that  $c_j^B < w_j^B$ ,  $j = 1, 2$ , must hold at an optimum. Suppose  $c_1^B = w_1$ , so  $\gamma_1 \geq 0$ . Then for equation 20 to hold, its first term must be positive. Using equation 7, we can verify this requires  $c_1^B < w_1$ , contradicting our initial assumption. An analogous argument can be used to rule out  $c_2^B = w_2^B$ . Thus, both variable inputs must be subsidized.

We now show that  $\lambda < \beta$  cannot hold at an optimum. For condition 21 to hold when  $\lambda < \beta$ ,  $\gamma_3$  must be positive. This implies the fixed input is not subsidized. Therefore, one or both of the variable inputs must be subsidized for the participation constraint to hold. Suppose the chemical input is subsidized,  $c_1^B < w_1$ . Then, for  $j = 1$ , equation 20 must hold as an equality with  $\gamma_1 = 0$ . For this to be feasible, the first term in equation 20 must be negative. This implies, using equation 7, that the nonpolluting input must be subsidized,  $c_2^B < w_2^B$ . Thus, for  $j = 2$ , equation 20 must hold as an equality with  $\gamma_2 = 0$ . Once again, for this to be feasible, the first term in equation 20 must be negative, which implies, using equation 8, that the

chemical input is subsidized. Thus, both variable inputs must be subsidized. We would reach the same conclusion if we began by assuming the nonpolluting input was subsidized. Thus, if one of the variable inputs is subsidized, the other one must be too. As noted above, this implies the first term in equation 20 must be negative for both variable inputs. As noted above, however, this is infeasible. Therefore, a solution to the cost-sharing problem does not exist when  $\lambda < \beta$ , hence  $\lambda < \beta$  cannot hold at an optimum.

**Proof of Proposition 4.** (i)  $\lambda < \beta$ . Condition 21, together with the first complementary slackness condition in equation 22, implies  $c_3^B = w_3^B$  at an optimum. Since the fixed input is not subsidized, either the nonpolluting or chemical input must be, otherwise the participation constraint would not hold. We now show by contradiction that the chemical input cannot be subsidized. Suppose  $c_1^B < w_1$ , so  $\gamma_1 = 0$ . Then for equation 20 to hold for  $j = 1$ , its first term must be negative. Once again, from equation 7, this implies the nonpolluting input must be subsidized,  $c_2 < w_2^B$ . Thus, if the chemical input is subsidized, the nonpolluting input must also be. This implies that equation 20 must hold as an equality for both inputs with  $\gamma_j = 0$ . For this to be true, the sum of the first and second terms in equation 20 must be negative for both inputs. This cannot hold, however. From equation A-1 we know the sum of the first terms for the two inputs cannot be negative. Similarly, the sum of the second terms for the two inputs cannot be negative, given condition 2. Thus, equation 20 cannot hold as an equality for both inputs with  $\gamma_j = 0$ . It follows that the chemical input cannot be subsidized. Thus, only the nonpolluting input is subsidized. One can verify that equation 20 can hold when  $\gamma_2 = 0$  and  $c_2^B < w_2^B$ .

(ii)  $\lambda = \beta$ . An argument nearly identical to the one presented in (i) above can be used to rule out  $c_1^B < w_1$ . Thus,  $c_1^B = w_1$  at an optimum. We can now show, again by contradiction, that the nonpolluting input must be subsidized. Suppose  $c_2^B = w_2^B$ , so  $\gamma_2 > 0$ . Then for equation 20 to hold for  $j = 2$ , its first term must be positive. But for this to be true, the nonpolluting input must be subsidized,  $c_2^B < w_2^B$ , contradicting our initial assumption. For the fixed input, condition 21 and the second complementary slackness condition in equation 22 cannot hold when  $\gamma_3 > 0$ , therefore the fixed input must be subsidized.

(iii)  $\lambda > \beta$ . Condition equation 21 and the first complementary slackness condition in equation 22 imply the fixed input is fully subsidized,  $c_3^B = 0$ . As for the nonpolluting input, we can rule out the possibility that it is not subsidized. Suppose  $c_2^B = w_2^B$ , so  $\gamma_2 \geq 0$ . Then for  $j = 2$ , the first term in equation 20 is nonpositive. Since the other two terms in equation 20 are negative, it cannot hold. As for the chemical input, we cannot rule out the possibility that it is not subsidized: for  $j = 1$ , condition equation 20 can hold for any value of  $c_1^B$ . Thus, the chemical input may be subsidized.



## SUMMARY OF REPORT

# Restricting Chemical Use on the Most Vulnerable Cotton Acreage Can Protect Water Quality With Only Minor Effects on Cotton Yields and Prices

Number 6, January 1993

Contact: Stephen R. Crutchfield, (202) 219-0444.

**E**nvironmental damage to surface and ground water posed by cotton farming may be reduced, with only limited effects on yields and prices, if restrictions on agrichemical use or production are applied to just those acres most vulnerable to water-quality problems. The most widespread potential damage is from nitrates in fertilizer that can pollute ground water and pesticides that can contaminate surface water.

Production of cotton appears less likely than other crops to cause erosion-induced water-quality problems because cotton acreage is not the major source of cropland erosion in most regions. Widespread restrictions on the use of chemicals likely to leach, dissolve in cropland runoff, or attach to eroding soils may reduce the risk of water-quality degradation, but may also raise cotton prices by reducing yields. These conclusions flow from USDA's 1989 Cotton Water Quality Survey that gathered data on cotton agricultural chemical use and related production practices and resource conditions in 14 cotton States. Data gathered on the use of fertilizers,

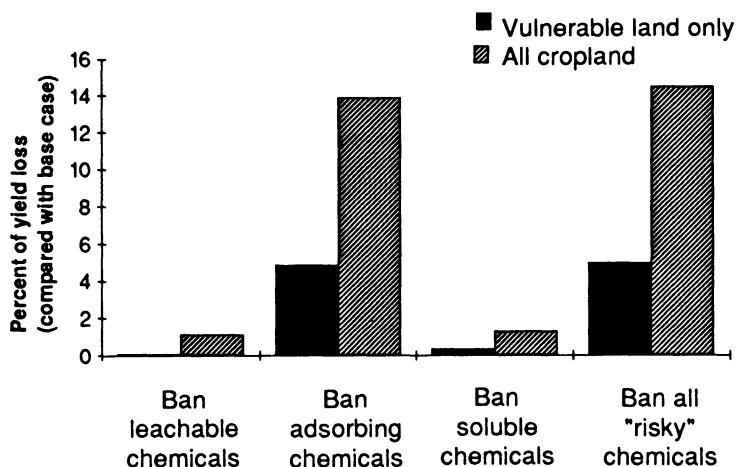
herbicides, insecticides, and other agricultural chemicals were analyzed to assess the potential water-quality problems that may be associated with cotton production.

## Widespread Restrictions Could Raise Cotton Prices

The study's results highlight the importance of targeting pollution-prevention programs to attain the most cost-effective environmental protection strategies. Restricting the use of environmentally damaging chemicals on all cotton acreage could reduce the overall potential for water-quality impairment, but could raise cotton prices by as much as 31 percent. More specific chemical-use restrictions, targeted to acreage considered at greatest water-quality risk, could achieve nearly the same level of environmental protection, but would limit price increases and reduce yield losses. Modifying production practices to reduce soil erosion could generate \$25 million in economic benefits by reducing sedimentation in surface water systems.

### Yield losses from chemical restrictions on cotton acreage

*Yield losses are minimized if chemical restrictions are targeted to only cotton acreage at greatest water-quality risk.*



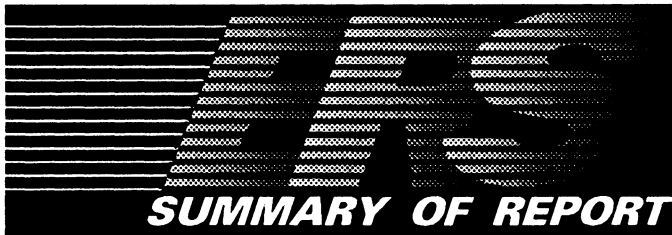
## To Order This Report...

The information presented here is excerpted from *Cotton Production and Water Quality: Economic and Environmental Effects of Pollution Prevention*, AER-664, by Stephen R. Crutchfield, Marc O. Ribaud, LeRoy T. Hansen, and Ricardo Quiroga. The cost is \$8.00.

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U.S. Department of Agriculture  
Economic Research Service

# Surge in Ethanol Production Would Benefit Grain Farmers

Number 19, June 1993

Contact: Robert House (202) 219-0689

**A** major expansion of ethanol production could increase U.S. farm income by as much as \$1 billion (1.4 percent) by 2000, according to the U.S. Department of Agriculture report *Ethanol and Agriculture: Effect of Increased Production on Crop and Livestock Sectors* (AER-667). Because corn is the primary feedstock for ethanol, growers in the Corn Belt would benefit most from improved ethanol technology and heightened demand. Coproducts from the conversion process (corn gluten meal, corn gluten feed, and others) compete with soybean meal, so soybean growers in the South may see revenues decline. The U.S. balance of trade would improve with increased ethanol production as oil import needs decline.

Ethanol production is expected to rise to 1.2 billion gallons per year by 1995 and remain at that level. Ethanol's environmental benefits could lead to increased demand. This analysis looks at consequences for agriculture of two possible demand alternatives: producing 2 billion gallons of ethanol per year by 1995 (a 0.8-billion gallon increase over expected production) and 5 billion gallons by 2000 (a 3.8-billion gallon increase).

Ethanol is an attractive supplement to gasoline for many reasons. Increased ethanol use reduces levels of carbon monoxide and carbon dioxide emissions, and improves energy security by reducing reliance on oil imports, thereby improving the U.S. balance-of-payments account. Increased ethanol production also benefits agriculture. Wider use of ethanol would provide new uses for domestic farm resources, increase grain production, support grain prices, reduce deficiency payments, and increase total farm income. Boosting ethanol production to 5 billion gallons per year would lead to significant increases in farm income, particularly for grain farmers.

**Corn.** Most ethanol is processed from corn, but research aims at economical production of ethanol from biomass crops (energy sorghum, switchgrass, and other energy crops). In the near term, major increases in ethanol output would likely come from expanded corn production. Increased ethanol production will increase corn

demand, leading to more production of and income from corn and other feedgrains. Increased competition for cropland will boost corn and other feedgrain prices if ethanol production is more than doubled. Feedgrain prices will change little if corn production expands on cropland not currently in production. Land idled in 1992 feedgrain acreage reduction programs, for example, could be employed to roughly double ethanol production without significant effects on feedgrain prices.

**Soybeans.** Increasing ethanol production increases the supply of ethanol coproducts--corn gluten feed, corn gluten meal, distillers' dried grains, and corn oil--which compete with soybeans in animal feed and vegetable oil markets. The increased competition exerts downward pressure on soybean meal and oil prices. At the same time, corn competes with other feedgrains and soybeans for land. Expanding ethanol production could lead to reduced soybean production, which would offset some of the price-dampening effects of increased coproduct production.

## To Order This Report...

The information presented here is excerpted from *Ethanol and Agriculture* (AER-667). A companion report, *Emerging Technologies in Ethanol Production* (AIB-663) is also available. Each report costs \$6.00.

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**Livestock.** Farmers feeding livestock will incur higher feed costs due to higher grain prices if ethanol production more than doubles. Increased supplies of coproduct feeds would offset some feedgrain use. Total feed costs would depend on how much prices of grain and coproducts change. A smaller increase (less than double) in ethanol production could mean lower feed costs, if feedgrain prices were unchanged and protein feed (such as soybean meal and ethanol coproducts) prices fell. Feedgrain costs account for about one-quarter of livestock production costs, so changes in feed markets can lead to changes in income from livestock production.

**Regional Effects.** Farmers' individual income prospects depend on their mix of crop and livestock enterprises. In the Corn Belt, Lake States, and Northern Plains, farmers often combine soybean or livestock production with the production of corn or some other grain. Farmers would probably experience a net gain from increased crop production, and farm income is likely to increase. In the South, farmers seldom combine soybeans with corn or other grains, and possess few alternatives as profitable as soybeans. If soybean demand fell, soybean farmers there would probably see a decline in crop revenues.

**Energy Crops.** Farmers may shift to energy crops if technological advances make conversion to ethanol from biomass more economical than from corn. Energy

crops have shown most promise when produced on prime farmland. Increased ethanol production from energy crops grown on such land would compete with conventional crops. Energy crops may be produced on marginal lands with fewer productive alternatives, which could benefit producers in Southern States whose land is less able to compete with grains produced in the Corn Belt and Lake States.

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### Companion Report:

The fuel ethanol industry is poised to adopt a wide range of technologies that would reduce costs at every stage of the production process. Adoption of improved enzymes, fermenter designs, membrane filtration, and other innovations in the next 5 years is expected in new ethanol plants constructed to meet new demand resulting from Clean Air Act stipulations for cleaner burning fuel. A new report, *Emerging Technologies in Ethanol Production*, examines the likelihood of near- and long-term cost reductions in producing ethanol, as well as the potential of biomass (agricultural residues, municipal and yard waste, energy crops like switchgrass) to supplement corn as an ethanol feedstock. (See ordering information in the box on the obverse.)