Instrument Choice and Budget-Constrained Targeting

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Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, CO, August 1-4, 2004.

This work has been funded by the USDA-NRICGP, grant number 2001-35400-10558. The views expressed are those of the authors and cannot be attributed to the Economic Research Service or the U.S. Department of Agriculture. The authors also thank Valerie Mueller for computational assistance.

Abstract

We analyze how choosing to use a particular type of instrument for agri-environmental payments, when these payments are constrained by the regulatory authority's budget, implies an underlying targeting criterion with respect to costs, benefits, participation, and income, and the tradeoffs among these targeting criteria. The results provide insight into current policy debates.

Instrument Choice and Budget-Constrained Targeting

In a series of papers, Babcock et al. (1997) and Wu and Babcock (2001) discuss the economic impacts, including efficiency losses and program participation implications, of designing policy tools to satisfy three forms of targeting rules or criteria: (a) cost targeting, (b) benefit targeting, and (c) cost-benefit targeting. They analyzed these criteria in the context of land use choices – that is, enrolling particular acres of land into a conservation program (e.g., the Conservation Reserve Program) on the basis of the costs and/or benefits of doing so – and found that the distribution of land characteristics (e.g., the variability of and correlation between costs and benefits from land retirement) and also market characteristics (e.g., demand elasticities) affected the efficiency loss associated with targeting on the basis of only costs or only benefits. The implicit assumption throughout was that the instruments being used were unrestricted – that the policy makers had a perfect ability to target on the basis of whatever criterion they preferred.

In a separate but related literature on second-best policy instruments (which focuses more on infra-marginal choices), economists have considered situations in which the regulatory agency seeks to maximize an objective function based on a cost-benefit criterion, but where there are restrictions on the types of instruments being used. A first-best outcome is unattainable when the restrictions result in a smaller number of instruments than the number of policy concerns (Timbergen 1952), so that the externality can only be imperfectly targeted. Rather, policy instruments are considered second-best whenever restrictions are placed upon their design and/or upon the available set of instruments in the regulator's toolbox. Most often the focus has been on the use of uniformly applied instruments in situations where differentiated instruments would be more efficient, and/or instruments that imperfectly target the externality (e.g., incentives based on only a few of the input choices influencing emissions) (e.g., Helfand and House 1995; Larson et al. 1996; Shortle et al. 1998).

The targeting and second-best literatures are related in that the particular choice of instrument and its manner of implementation implicitly defines the type of targeting that can actually be achieved – even if the explicit objective is one of cost-benefit targeting (Horan, Claassen, and Zhang 2003). The reason is that the restrictions that lead to second-best instruments are really just restrictions on a regulator's ability to target, with different types of restrictions implying different types of tradeoffs among the targeting criteria. In turn, the same sorts of factors (e.g., distributions and correlations of costs and benefits across sources) that affect the efficiency of a particular targeting criterion affect the efficiency of the second-best instruments that are consistent with that criterion.

In addition to cost and/or benefit targeting, two other targeting criteria deserve mention: participation targeting and income targeting, as these criteria often play an important role in discussions surrounding actual policy choices, such as agricultural green payment programs like the Environmental Quality Incentives Program (EQIP) or the Conservation Security Program (CSP). Babcock et al. (1997) and Wu and Babcock (2001), in discussing land retirement programs, do not discuss participation targeting separately from cost and/or benefit targeting. This is because, given a perfect ability of the regulatory authority to target individual parcels of land and to pay producers their opportunity cost of enrolling these parcels, cost targeting and benefit targeting are each synonymous with participation – a targeted parcel of land implies participation. Moreover, income targeting is not an issue when land is enrolled at its opportunity cost, as producers earn no rents from the deal (although landowners could earn more rents through increased prices). But what if restrictions did arise that limited the regulatory authority's ability to perfectly price discriminate? In that case, there would be implications for the degree to which the program was targeted in terms of participation and/or income. When the authority's budget is also constrained, then the ensuing tradeoffs could also have implications for targeting costs and benefits.

In this paper, we explore targeting issues given a budget constraint and second-best restrictions on the setting of environmental subsidies. We find that when there are restrictions that limit the regulatory authority's ability to perfectly price discriminate, then there are implications for the degree to which the program can be targeted in terms of participation and/or income. When the authority's budget is also constrained, then the ensuing tradeoffs also have implications for targeting costs and benefits. The analytical results are explored using a numerical model of agricultural nutrient pollution in the corn belt region of the U.S.

A model of pollution and targeting

We begin with a simple analytical model of agricultural pollution to investigate the relation between instrument choice and targeting when policy makers are faced with a budget constraint. For simplicity, we ignore the complexities of price effects for now, although we consider this in the numerical section below. Define $r_i(x_i)$ to be the ith ($i \in \Omega = \{1, \ldots, n\}$) farm's expected emissions (e.g., runoff), which depend on the farm's vector of input choices, x_i. Farm i's costs of reducing mean emissions are given by $c_i(r_i)$, with $c_i' < 0$, $c_i'' > 0$. At the ith producer's level of unregulated mean emissions, r_i^0, emission reduction is zero and, hence, $c_i(r_i^0) = 0$. When emissions are reduced, i.e., when $r_i < r_i^0$, then cost is positive, i.e., $c_i(r_i) > 0$. Suppose each of n farms contributes pollution to a body of water such as a lake. The expected ambient pollution concentration in the lake is given by $a = \sum_{i=1}^{n} \omega_i r_i$, where ω_i is the expected delivery coefficient representing the mean proportion of emissions from farm i that are actually delivered to the lake. Within this framework, marginal pollution control costs are represented by c_i' and the marginal (physical) benefits of pollution control are represented by ω_i.

Following Babcock et al. (1997), a cost-targeted approach to pollution control would account for farm-level differences in c_i' but not in ω_i, a benefit-targeted approach would account for farm-level differences in ω_i but not in c_i', and a cost-benefit-targeted approach would account for farm-level differences in both c_i' and ω_i. The final two targeting concepts are income targeting and participation targeting. Income targeting does not account for farm-level differences in c_i' or ω_i. Rather, the primary goal is a transfer of income to the agricultural sector. Participation targeting, in a broad sense, relates to which producers voluntarily opt into the subsidy program.

Policy design to address a cost-benefit targeted criterion

Economists generally advocate designing pollution control policies to be cost-benefit targeted. Consider a cost-benefit targeting criterion, where subsidies based on reductions in mean emissions are designed to maximize environmental quality, or alternatively, minimize ambient pollution levels subject to a cost constraint. The cost constraint limits cost and, therefore, emission reduction to a level policy makers believe is concomitant with cost. Thus, the cost-constrained problem yields a first-best solution (at least in the context of the minimization problem being considered, but not necessarily from an efficiency perspective) which serves as a base of comparison for the budget constrained models discussed below. Given subsidies of the form, $\max\{s_i(\bar{r}_i - r_i),0\}$, where s_i is the subsidy rate and $\bar{r}_i$ is the baseline from which subsidy payments are evaluated, the minimization problem is written

$$(1) \qquad \underset{s_i,\bar{r}_i}{Min} \quad a = \sum_{i=1}^{n} \omega_i r_i(s_i)$$

subject to

$$(2) \qquad \sum_i c_i(r_i(s_i)) \le T$$

(3) $r_i(s_i) \in \arg\min\{c_i(r_i) - \max\{s_i[\bar{r}_i - r_i],0\}\}$

(4) $$\begin{aligned} &s_i[\bar{r}_i - r_i(s_i)] \geq c_i(r_i(s_i)) \quad \forall i \in \Phi \\ &s_i[\bar{r}_i - r_i(s_i)] < c_i(r_i(s_i)) \quad \forall i \in \Phi^{-1} \end{aligned}$$

where *T* in constraint (2) represents an aggregate cost target, $r_i(s_i)$ is defined in constraint (3) to be the *i*th producer's optimal emissions response to the subsidy rate (i.e., the solution to $-c_i' = s_i$ in the case of a positive subsidy), and Φ is the subset of participating producers with complement Φ^{-1}, i.e., $\Phi \cup \Phi^{-1} = \Omega, \text{and } \Phi \cap \Phi^{-1} = \varnothing.$ Constraint (3) characterizes the producers reaction to the subsidy program and states that the policy maker leverage emission reduction only to the extent that producers respond to the subsidy program. Constraint (4) states that producers will participate only if their subsidy payments exceed their pollution control costs. Implicitly, Φ, is an endogenous response to this choice.

The first-best solution is the set of subsidies at the producer-specific rate $s_i = \omega_i / |\rho|$ (i.e., the imputed value of the marginal impacts of the producer's mean emissions), where ρ<0 is the shadow value of the cost constraint (2). Full participation is optimal so long as $c_i'(r_i^0) = 0$ for all producers and abatement is continuously variable. In other words, the first unit of abatement is always gained at a very low cost. Thus, it is also necessary to set the baseline levels $\bar{r}_i$ large enough to ensure participation by all producers. If $c_i'(0)$ is sufficiently large for each producer, ambient pollution is minimized for a given aggregate cost target *T* if and only if the resulting minimized ambient pollution level is achieved at least cost, i.e., if the condition $\omega_i / [-c_i'^*] = \omega_j / [-c_j'^*]$ $\forall i,j$ holds. The differentiated subsidy rates defined above ensure this condition holds as long as there is full participation.. To ensure full participation, it is generally sufficient (but not necessary) to set $\bar{r}_i = r_i^0$, where r_i^0 is the *i*th producer's level of unregulated mean emissions (i.e., the solution to $c_i' = 0$). In this, the most-often considered case, producers are paid a constant rate for each unit of abatement. This provides them with rents because the subsidy rate equals their equilibrium marginal abatement cost, which is greater than their average abatement cost. These rents are not a problem in the cost-constrained problem because policy makers care only about the cost of abatement, not about government expenditures.

In the first-best solution, differentiated subsidy rates are required to address the externality and differentiated baselines are required for the participation constraint (since participation under this policy is voluntary) (Tinbergen 1952). Moreover, once participation is addressed, then the baseline affects income transfer as the subsidy component $s_i\bar{r}_i$ represents a lump sum payment that is varied by changing the baseline.[1] Therefore, with no constraints on how policy instruments can be designed and implemented, we have a cost-benefit targeted policy with full participation in which the resulting income distribution can be adjusted. Hence, each of the targeting criteria can be fully addressed.

A budget constraint

Agri-environmental programs do not have unlimited funds, so consider what happens when we incorporate the following budget constraint

$$(5) \qquad \sum_{\mathrm{i}\in\Phi} s_i[\bar{r}_i - r_i(s_i)] \le B$$

where *B* is the available program budget. Generally, either the cost constraint (2) or the budget constraint (5) will bind, but not both. The budget constraint differs from the cost constraint in the sense that program expenditure can exceed abatement cost[2]. Suppose constraint (5) binds and (2)

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[1] Baumol and Oates (1998) correctly point out that $s_i\bar{r}_i$ is not lump sum if it influences the producer's decision to stay in business.

[2] Program budgets may also be influenced by fiscal issues unrelated to agri-environmental payment programs.

is non-binding (so that ρ=0). The Lagrangian for this problem is

$$(6)\qquad L=\sum_{i\in\Phi}\omega_i r_i(s_i)+\sum_{i\notin\Phi}\omega_i r_i^0+\lambda[B-\sum_{i\in\Phi}s_i[\bar{r}_i-r_i(s_i)]]+\sum_{i\in\Phi}\phi_i[s_i[\bar{r}_i-r_i(s_i)]-c_i(r_i(s_i))]$$

where $\lambda<0$ is the shadow value of the budget constraint and $\phi_i\leq 0$ is the shadow value of the *i*th producer's participation constraint. The Kuhn-Tucker conditions for this problem are

$$(7)\qquad \frac{\partial L}{\partial s_i}=[\omega_i+\lambda s_i - \phi_i s_i-\phi_i c_i']\frac{\partial r_i}{\partial s_i}+[-\lambda+\phi_i][\bar{r}_i-r_i]\geq 0;\quad \frac{\partial L}{\partial s_i}s_i=0\quad\forall i$$

$$(8)\qquad \frac{\partial L}{\partial \bar{r}_i}=-\lambda s_i+\phi_i s_i\geq 0;\quad \frac{\partial L}{\partial \bar{r}_i}\bar{r}_i=0\qquad\forall i$$

as well as the constraints defined in (3)-(5). It is clear that $\phi_i<0$, $s_i>0$, and $\bar{r}_i>0$ must hold for participating producers. From condition (8), this means that $\lambda=\phi_i$ for participating producers, which when combined with conditions (7) and (3) results in the farm-specific rate

$$(9)\qquad s_i^*=\omega_i/|\lambda^*|\qquad\forall i\in\Phi$$

These subsidy rates are analytically equivalent to the first-best rates, although with $|\lambda^*|$in the denominator as opposed to |ρ|. If the budget imposes more of a constraint than does the cost constraint, it must be that $|\lambda^*|>$ |ρ| so that the budget-constrained subsidy rates are smaller than the cost-constrained ones, with subsidy rates being positively related to the size of *B*.

Optimally, the budget constraint should be satisfied as an equality – if money is available it can be spent to further reduce ambient pollution. Similarly, the participation constraints should optimally bind for participating firms – if not, producers may earn rents that could otherwise be available for additional pollution reductions. From constraint (4), this means that participating producers' baselines are optimally set at the farm-specific level

$$(10)\qquad \bar{r}_i^*=c_i(r_i^*)/s_i^*+r_i^*=r_i^*[1-1/\varepsilon_{rci}^*]$$

where $\varepsilon^{*}_{rci} = [dr_i^* / dc_i^*][c_i^* / r_i^*]$ is the elasticity of mean emissions with respect to pollution control costs, and the superscript (*) indicates that variables are evaluated at their second-best values given the budget restriction. Equation (10) looks very much like an equilibrium condition in a monopsonistic factor market, except that prices and quantities are reversed in (10) relative to traditional monopsony conditions. Still, the monopsony interpretation applies. The regulator is a monopsonist in the market for pollution control. As such, it has the ability to perfectly discriminate among producers to extract all rents from them. In a conventional monopsony, the monopsonist discriminates with respect to price. In this case, the monopsonist uses quantity (the baseline) to discriminate.

With no rents accruing to individual farmers, the regulator only pays for the total cost of pollution control. Analogous to the case of a cost constraint, ambient pollution is therefore minimized for a given budget *B* if and only if the resulting minimized ambient pollution level is achieved at least cost, i.e., if the condition $\omega_i /[-c_i'^*] = \omega_j /[-c_j'^*]$ $\forall i,j$ holds. The differentiated subsidy rates in (9) ensure this condition holds as long as there is full participation.

Given complete control over all choice variables, the optimal budget-constrained policy differs from the first-best policy in two respects: (i) subsidy rates are lower, which means environmental quality is reduced – although the resulting outcome is still cost-benefit targeted, and ; (ii) income transfer no longer occurs, as this would come at the expense of environmental improvements.

We now explore the more realistic case in which there are restrictions on the use of instruments so that targeting becomes imperfect. Specifically, the regulatory authority might not have flexibility to set baselines as in (10). Rather, it might be constrained by some exogenous rule such as setting baseline emissions at unregulated levels, i.e., $\bar{r}_i = r_i^0$, or setting baselines uniformly for all producers, i.e., $\bar{r}_i = \bar{r} \;\; \forall i$. We begin with the uniform case.

Constraining baselines to be uniform

Suppose the baseline levels were required to be uniform across producers. The uniformity requirement could apply to absolute levels or to percentage reductions from unregulated emissions. The analysis for each case is analogous, and so we focus on absolute levels for simplicity, i.e., $\bar{r}_i = \bar{r} \;\; \forall i$.

First order condition (7) is unchanged by this assumption (except that $\bar{r}$ is substituted for $\bar{r}_i$. Condition (8) is affected, however, and intuitively this could have implications for the optimal level of participation. The necessary condition for the choice of baseline is

$$(11) \qquad \frac{\partial L}{\partial \bar{r}} = -\sum_{i\in\Phi} \lambda s_i + \sum_{i\in\Phi} \phi_i s_i = 0$$

With a uniform baseline and heterogeneous producers, it will only be possible to ensure zero rents for one producer – generally, the highest abatement cost producer (the highest $c'(r_i^0)$ among the set Φ) at the endogenously-chosen level $\bar{r}$. Without loss we denote this producer earning zero rents as *i*=1 or the marginal producer (the other producers earn rents for being more efficient abaters). Hence, $\phi_i = 0 \;\; \forall i \neq 1$ and $\phi_1 < 0$. For producers *i*≠1, condition (7) can be solved for the second-best farm-specific subsidy rates

$$(12) \qquad s_i = \frac{\omega_i}{|\lambda^{**}|} + c_i'(r_i^{**})\varepsilon_{sci}^{**} + I_i^{**}\varepsilon_{sri}^{**} \qquad\qquad \forall i \neq 1$$

where $\varepsilon_{sci}^{**} = [ds_i^{**}/dc_i][c_i^{**}/s_i^{**}] > 0$ is producer *i*'s inverse elasticity of abatement costs with respect to the subsidy, $\varepsilon_{sri}^{**} = [ds_i^{**}/dr_i][r_i^{**}/s_i^{**}] < 0$ is producer *i*'s inverse elasticity of mean runoff with respect to the subsidy, $I_i^{**} = [s_i^{**}[\bar{r}^{**} - r_i^{**}] - c_i(r_i^{**})]/r_i^{**}$ is average rent paid to producer *i*, and the superscript (**) indicates that variables are evaluated at their second-best values given the budget and uniform baseline restrictions. Producer *i*'s optimal subsidy rate therefore equals the producer's imputed marginal damages, minus terms that account for marginal abatement costs and the per unit rent paid to the producer.

Unlike the subsidy rates in (9), the subsidies in (12) will not yield a cost-benefit targeted outcome because they reflect more than just the benefits of abatement. Rather, the three right-hand-side (RHS) terms in (12) explicitly indicate tradeoffs between benefit targeting, cost targeting, and income targeting. Specifically, a producer faces larger abatement incentives (greater s_i) when his/her emissions generate greater marginal damages, but the incentives are reduced to reflect the budgetary impacts of the subsidy – with larger reductions occurring for producers having larger marginal abatement costs and/or for producers receiving larger per unit equilibrium rents. This means that the resulting ambient pollution level will not be achieved at the lowest possible abatement cost but rather at least public expenditure, where this expenditure includes both costs and rents as a result of the baseline constraint leading to rent transfers. Note that both the baseline and budget constraints are required for the cost, benefit, and income tradeoffs to emerge because, as indicated above, the tradeoffs do not arise when only one of these constraints holds.

The reason the subsidy reflects multiple tradeoffs is that the subsidy now has to perform two tasks – pollution control and budget allocation, and it cannot do both efficiently. So in this sense the subsidy rate in (12) is only second-best. As described above, economically optimal subsidy rates equal the imputed marginal damages created by each source. But, in the present case, the baseline restrictions reduce the ability of the subsidies to efficiently improve environmental quality. In consequence, the second-best subsidy rates are modified by two additional terms that account for the inefficiencies created by the restrictions in terms of the budget allocation impacts (i.e., for covering both costs and rents), which reduces the potential for environmental improvements. Additional terms typically arise for second-best incentives to reflect the impact of the incentive on externalities or distortions that the regulator is unable to perfectly target in a second-best world (e.g., Baumol and Oates).[3]

If the marginal environmental benefit of a producer's abatement is small relative to the producer's marginal abatement costs or the rents that the producer would receive as a result of a subsidy, then the producer could optimally face a very small or even zero subsidy rate. Indeed, full participation may not be optimal when baselines and the budget are restricted. But then from whom is it efficient to encourage participation? If we assume that small-scale polluters (i.e., small r_i^0) have the largest marginal abatement costs (since one unit of abatement represents a larger proportionate reduction in mean emissions when r_i^0 is smaller), then, under a uniform baseline, small-scale polluters will require the largest transfer payments to achieve a given level of abatement. Other things being equal, this means that society would do better to encourage participation only among larger-scale polluters – potentially penalizing those producers who have undertaken pollution control investments in the past. Of course, other things are not equal as a producer's marginal environmental benefits of abatement must also be considered. Still, there may clearly be social benefits from not encouraging participation from small-scale

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[3] There is a large economic literature on second-best policy problems. Lipsey and Lancaster first formalized the concept of second-best. They addressed the optimal design of policies intended to improve economic efficiency in particular sectors of the economy in the presence of distortions in one or more others. The basic result was that "first-best" rules (e.g. marginal cost pricing in a particular sector) may not be appropriate if distortions (i.e., prices not equal to marginal cost) remain in one or more other sectors. In the environmental economics literature, the classic example is of a monopolist, where two distortions exist: pollution and an inefficient output price. The optimal emissions tax rate will differ from the Pigouvian prescription, as an emissions tax cannot efficiently address both distortions. Rather, the second-best emissions tax in this case reflects both distortions and equals marginal damages plus a term that accounts for the impact of the tax on reducing the pre-existing monopoly distortion. More generally, the concept of second-best is applied to situations in which legal, institutional or informational constraints on policy makers restrict their choice or design of policy instruments in a way that prevents them from achieving first-best allocations (i.e., usually meaning Pareto Optimal) (Mas-Colell et al.; Boadway). For example, it has been demonstrated that when polluting discharges are imperfectly mixed, an optimal emissions tax structure would be differentiated to account for the fact that emissions from alternative sources are not perfect substitutes (Baumol and Oates). In such contexts, a restriction requiring uniform tax rates would create second-best problems for the policy maker.

polluters, for budgetary reasons. As we indicate above, the marginal producer in this case would not have the largest marginal abatement costs overall – just among the participating set.

Now consider the case of the marginal producer. We can solve condition (11) for $\phi_1 - \lambda = \lambda \sum_{i \neq 1} s_i / s_1$. Using this relation in (7), the optimal subsidy for producer *i*=1 can be calculated as

$$(13) \qquad s_1 = \frac{\omega_1}{|\lambda^{**}|} + \frac{\bar{r}^{**} - r_1^{**}}{r_1^{**}} \varepsilon_{sr1}^{**} \sum_{i \neq 1} s_i$$

Plugging the relations $-c_1' = s_1$ and $s_1(\bar{r}^{**} - r_1^{**}) = c_1(r_1^{**})$ (i.e., the marginal producer earns no rents) into equation (13), we obtain

$$(14) \qquad s_1 = \frac{\omega_1}{|\lambda^{**}|} - \varepsilon_{sc1}^{**} \sum_{i \neq 1} s_i$$

The marginal producer faces larger abatement incentives when his/her emissions generate greater marginal damages, but the incentives are reduced to reflect the budgetary impacts of other producers' subsidies. Finally, the optimal uniform baseline is calculated as in (10) to ensure the marginal producer earns zero rents:[4]

$$(15) \qquad \bar{r}^{**} = r_1^{**}[1 - 1/\varepsilon_{rc1}^{**}]$$

Assuming the marginal producer does not have the smallest marginal abatement costs overall (e.g., the producer is a medium-scale polluter), this baseline could be set at a relatively large value. Smaller-scale polluters would not benefit from the large baseline as long as the subsidy rates are adjusted to limit participation.

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[4] In the case of a uniform proportional reduction in baseline emissions, $\bar{r}_i^0 = \delta r_i^0$ (with δ<1), the subsidies in (12) are unchanged, while the subsidy in (14) becomes $s_1 = \omega_1 / |\lambda^{**}| - \varepsilon_{sc1}^{**} \sum_{i \neq 1} s_i r_i^0 / r_1^0$. The proportion δ is set to ensure zero rents for the marginal producer: $\delta^{**} = (r_1^{**} / r_1^0)(1 - 1/\varepsilon_{rc1}^{**})$.

Constraining baselines to historical levels

Now consider the case where baselines are set at historical levels, i.e., $\bar{r}_i = r_i^0$. In this case, the necessary condition for optimization is condition (7); condition (8) is no longer relevant. Moreover, each producer who is offered a positive subsidy rate will participate, with each participating producer earning positive rents (due to convex abatement costs); hence, $\phi_i = 0$ $\forall i \in \Phi$. Given these outcomes, the second-best subsidy rates for this case are as defined in (12) – even for the marginal producer. As above, the resulting environmental outcome will not be attained at least cost, as tradeoffs arise among cost, benefit, and income targeting due to the combination of the budget and baseline constraints. Participation could also be affected if it is deemed optimal to set $s_i = 0$ to some producers.[5]

Numerical Example

The model

We develop a model of corn production and associated nonpoint pollution for that part of the central U.S. (often referred to as the Corn Belt) that is a major contributor of nutrient loads to the Gulf of Mexico. Specifically, we selected the portion of the ERS farm resource region known as the 'Heartland' (see *Farm Resource Regions*, Economic Research Service, USDA, www.ers.usda.gov/publications/aib760) that coincides with USGS water resource regions

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[5] Another interesting case, which we do not consider here due to our focus on policy restrictions related to the baseline as opposed to subsidy rates, is where baseline restrictions are in place and where the regulator is restricted to offering uniform subsidies across producers. Optimal uniform subsidy rates in this case would simply be a weighted average of the values defined by (12) (see Shortle et al. 1998 for a somewhat analogous derivation, but for the case of no budget constraint or baseline restrictions). The key difference here, however, is that the regulator cannot individually adjust subsidy rates (e.g., to zero) to discourage participation among some producers. If baselines are set to historical levels, there is no way to limit participation and significant rent transfers might reduce the potential for environmental gains. If baselines were set uniformly, then this value could be varied to affect participation. The only way to limit participation in this case is to reduce the baseline. Somewhat paradoxically, this would tend to crowd out large-scale polluters – exactly the opposite of the case where subsidy rates could be independently varied. This is because a large uniform baseline results in substantial rent transfers to small-scale producers (possibly for doing nothing!), resulting in a smaller subsidy rate for encouraging environmental improvements.

(WRR) 05, 07, and 10 (see *http://water.usgs.gov/images/regions.gif*). The Heartland region accounts for a large share of U.S. corn production and for most of the nitrogen that flows into the Gulf of Mexico through the Mississippi River, which is believed to contribute to a large zone of hypoxic waters off the Gulf Coast (CAST 1999). Developing the model along Water Resource Region (WRR) boundaries facilitates the analysis of nutrient runoff and long-range transport that is typical of nitrogen.

Within each of the three USGS water resources regions in our study area, we define four land quality (LQ) classes: LQ1. highly productive land (HPL)/non-highly erodible (non-HEL) land (58.2 million acres), LQ2. HPL/HEL (10.39 million acres), LQ3. non-HPL /non-HEL (21.74 million acres), and LQ4. non-HPL/HEL (10.33 million acres). Productivity is defined as corn yield potential, calculated using a productivity index (Pierce et al.1983) and county average corn yields available from NASS-USDA (see Claassen et al. 1998 for more details). Productivity is considered high when the expected corn yield is 120 bushels per acre or higher. Erodibility is measured by the erodibility index, which is a measure of the soil's inherent propensity to erode, given local climatic conditions, relative to the soil's natural ability to withstand erosion without long-term productivity damage. Land is considered highly erodible or HEL, when the erodibility index is 8 or larger. Because runoff and erosion are closely related, the erodibility index is also a reasonable (and available) proxy for nutrient losses (emissions).

Our model of corn production and pollution generation is similar to that of Claassen and Horan, but incorporates nutrient transport and represents more heterogeneity. We consider aggregate production by groups of producers or farms, defined by the three water resource regions and four land quality types, for a total of 12 regions. The model therefore captures production over a range of climate, soil, and hydrologic conditions. Denote farm *i*'s production by the concave function $f_i(x_i)$, where x_i is an (*m* x 1) vector of inputs (*j*th element x_{ij}). The price of corn is *p*, with inverse demand $p(\sum_i f_i)$ $(p'(\sum_i f_i) < 0)$. Define x_{i1} to be farm *i*'s allocation of land, supplied according to a regional inverse supply $w_{i1}(x_{i1})$ $(w'_{i1}(x_{i1}) > 0)$. All other inputs $j\neq1$ are supplied according to an aggregate inverse supply $w_j(\sum_i x_{ij})$ $(w'_j > 0)$.

Each farm *i* is a price-taker operating in competitive input and output markets, with profits $\pi_i = pf_i\ (x_i) - \sum_j w_j x_{ij}$. Pollution control costs would simply be the reduction in profits relative to unregulated levels, π_i^u, restricted on emissions and prices, i.e., $c_i(r_i, p, w) = \min_{x_i}\ \{\pi_i^u - \pi_i \mid r_i(x_i) \le r_i\}$, where $r_i(x_i)$ is the relation between input use and emissions. For ease of exposition, our earlier specification of the cost function did not account for prices although in principle they could be important (Claassen and Horan). We indicate in the next section how price effects influence the numerical results.

Assuming income and substitution effects are small, net social surplus (not including the expected economic damages from pollution) is the sum of consumer surplus, firm-quasi rents, and the economic surplus to factors of production not supplied at a constant cost to the industry (Just et al. 1982). The social costs of pollution control are therefore

$$V = SNB^U - [\int_0^{\sum_i f_i} p(v)dv - \sum_i \int_o^{x_{i1}} w_{i1}(v)dv - \sum_{j\neq1} \int_0^{\sum_i x_{ij}} w_j(v)dv]$$

where SNB^U represents net social surplus in the unregulated, competitive equilibrium.

We take production to be a two-level, constant elasticity of substitution (CES) technology (Sato 1967) that exhibits constant returns to scale. Following prior work (Abler and Shortle 1992; Claassen and Horan; Kawagoe *et al.* 1985; Hayami and Ruttan 1985; Thirtle 1985; Binswanger 1974), production is a function of a composite biological input (produced using land

and nutrients) and a composite mechanical input (produced using capital and labor). Nitrogen is more or less a fixed proportion of nutrient applications, and so we refer to nutrients as nitrogen.

Inverse demand for corn is a first order approximation of actual inverse demand, $p = \alpha_1 - \alpha_2 \sum_i f_i$. Factor supplies take a constant elasticity form, $w_j = \gamma_j (\sum_i x_{ij})^{\eta_j}$, in the case of non-land inputs, and $w_{il} = \gamma_{il} x_{il}^{\eta_{il}}$ in the case of land. Land supply is specified at the (aggregate) farm level, while other factors are freely allocated through region-wide markets, given the long-run nature of the model. Elasticities of substitution among inputs in production and elasticities of input supply and output demand are set at the mean values used by Claassen and Horan (2001). The rest of the economic model is developed using cost share and production share data from the USDA Agricultural Resource Management Survey (ARMS) and the USDA National Resource Inventory (NRI).

Now consider the environmental side of the model. Corn production creates external social costs through the unintended generation of nonpoint source nutrient emissions. Aggregate emissions for a region are defined as $r_i = g(P_i^{\xi_{i1}} x_{iN}^{\xi_{i1}} x_{il}^{\xi_{i1}})$, where P_i is precipitation, x_{iN} is aggregate nitrogen use, and x_{il} is the amount of land used in corn production. Specification and estimation of this model is described in the Appendix. Emissions are increasing in nitrogen use $\partial r_i / \partial x_{iN} > 0$, decreasing in cropland ($\partial r_i / \partial x_{il} < 0$, i.e., applying the same total amount of nitrogen over a larger land base reduces emissions), and increasing in precipitation $\partial r_i / \partial P_i > 0$.

Emissions from each region are transported to the Gulf of Mexico, which is the chief area of concern for policy purposes. The proportion of loads that is delivered is modeled as a constant delivery coefficient, T_i, so that total mean delivered loads are $a = \sum_i \omega_i r_i$. This relation represents a first-order approximation to the actual transport process, which is thought to be reasonable in many cases (Roth and Jury 1993).

Results

We investigated three scenarios: (A) non-uniform subsidy rates and non-uniform baselines, (B) non-uniform subsidy rates and uniform baselines, and (C) non-uniform subsidy rates and historical baselines. In each case, the cost constraint was defined in terms of net social costs, which includes reduced consumer surplus and rents to productive factors. Specifically, net social costs were constrained to a 20% reduction in net social surplus relative to the unregulated, competitive outcome. The budget constraint was set at $600 million, which is in line with recent EQIP and CSP budgets, taking into account the size of the study region.

The results of the three scenarios are presented in Table 1. Ambient pollution levels are considerably smaller in scenario A than in the other two scenarios, as the budget constraint was not binding for scenario A. The budget constraint was not binding in scenario A due to the assumptions of constant returns to scale (CRTS) in production and competitive input and output markets. Producers earn zero profits in the competitive, unregulated equilibrium under CRTS and so they face zero opportunity cost of participation. In other words, producers will participate as long as they are offered a positive subsidy rate and a non-negative total subsidy payment. And since the subsidy rate provides marginal incentives while the baseline determines degree of income transfer, setting the baseline only marginally above the resulting emissions level (i.e., so that $\bar{r}_i - r_i(s_i)$ is only marginally positive) ensures there will be full participation and no (significant) income transfer.[6] The result is that the budget constraint is non-binding and hence subsidies can be set at levels such that the cost constraint binds. Hence, all resources are devoted

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[6] As described above, the baseline provides a lump sum entitlement to participating producers, and in this case the entitlement exactly offsets the opportunity cost of emitting that the subsidy rate creates.

to pollution control instead of income transfer and the solution is cost-effective.

Now consider scenario B, which exhibits the second-largest reduction in ambient pollution among the three scenarios. The uniform baseline in this case results in income transfers to all but the marginal producers, and subsidy rates are adjusted to account for this transfer. Indeed, as Table 1 indicates, the correlation between subsidy rates and delivery coefficients is –0.2 in this case, in stark contrast to the correlation of 1.0 in the cost-effective scenario A. Moreover, the correlation between subsidy rates and the basis for subsidy payments (i.e., $\bar{r}_i - r_i(s_i)$, which is larger for a larger degree of income transfer) is –0.47 – meaning that subsidy rates are generally larger for producers receiving smaller income transfer.

The optimal policy variables by region for scenario B are illustrated in Figure 1. The horizontal axis in each panel is the ratio of the baseline to unregulated emissions levels, $\bar{r} / r_i^0$. Ratios greater than unity indicate that the producer, if offered a positive subsidy, would be paid even if no abatement was undertaken. Ratios less than unity indicate that the producer would not receive any payments for some initial units of abatement. Given that the baseline is uniformly applied, the ratio provides information on the scale of pollution, with smaller ratios being associated with producers having larger-scale unregulated emissions. Figure 1a illustrates the relation between subsidy rates and the ratio $\bar{r} / r_i^0$. In Figure 1b, the solid line illustrates the relation between the ratio of the baseline to post-subsidy emissions levels, $\bar{r} / r_i(s_i)$, and the ratio $\bar{r} / r_i^0$. Values on the vertical axis closer to one imply a smaller degree of income transfer, provided a positive subsidy rate is offered. The dotted curve in Figure 1b represents the diagonal, although the two axes are not presented in the same scale. Values above the diagonal indicate that emissions have decreased relative to unregulated levels, and values below the diagonal indicate an increase in emissions relative to unregulated case.

Together, Figures 1a and 1b clearly indicate that the largest source of pollution (WRR 07-LQ1) is generally provided with the largest subsidy rate to encourage the most pollution control, but the uniform baseline is set at a level such that minimal payments are made to this source. This leaves a lot of money for encouraging pollution control among other sources – primarily other large emitters because their post-subsidy emissions will be closer to the baseline level, resulting in fewer income transfers. In contrast, given that the uniform baseline equals the largest polluter's post-subsidy emissions level, smaller-scale polluters would require larger total subsidy payments for a given incentive rate. The result would be more income transfer and less money available for encouraging abatement (via larger subsidy rates). The smallest-scale polluters, which reside in WRR 05, are therefore offered no subsidy and only partial participation results – even though these producers generally have the largest delivery coefficients. Hence, targeting is based more on income transfer than on marginal ambient impacts.

Figure 1b illustrates that post-subsidy emissions levels actually increase among WRR 05 producers. This is because of output price effects: reduced production by other producers increases the output price and encourages WRR 05 producers to produce more corn and hence emissions. Note that some participating producers in WRR 10 also increase their emissions relative to unregulated levels. This is also due to output price effects. A larger subsidy rate could offset these price effects and reduce emissions, but this would come at a higher subsidy payment. But rather than doing this, a lower subsidy rate is applied in order to keep emissions from increasing too much, and this frees up money for controlling other sources having larger marginal impacts.

Finally, Table 1 indicates that ambient pollution is reduced the least under Scenario C. In this case, each participating producer will receive an income transfer, and this transfer grows quickly with the level of abatement since increasingly larger subsidy rates are required for additional units of abatement. Therefore, encouraging only partial participation, in which only a few producers take on enough abatement responsibilities to consume the entire budget, would result in large income transfers and possibly small reductions in ambient pollution. Ambient pollution is more effectively reduced by spreading emissions controls among all producers, thereby limiting the income transfer per producer while increasing aggregate pollution reductions. At the same time, the subsidies can be better targeted according to environmental benefits, as indicated by equation (12) when the degree of income transfer is reduced. This tradeoff is apparent in Table 1, as the correlation between subsidy rates and benefits is positive in scenario C, and the correlation between subsidy rates and the payment basis (income transfer) is reduced relative to scenario B.

Concluding remarks

Our emphasis on the subsidy baseline and budget constraints is particularly relevant to recent and ongoing conservation policy debates. In U.S. agri-environmental policy, the Environmental Quality Incentives Program (EQIP) represents the traditional approach which employs a historical baseline: cost-sharing for the installation of adoption of new practices that will produce additional environmental benefits. The Conservation Security Program (CSP), created by the 2002 farm bill, represents a more generous baseline under which producers can be rewarded for past conservation efforts. Funding for both programs is limited[7].

We have analyzed the design of subsidies based on abatement and found that setting subsidy rates equal to the (imputed) marginal benefits of abatement is not necessarily optimal when a budget constraint is introduced and when the regulatory authority is restricted in setting

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[7] Although first approved as an entitlement program, CSP is now a capped entitlement.

the subsidy baseline, which determines the payment basis. When the baseline is restricted, optimal subsidy rates target marginal costs and income transfer to producers in addition to marginal benefits. The upshot is that tradeoffs emerge between targeting on the basis of benefits, costs, income transfer, and participation. Numerically, we found that the optimal subsidy rates may be less correlated with benefits than with income transfer, depending on the type of baseline restriction in place.

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Table 1. Numerical results

Scenario	Ambient pollution level	Net social Costs Less Environmental Gain (percentage reduction from unregulated net social surplus)	Correlation between subsidy rates and delivery coefficients	Correlation between subsidy rates and payment basis ($\bar{r}_i - r_i(s_i)$)
Unregulated, competitive outcome	100.0	0		
A. Differentiated subsidy rates and differentiated baseline	22.1	20.0	1.0	0.0
B. Differentiated subsidy rates and uniform baseline	70.4	11.5	-0.2	-0.47
C. Differentiated subsidy rates and historical baseline	83.5	1.4	0.3	-0.14

Figure 1a.

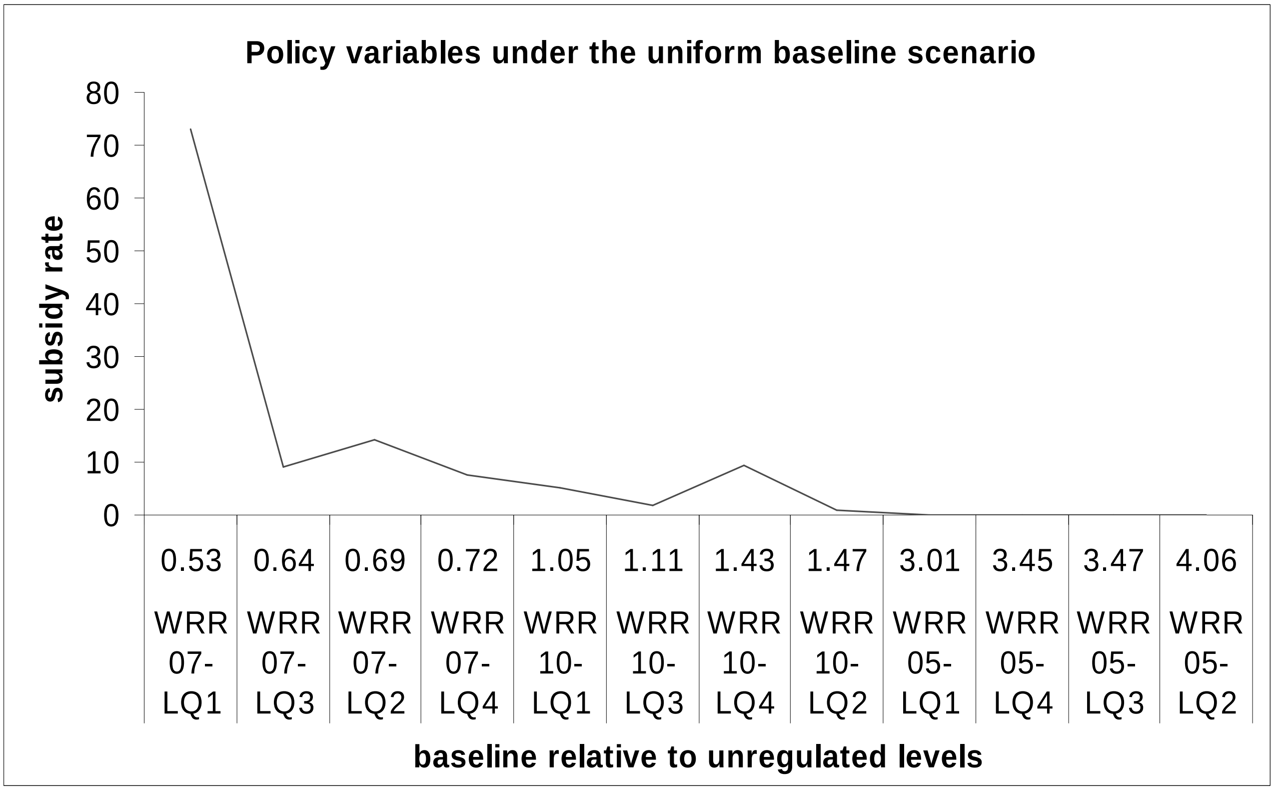
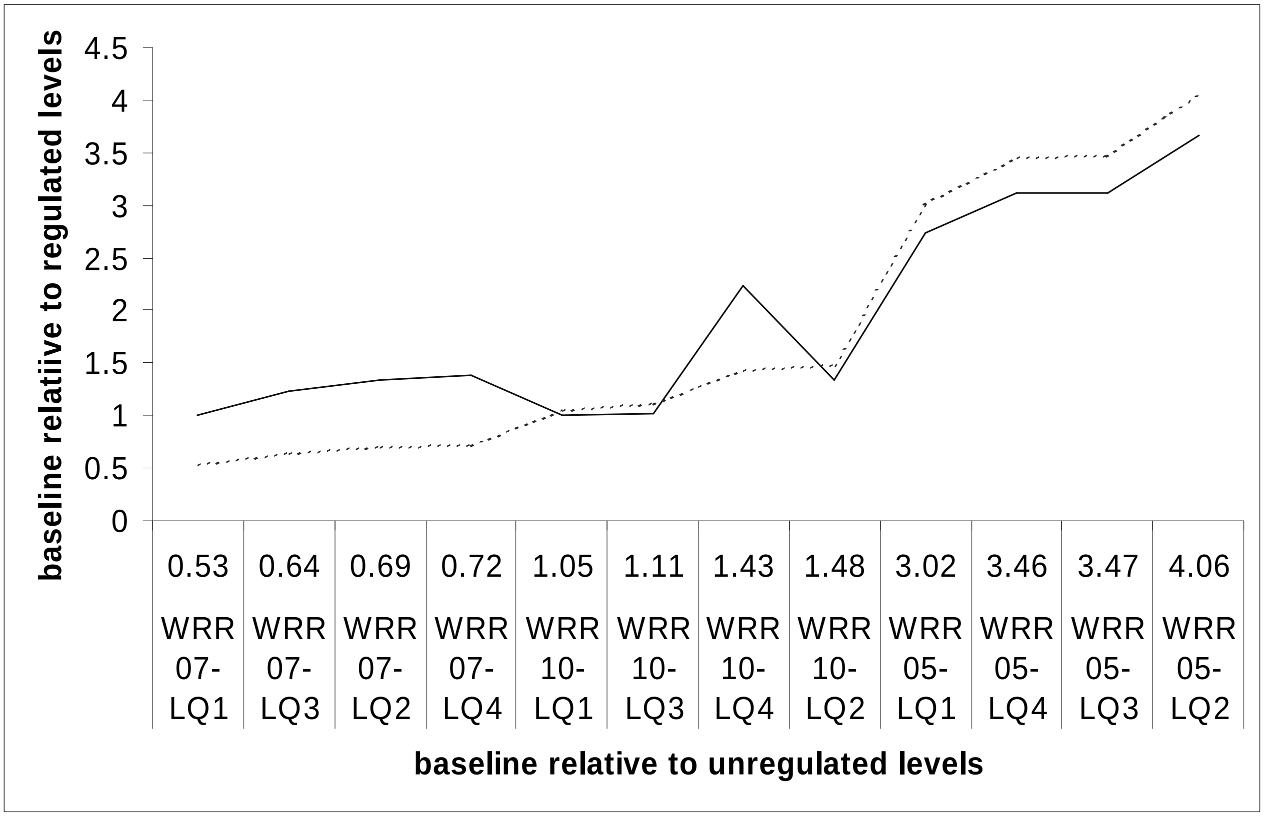


Figure 2b



Appendix

The environmental model is based on the Soil and Water Assessment Tool (SWAT). SWAT was calibrated using data on climate, soils, land uses, crop allocations, and management practices. Next, the SWAT model was run repeatedly using random variations in per acre fertilizer application rates and past data on precipitation (see e.g., Helfand and House for a similar procedure). Finally, SWAT output was analyzed to link fertilizer application to runoff per acre.

The SWAT model is calibrated for 8-digit USGS hydrologic cataloguing units (HUCs). Within each HUC, multiple hydrologic response units (HRUs) were specified using combinations of the 4 land classes, 4 modeled crops (corn, soybeans, wheat, and hay), and other land uses. Within each HUC, one soil was selected to represent each land class. Using National Resources Inventory (NRI) data and the Soils5 data, the soil with the largest cropland acreage for each land class within each HUC was selected to represent the land class in that HUC.

Acreages, by land quality class and land use, are obtained from the 1997 NRI data. Acreage of four crops was used: corn, soybeans, wheat, and hay. The balance of crop acreage was generally very small. To avoid unnecessarily complicating the model runs, these acres were allocated proportionally to other crops. Non-cropland acres were represented by a single HRU. The land use was determined by the predominant non-cropland use in the watershed and could be pasture, forest, urban, or wetland.

Production practices and inputs were specified using ARMS data. Nitrogen application rates in corn were specified by calculating average application rates by land type, then testing for significant differences among land types. Application rates where significantly different between high and low quality land, but not between highly erodible and non-highly erodible land. Other inputs for corn and other crops were similarly specified.

Once the SWAT model was calibrated to the baseline data, a dataset was created by varying per acre nitrogen application rates over repeated model runs. Nitrogen application rates range from 80 to 100 percent of the baseline rate. Historical data on weather was used to account for variations in weather conditions that are also important in determining nutrient runoff. To "wet" the model, SWAT was run for at least 5 years worth of weather data with management variables set to baseline levels. Then management variables were shocked and the model was run for the next five years worth of weather data.

We regressed nitrogen runoff per acre against data on precipitation, nitrogen application, and land quality. While SWAT is a complex system, the goal of this parameterization is to develop a single equation describing the relationships between a specific environmental outcome and relevant management factors, accounting for land types and climatic conditions. This procedure is tantamount to estimating a reduced form equation from a system of structural equations. The runoff function is specified in a log-log form:

$$\log(r_i / x_{il}) = c_0 + c_1 \log(P_i (x_{iN} / x_{il})) + c_2 \log(P_i (x_{iN} / x_{il})(1+E)) + c_3 \log(P_i (x_{iN} / x_{il})(1+H))$$

where x_{il} is area planted in corn (ha), r_i / x_{il} is per-acre nitrogen runoff (kg/ha), P_i is annual precipitation (millimeters), x_{iN} is total nitrogen application (kg), E equals one for highly erodible land, zero otherwise, H equals on for high productivity land, zero otherwise.

The model is specified to focus on the interaction between nitrogen application, precipitation, and land quality. Nitrogen application and land quality variables are interacted with precipitation given that precipitation drives all nutrient runoff. Nitrogen runoff per unit of precipitation can vary in the context of land quality variations, which represent differences in underlying soils, topography and proxy for differences in management variations other than nitrogen application. Separate equations were estimated for each Water Resources Region using OLS with observations weighted by corn acreage.