MARKET AND BARGAINING APPROACHES TO NONPOINT SOURCE POLLUTION ABATEMENT PROBLEMS

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ABSTRACT

The ability of a market type mechanism to significantly reduce the compliance costs of current state and national erosion standards is investigated. The ability of such an institution when applied to a recursively produced pollutant such as sediment from agricultural land is, however, extremely sensitive to the order in which contracts are executed. The gain-ranked order of contracting is found to result in a larger reduction in costs than the mean cost reduction calculated under a random order of contracting. The degree to which actual contracting more closely corresponds to the random or gain-ranked order is, therefore, of crucial importance given the desirability of achieving a sediment load at the least cost possible.

KEYWORDS

Nonpoint pollution; sediment; agricultural land; markets.

INTRODUCTION

During the past two decades, concern has shifted from soil erosion's effect on agricultural productivity to its role as a pollutant. Sediment from agricultural runoff decreases water clarity, affects aquatic plant life, impairs recreational uses and clogs streams, rivers, and harbors, thereby hindering transportation and increasing flooding. Perhaps more importantly, sediment is also the primary carrier of other pollutants such as phosphorus, pesticides, and several heavy metals.

Soil eroded from agricultural lands is considered to be a nonpoint source of pollution and together with urban runoff, constitutes the major American water pollution problem resulting in damages estimated to be between $3.6 billion and $4.2 billion dollars annually (Clark et al. 1985). The importance of controlling nonpoint sources of pollution is evidenced by the introduction of a national water quality goal into the 1987 Clean Water Act Amendments requiring states to formulate nonpoint source pollution abatement programs. No specific mechanism for the solution of this problem is provided in the Amendments, and thus far the plans implemented by states fall far short of achieving national water quality goals.

A policy which has received increasing attention because of its potential to achieve a desired water quality goal in a cost-effective manner is "targeting". A "targeted" policy is one that focuses upon measures that have the highest return, in damages avoided per unit of abatement or averting costs (Nichols 1984; Braden, et al. 1987). In formulating a targeted management regime it is necessary to estimate abatement and damage
cost functions and link these with environmental models. However, the modeling of these pollution processes may prove to be complex. Additionally, the outcomes of these models may be questioned on legal grounds since similar entities may not be treated similarly.

The difficulties associated with a targeted approach might be overcome if the individuals affected by these policies had a strong incentive to act in ways that promote efficient solutions. A market system is of great interest in this regard since it has the ability to convert a uniform policy into a targeted policy through voluntary exchanges. Under this type of system it would be in the owners' best interest to examine the various management options available and choose the alternative that would be the most profitable.

This research empirically evaluates a transferable discharge system to control nonpoint source pollutants, with particular reference to sediment from agricultural lands. The next section develops an economic model which highlights the potential for gains from exchange when bargaining and contracting between landowners is permitted. The third section describes the program used to simulate bargaining and contracting between landowners. The fourth section presents the empirical results of an investigation of the impact of various regulatory constraints and trading scenarios on the ability of landowners, through bargaining and contracting, to achieve the least-cost solution. The final section of this paper details the policy implications of the empirical results.

**ECONOMIC MODEL**

In the following analysis, it is assumed that the primary goal of landowners is to maximize their site profit. Any soil which moves offsite, therefore, is the result of a profit maximizing decision and will not be voluntarily reduced.

In seeking to control this externality, the regulatory authority must choose among several policies each with its own political, economic, and legal ramifications to attain the desired ambient condition. This work will focus upon policies under which the regulatory authority permits sites to enter into contracts with other sites to alter their management practices and, therefore, their discharges.

For the externality that we will be focusing on, sediment from agricultural lands, the spatial setting is of great importance. The term "watershed" will refer to an area of land that exhibits specific hydrological and topographic characteristics and drains into a common body of water. Within a watershed, we can envision paths along which sediment flows towards the body of water for particular areas. These areas, whose surface hydrology of runoff is independent from each other, will be referred to as "catchments", and the paths along which sediment characteristically flows will be called "transects".

The amount of eroded (dislodged) soil that eventually enters the body of water depends upon numerous factors including characteristics of the land such as slope and soil types, the climate of the area, the proximity of the land to surface waters as well as management practices.

Management practices are taken to consist of numerous factors including the crop that is planted, tillage practices, and conservation measures. Since changes in management practices affect the soil entrained in surface runoff, it is important to identify points where these occur, for example, variations in these factors can occur either at the boundaries between fields, or within actual fields due to, for example, a change in slope.

It is necessary, therefore, to introduce the idea of a land management unit (or site) as an area in which land characteristics and management practices are homogeneous. Note that the boundaries of land management units (LMUs) are equivalent to field boundaries when the field characteristics and/or management practices do not change, or they are set at points within a field when there exists a significant change in one of the previously mentioned factors.
In the following analysis, the index \( j = 1, \ldots, J \) denotes catchments within the watershed and \( i = 1_j, \ldots, I_j \), denotes the sites located in catchment \( j \) with site \( 1_j \) located closest to the body of water, and site \( 1_j \) located furthest away. We assume that sites within the watershed produce both an \( X \)-vector of saleable outputs \( q_{ij} \) and a nonsaleable output, eroded soil, which is represented by \( b_{ij} \). The production function is given by:

\[
q_{ij} = Q_j(z_{ij}) \quad i = 1_j, \ldots, I_j, \quad j = 1, \ldots, J
\]

Where \( z_{ij} \) refers to a \( K \)-vector of management (input) variables for site \( ij \). This function is assumed to be continuous and concave.

The relationship between the input variables and the amount of eroded soil is described by the erosion function:

\[
b_{ij} = B_j(z_{ij}) \quad i = 1_j, \ldots, I_j, \quad j = 1, \ldots, J
\]

For each \( z_{ij} \), this function gives the quantity of soil that is dislocated (eroded) for that field. Additionally, the choice of \( z_{ij} \) determines how sediment from further upslope is contained. This is assumed to be continuous and quasi-concave.

A reasonable and useful assumption that is made in this analysis is that the environmental process function, which describes how cumulative discharges are produced, is strongly recursive. The following definition of strong recursivity, which is based upon theorem 6.1 (pp. 221-2) proven in Blackorby, Primont and Russell (1978), is important for understanding the implications of this assumption.

Let \( z \) represent the management practices (combinations of production activities, input uses, and mechanical controls) for all sites within the watershed, and let \( z_j \) represent the management practices for sites located within catchment \( j \), where \( j = 1, \ldots, J \). The partition \( i \), or \( z_j \), subdivides the catchment into sites denoted by \( i = 1_j, \ldots, I_j \).

Let \( <ij> \) denote the ordered partition \( <1_j, \ldots, I_j> \) of sites. The continuation vector of sites, \( <i=1_j, \ldots, I_j> \) relative to \( ij \) is denoted by \( <i'> \), and the precursor vector, \( <1_j, \ldots, i-1_j> \) is denoted by \( <ij> \).

**Definition 1:** Let the real valued function \( H(z_j) \) be continuous, monotone, and quasiconcave. Then \( H(z_j) \) is strongly recursive over the ordered partition of sites \( <ij> \) if and only if there exist functions \( H_{ij}(\cdot), i = 1_j, \ldots, I_j; j = 1, \ldots, J \) such that:

\[
\begin{align*}
H_{ij} &= h_{ij}(b_{ij}(z_{ij})) \\
H_{ij} &= h_{ij}(b_{ij}(z_{ij}), H_{i+1,j}) \\
H_{ij} &= H(z_j) = h_{ij}(b_{ij}(z_{ij}), H_{ij})
\end{align*}
\]

and \( h_{ij}, i = 1_j, \ldots, I_j \) also is monotone.

This implies that the marginal products of elements of \( z_{ij} \) cannot be affected by elements of the continuation vector, but can be affected by elements of the precursor vector. Note that the impact of the management decisions of other sites in catchment \( j \) on site \( ij \) are entirely captured by that site's management choices, \( z_{ij} \), as well as by the cumulative discharges \( (H_{i+1,j}) \) of the immediately preceding site.
The importance of the recursive relationship between sites located adjacent to each other and within the same catchment lies in the possibility for the owners of these sites to contain the cumulative movement of sediment within their catchment.

Based on definition 1 and equation (2), the environmental process function takes on the following nested structure:

\[ h_y(b_y, h_{yj}, h_{yj}(..., h_y(b_y)...)) \]  

This function is assumed to be continuous, nondecreasing, and quasi-concave in the \( z_{ij} \)'s. This implies that a practice that increases output will not reduce the flow of pollution and may increase it.

In addition to the assumptions made on the functional forms, the prices of the saleable outputs (denoted by the X-vector \( P \)) as well as the prices of inputs (denoted by the K-vector \( w \)) are assumed to be exogenously given. It is also assumed that the regulatory authority sets a pollution constraint at the catchment level \( -h \), or at the watershed-wide level \( H \).

The regulatory authority's problem is to maximize the joint profits of all landowners in the watershed subject to a limit on watershed wide discharges. The solution to this problem represents the cost-effective set of management options. The regulatory authority's problem is expressed by:

\[ \Pi^*(H): \text{maximize } \sum_{i=1}^{J} \sum_{j=1}^{I} P_r q_{ij} - w^T z \]

subject to:

\[ \sum_{j=1}^{J} h_i (b_i, h_{ij}, h_{yj}(..., h_y(b_y)...)) \leq H \]

\[ q_{ij} = 0; \quad i=1,...,I; \quad j=1,...,J \]

The vector of management practices, \( z^* \) that solves the regulatory authority's problem must satisfy the following Kuhn-Tucker conditions (the condition with respect to the Lagrangian multiplier is straightforward and omitted below):

\[ \frac{\partial \Pi}{\partial z_{yk}} = \sum_{x=1}^{x} \frac{\partial d_{yx}}{\partial z_{yk}} - w_k - \sigma \left( \frac{\partial h_i}{\partial b_i} \frac{\partial h_{ij}}{\partial z_{yk}} + \frac{\partial h_i}{\partial z_{yk}} \right) \leq 0. \quad \text{For All } i,j,k. \]

\[ \frac{\partial \Pi}{\partial z_{yk}} \leq 0; \quad z_{yk} \geq 0; \quad \left( \frac{\partial \Pi}{\partial z_{yk}} \right)(z_{yk}) = 0; \quad k = 1,...,K \]

This condition describes the manner in which changes in management practices impact output and discharges. The first two expressions represent the change in profit for field \( ij \) resulting from a change in input \( k \). The expression that begins with \( \sigma \) describes how changes in management practices on field \( ij \) affect discharges from field \( ij \). Discharges are influenced by changes in erosion on field \( ij \) (the expression inside the parentheses) as well as by the movement of discharges (the second expression). The Lagrangian multiplier represents the value of a marginal relaxation in the watershed-wide discharge constraint. This expression, therefore, represents the value of a change in discharges from site \( ij \) resulting from a change in input \( k \).

A policy which is currently employed by several states to control agricultural nonpoint pollution involves the imposition of a soil loss tolerance standard. Within the context of our model, this can be represented as a
uniform limit on the quantity of eroded soil, which will be symbolized as \( b \) with an implied watershed-wide sediment load of \( H \). Since all landowners are constrained to the same erosion standard \( b \) we will simplify our notation by dropping the subscript which denotes transects \( j \) and view a representative landowner, \( i \).

The goal of the individual landowner is to maximize the profit of his or her site subject to the erosion constraint. A representative landowner faces the following problem:

\[
\Pi'_i(b) \rightarrow \text{maximize } P^Ty - w^Tz
\]

\[
\text{s.t. } b(z) \leq \tilde{b}
\]

\[
q_{i\alpha}, b, z_{i\alpha} \geq 0
\]

The individually optimal solution to this problem must satisfy the following Kuhn-Tucker conditions (the condition with respect to the Lagrangian multiplier \( \mu_i \) is straightforward and omitted below):

\[
\frac{\partial \Pi_i}{\partial z_{i\alpha}} = \sum_{x=1}^{X} P_x \left( \frac{\partial q_{i\alpha}}{\partial z_{i\alpha}} \right) - w_k - \mu_i \left( \frac{\partial b}{\partial z_{i\alpha}} \right)
\]

\[
\frac{\partial \Pi_i}{\partial z_{i\alpha}} \leq 0; \ z_{i\alpha} \geq 0; \ \left( \frac{\partial \Pi_i}{\partial z_{i\alpha}} \right)(z_{i\alpha}) = 0; \ k = 1, ..., K
\]

For the individual landowner, this condition describes how changes in management practices affect output and erosion on his or her site. The first two expressions describe how changes in management practices change site profit, while the third term represents the value of a change in erosion on site \( i \) resulting from a change in input \( k \).

Comparing the regulatory authority's solution and the solution to the individual landowner's maximization problem reveals that the individual landowner, when faced with an erosion constraint, does not take into account how changes in erosion translate into changes in discharges and his or her ability to alter the movement of sediment. The result is that a non-optimal management policy is undertaken (from the regulatory authority's perspective) unless there is a delivery ratio which is fixed and equal to one.

The assumption of a fixed delivery ratio has been shown to be inefficient (Braden et al., 1989). A regulatory policy which, therefore, relies upon an erosion constraint to meet an overall ambient standard will surely be inefficient. Since there exists a divergence between the independent maximization problem and the regulatory authority's problem, there exists a strong incentive for bargaining and contracting to occur between landowners. The seriousness of the inefficiency resulting from various policy settings is an empirical issue to which the next two sections are devoted.

**EMPIRICAL MODEL**

The development of several programs (collectively known as SEDEC (SEDiment EConomics)) integrates both economic and physical models of sediment transport (SEDEC User's Guide 1989; Braden, et al. 1985, 1987, 1989; Bouzaher, et al. 1990). SEDEC permits the user to investigate what was generally seen as impossible or too costly – the determination of what is happening in a particular watershed at various levels of disaggregation.

The first component of SEDEC, SOILSED focuses upon the most disaggregated level of the watershed, the land management unit (LMU) providing as output the set of non-dominated management options in erosion-
cost space for each LMU. The second module of SEDEC, S-PGEN calculates the non-dominated sediment/cost combinations for each transect. Additionally, information on the management options employed on each transect and, therefore, each LMU is included.

The third and fourth modules in SEDEC, OPT and DPSOLVE, are used to calculate the least cost (socially optimal) solution for a specified level of sediment. In addition to the information on the total cost of attaining specific sediment levels, DPSOLVE provides information on the corresponding management options for each LMU in the watershed.

The development of a market simulation program greatly extends the capabilities of SEDEC. Using as input the outputs of S-PGEN and SOILSED, this program calculates, based upon user-specified assumptions, the number of contracts that are executed, the reduction in sediment and costs, and the corresponding management options on each LMU in the watershed.

DATA

The data for this analysis represents a 1,064-acre site in the Long Creek (LC) watershed of Macon County, Illinois. The study area includes seventeen catchments containing a total of seventy-eight LMUs with the number of LMUs on each catchment ranging between two and eight. Long Creek is a tributary to Lake Decatur, a municipal water supply reservoir in which sediment deposition is a major problem. Land in the area is gently sloped, highly productive, and used predominantly to grow row crops (Braden et al. 1989).


Management options include one of four crop rotations (continuous corn, corn-soybeans, corn-soybeans-oats or corn-soybeans-oats-meadow), one of six tillage practices (fall plowing, spring plowing, spring disking, till-planting, chiselling or no-till), and one of three structural measures (plowing and planting across contours, along contours, or in contoured strips of different crops in the rotation) (Braden et al. 1989).

EMPIRICAL RESULTS

The effect of intercatchment bargaining and contracting is analyzed in the context of three regulatory policies and two erosion levels: 3 t/a/y and 5 t/a/y, where erosion is measured as an average annual rate. The erosion levels studied reflect current and proposed regulations in Illinois (Braden and Johnson 1985; Braden et al. 1984).

Policy 1: Uniform erosion constraint on streambank sites (\(l_j, j = 1, \ldots, J\)). This case is studied at both the 3 t/a/y (policy 1-3) and 5 t/a/y (policy 1-5) level of erosion.

Policy 2: Uniform erosion constraint on all sites in the watershed. This case is studied at both the 3 t/a/y (policy 2-3) and 5 t/a/y (policy 2-5) level of erosion.

Policy 3: Non-uniform discharge constraint on streambank sites (\(l_j, j = 1, \ldots, J\)). The non-uniform discharge constraint is calculated such that the level of sediment emanating from each catchment under policies 2-3 and 2-5 is met or exceeded. Hence, policy 3-3 constrains only the management practices of those

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1 The descriptions of the modules of SEDEC are based upon descriptions found in the SEDEC User's Guide (1989).
2 Information on the data used in this analysis is based upon descriptions in: Braden et al. 1984; Braden et al. 1989; and Braden and Johnson 1985.
landowners located along the body of water to produce at most the level of sediment coming from his or her catchment under policy 2-3. Policy 3-5 is defined in a similar manner.

It is assumed that discharges are monitored downstream, and that bargaining and contracting is permitted to take place between sites located anywhere in the watershed provided the overall ambient condition, set by the regulatory authority, is not violated. The transportation of sediment in water is assumed to be strongly separable, that is, the overall ambient condition equals the sum of discharges from each site \( j \) (\( j = 1, ..., J \)). For each of the analyses performed, it is assumed that internal contracts, that is, those contracts which involve a change in management practices on LMU(s) under common ownership dominate all other contracts. This assumption is based on the significant transactions costs that would be avoided by executing an internal contract. Additionally, it is assumed that executing a contract precludes a landowner from entering into another contract.

In conjunction with the erosion constraints, two restrictions on the order of bargaining and contracting are explored. First it is assumed that those landowners for which the gains from contracting are greatest execute their contracts first. The alternative assumption that is studied is one under which the order of contracts is randomly determined.

### GAIN-RANKED ORDER OF CONTRACTING

The first assumption on the order of contracting to be investigated is referred to as "gain-ranked". Under this assumption, the set of potential contracts is determined and ranked according to their ability to decrease costs. The contract which, when implemented, results in the largest decrease in costs is executed first. After this contract is implemented, the pool of potential contracts is recalculated and ranked, and an iterative procedure is followed until all possible gains from exchange are exhausted. The results of this analysis are presented in Table 1 which contains information on both sediment load and total cost, where total cost represents the decrease in annualized net returns from their most profitable level. The watershed wide level of sediment is enclosed by parentheses.

#### TABLE 1: COMPARISON OF COST AND SEDIMENT UNDER GAIN-RANKED CONTRACTING

<table>
<thead>
<tr>
<th>Policy 1</th>
<th>Regulatory</th>
<th>Least Cost</th>
<th>Intercatch</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 3 \ t/a/y )</td>
<td>$3269.31 (501.30)</td>
<td>$1649.90 (500.10)</td>
<td>$2097.82 (482.51)</td>
</tr>
<tr>
<td>( 5 \ t/a/y )</td>
<td>$1414.15 (866.55)</td>
<td>$772.60 (865.50)</td>
<td>$879.38 (811.03)</td>
</tr>
<tr>
<td>Policy 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 3 \ t/a/y )</td>
<td>$4508.00 (430.90)</td>
<td>$1993.40 (429.20)</td>
<td>$2532.66 (397.80)</td>
</tr>
<tr>
<td>( 5 \ t/a/y )</td>
<td>$1783.03 (742.12)</td>
<td>$975.90 (741.60)</td>
<td>$1291.27 (669.25)</td>
</tr>
<tr>
<td>Policy 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 3 \ t/a/y )</td>
<td>$4037.96 (417.49)</td>
<td>$2098.40 (416.80)</td>
<td>$2304.41 (402.60)</td>
</tr>
<tr>
<td>( 5 \ t/a/y )</td>
<td>$1787.43 (636.23)</td>
<td>$1236.10 (632.20)</td>
<td>$1358.62 (609.27)</td>
</tr>
</tbody>
</table>
The total cost imposed on landowners as a direct result of the regulatory constraint are displayed under the "Regulatory" heading. The second column of Table 1 ("Least-cost") represents the least possible cost of achieving the overall sediment load implied by the initial regulatory constraint. These figures are used as a benchmark for measuring how effective the various scenarios are at capturing the potential gains from bargaining and contracting.

The results of intercatchment trading show that this form of trading greatly reduces the cost burden of each policy. The cost level resulting from intercatchment trading is, however, still significantly greater than the least-cost solution suggesting that gains from exchange are not being fully captured. The divergence between the least-cost solution and the intercatchment solution can be partly attributed to the trading rule which requires there to be no net change in the level of sediment after a contract is executed. This source of inefficiency is emphasized by Atkinson and Tietenberg (1991) who attribute part of the divergence between expected cost savings and achieved cost savings under the Emissions Trading Program to the process by which trades are executed, specifically, the requirement that there be no net decrease in ambient environmental quality.

The restriction on trading is, however, only part of the reason for the divergence. Using the DPSOLVE and OPT modules of SEDEC, the least-cost solutions were recalculated using the final sediment loads for each policy. The results of this analysis are presented in Table 2. They show that even at the adjusted sediment load there still exists a divergence between the intercatchment trading result and the new least-cost solution.

<table>
<thead>
<tr>
<th>Policy 1</th>
<th>Percentage difference between the cost found under intercatchment trading and the revised least cost solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 t/a/y</td>
<td>17.48%</td>
</tr>
<tr>
<td>5 t/a/y</td>
<td>2.11%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Policy 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3 t/a/y</td>
<td>12.24%</td>
</tr>
<tr>
<td>5 t/a/y</td>
<td>12.01%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Policy 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3 t/a/y</td>
<td>5.10%</td>
</tr>
<tr>
<td>5 t/a/y</td>
<td>3.27%</td>
</tr>
</tbody>
</table>

**RANDOM ORDER OF EXECUTION**

An alternative assumption on the order of contracting involves randomly picking and executing a contract from the set of potential contracts. After the implementation of a contract, the set of potential contracts is updated, and an iterative process is continued until the set of potential contracts is exhausted.
Six cases are explored with a total of 200 trials performed for each case. Information on the mean, maximum, minimum, and standard deviation for the total cost of the policy ($), sediment level (tons), and the number of contracts executed are contained in the following tables (Tables 3-8). For comparative purposes, the values obtained under the gain-ranked order of contract execution and the least-cost solution are also presented.

**TABLE 3: POLICY 1-3**

<table>
<thead>
<tr>
<th>POLICY 1-3</th>
<th>Gain-Ranked</th>
<th>Least Cost</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>Cost ($/year)</td>
<td>2097.82</td>
<td>1649.90</td>
<td>2361.48</td>
</tr>
<tr>
<td>Sediment (tons)</td>
<td>482.51</td>
<td>500.10</td>
<td>472.47</td>
</tr>
<tr>
<td>Contracts</td>
<td>6</td>
<td>6.29</td>
<td>7</td>
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</table>

**TABLE 4: POLICY 1-5**

<table>
<thead>
<tr>
<th>POLICY 1-5</th>
<th>Gain-Ranked</th>
<th>Least Cost</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>Cost ($/year)</td>
<td>879.38</td>
<td>772.60</td>
<td>1054.36</td>
</tr>
<tr>
<td>Sediment (tons)</td>
<td>811.03</td>
<td>865.50</td>
<td>797.66</td>
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<tr>
<td>Contracts</td>
<td>7</td>
<td>7.05</td>
<td>8</td>
</tr>
</tbody>
</table>

**TABLE 5: POLICY 2-3**

<table>
<thead>
<tr>
<th>POLICY 2-3</th>
<th>Gain-Ranked</th>
<th>Least Cost</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>Cost ($/year)</td>
<td>2532.66</td>
<td>1964.60</td>
<td>2947.98</td>
</tr>
<tr>
<td>Sediment (tons)</td>
<td>397.80</td>
<td>434.20</td>
<td>404.74</td>
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<tr>
<td>Contracts</td>
<td>11</td>
<td>11.50</td>
<td>13</td>
</tr>
</tbody>
</table>
### TABLE 6: POLICY 2-5

<table>
<thead>
<tr>
<th>POLICY 2-5</th>
<th>Gain-Ranked</th>
<th>Least Cost</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost ($/year)</td>
<td>1291.27</td>
<td>1065.20</td>
<td>1422.69</td>
</tr>
<tr>
<td>Sediment (tons)</td>
<td>669.25</td>
<td>434.20</td>
<td>677.39</td>
</tr>
<tr>
<td>Contracts</td>
<td>6</td>
<td>7.91</td>
<td>10</td>
</tr>
</tbody>
</table>

### TABLE 7: POLICY 3-3

<table>
<thead>
<tr>
<th>POLICY 3-3</th>
<th>Gain-Ranked</th>
<th>Least Cost</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost ($/year)</td>
<td>2304.41</td>
<td>2098.40</td>
<td>2876.07</td>
</tr>
<tr>
<td>Sediment (tons)</td>
<td>402.60</td>
<td>416.80</td>
<td>398.01</td>
</tr>
<tr>
<td>Contracts</td>
<td>7</td>
<td>7.95</td>
<td>10</td>
</tr>
</tbody>
</table>

### TABLE 8: POLICY 3-5

<table>
<thead>
<tr>
<th>POLICY 3-5</th>
<th>Gain-Ranked</th>
<th>Least Cost</th>
<th>Random</th>
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</thead>
<tbody>
<tr>
<td>Cost ($/year)</td>
<td>1358.62</td>
<td>1236.10</td>
<td>1527.49</td>
</tr>
<tr>
<td>Sediment (tons)</td>
<td>609.27</td>
<td>632.20</td>
<td>596.70</td>
</tr>
<tr>
<td>Contracts</td>
<td>5</td>
<td>4.27</td>
<td>5</td>
</tr>
</tbody>
</table>

A comparison of the total cost of compliance obtained under the gain-ranked and random order of contracting shows that although (with the exception of one case, policy 3-5) more contracts are executed under the random order of contracting, the average costs associated with this order of contracting are higher than under a gain-ranked order of contract execution.

It is also interesting to compare the minimum cost value under the random order of contracting with the value obtained under the gain-ranked assumption. For two of the cases (policy 1-5, policy 3-5), the minimum value is equal to the value found under the gain-ranked order of contracting. For one of the cases (policy 3-3), the minimum value is greater than the gain-ranked value, and for three (policy 1-3, policy 2-3, policy 2-5), the minimum value under random is less than the gain-ranked value. It should be emphasized, however, that the percentage difference is small-ranging between 2 and 5.5%.
Based upon the evidence contained in Tables 3 through 8, we can conclude that the gain-ranked order of contract execution yields a closer approximation to the least-cost solution than does a random order.

CONCLUSIONS AND POLICY IMPLICATIONS

Given the increasing reliance on market type mechanisms to promote environmental quality goals, the policy implications of these empirical results are especially interesting. Although, theoretically, markets in pollution rights are generally upheld as achieving substantial reductions in the costs of attaining an ambient standard, the combination of a trading restriction, transactions costs, and interdependencies between polluters significantly reduces the ability of such an institution to achieve a least-cost solution. The underlying cause of these distortions, as well as the ability or inability to reduce it, are important concerns for a regulatory authority who is charged with implementing a policy to achieve some ambient condition.

Additionally, the ability of such an institution to reduce the compliance costs of a regulation are extremely sensitive to the order in which contracts are executed. It then becomes appropriate to ask which of the two rules investigated more closely approximates how contracts are executed in a real world environment. With positive transactions costs, we might expect those landowners that have the largest gains from exchange to enter into a contract first. There exists, however, a valid counter argument. Due to the interdependent nature of the pollutant, waiting to contract may greatly reduce/enhance a landowners gains from contracting. Those landowners who perceive a loss in their ability to enter into contracts by waiting may find it in their best interest to execute a contract early, while those who perceive a benefit from waiting would have a strong incentive to do so. This type of interaction may result in a contracting pattern that approximates the random order of contracting.

REFERENCES