

Utah State University

DigitalCommons@USU

---

Economic Research Institute Study Papers

Economics and Finance

---

2001

## Environmental Determinants of Cost Sharing--An Application to Irrigation

David Aadland  
*Utah State University*

Van Kolpin

Follow this and additional works at: <https://digitalcommons.usu.edu/eri>

---

### Recommended Citation

Aadland, David and Kolpin, Van, "Environmental Determinants of Cost Sharing--An Application to Irrigation" (2001). *Economic Research Institute Study Papers*. Paper 221.

<https://digitalcommons.usu.edu/eri/221>

This Article is brought to you for free and open access by the Economics and Finance at DigitalCommons@USU. It has been accepted for inclusion in Economic Research Institute Study Papers by an authorized administrator of DigitalCommons@USU. For more information, please contact [digitalcommons@usu.edu](mailto:digitalcommons@usu.edu).



*Economic Research Institute Study Paper*

*ERI #2001-08*

**ENVIRONMENTAL DETERMINANTS OF COST SHARING—  
AN APPLICATION TO IRRIGATION**

by

**DAVID AADLAND**

**Department of Economics  
Utah State University  
3530 Old Main Hill  
Logan, UT 84322-3530**

and

**VAN KOLPIN**

**Department of Economics  
1285 University of Oregon  
Eugene, OR 97403-1285**

**April 2001**

**ENVIRONMENTAL DETERMINANTS OF COST SHARING—  
AN APPLICATION TO IRRIGATION**

**David Aadland, Professor**

**Department of Economics  
Utah State University  
3530 Old Main Hill  
Logan, UT 84322-3530**

**Van Kolpin**

**Department of Economics  
1285 University of Oregon  
Eugene, OR 97403-1285**

The analyses and views reported in this paper are those of the author(s). They are not necessarily endorsed by the Department of Economics or by Utah State University.

Utah State University is committed to the policy that all persons shall have equal access to its programs and employment without regard to race, color, creed, religion, national origin, sex, age, marital status, disability, public assistance status, veteran status, or sexual orientation.

Information on other titles in this series may be obtained from: Department of Economics, 3530 University Boulevard, Utah State University, Logan, Utah 84322-3530.

**Copyright © 2001 by David Aadland and Van Kolpin.** All rights reserved. Readers may make verbatim copies of this document for noncommercial purposes by any means, provided that this copyright notice appears on all such copies.

**ENVIRONMENTAL DETERMINANTS OF COST SHARING—  
AN APPLICATION TO IRRIGATION**

**David Aadland and Van Kolpin**

**ABSTRACT**

Multiple-cost sharing rules often coexist in seemingly identical environments. We use shared irrigation costs as a context for examining the extent to which the structural environment explains the selection of a cost sharing rule. We find that environmental factors that—induce greater dependence on the cooperation of others, influence majority interests, create difficulties for interpersonal utility comparisons, or impact notions of “fairness”—all have impressive explanatory power. These results present the first formal empirical analysis of the manner in which structural features influence the actual cost-sharing choices of economic agents.

*JEL* Classification: C71, D63, C25

Key words: cooperative games, cost allocation, equity, probit model

# ENVIRONMENTAL DETERMINANTS OF COST SHARING— AN APPLICATION TO IRRIGATION<sup>1</sup>

## Introduction

The success of cooperative ventures often hinges on the arrangements made to share the costs and benefits generated. Examples range from the large scale, such as funding of public projects through the taxation of a nation's citizenry, to the small scale, such as allocation of a restaurant's tips between its waiters and chef. Allocation mechanisms which are ill-suited for the task at hand may induce a "tragedy of the commons" or even create outright conflict. An extensive axiomatic literature has emerged that sheds light on such pitfalls and characterizes "optimal" allocation procedures. (See Moulin (forthcoming) and Thomson (forthcoming) for a broad coverage of the axiomatic approach to cost and resource allocation problems.) Even so, multiple-sharing mechanisms can often be observed coexisting harmoniously in seemingly identical environments. Does such behavior suggest that several sharing mechanisms are equally appropriate and the choice of which to adopt is essentially arbitrary? Or do environmental cues exist that reliably reveal the sharing mechanism of choice? If such explanatory power can be empirically established, does it support or run counter to the central spirit of axioms employed in the theoretical cost-sharing literature?

We use the costs incurred from the upkeep of a shared irrigation ditch as a context for examining the questions posed above. As detailed in section 3, our sample of irrigation ditches are drawn from Carbon and Stillwater Counties of Montana, USA. These ditches are used

---

<sup>1</sup>The authors wish to thank Jim Kindle and Marty van Cleave (MT Department of Natural Resources and conservation); the survey respondents from Carbon and Stillwater Counties, MT; Stephanie Kuster (MT Secretary of State Office); Dan Gustafson (Montana State University); Rick Krannich and Bob Hill (Department of Sociology and Department of Irrigation and Water Resources, respectively, Utah State University).

primarily to irrigate hayfields, although they are occasionally used to irrigate other cash crops, water stock animals, and irrigate lawns or gardens. A typical ditch begins at the headgate (a device that controls the volume of water diverted from the source stream) and then continues on a sequential path through the lands of each agent using this “main” ditch. (See Figure 1.1.) Agents (typically ranchers) also have their own private ditches that branch off from the main ditch and transport water to their parcels of land. Only the costs associated with the main ditch are shared as each agent is individually responsible for expenses incurred on their private ditches. The most common expenses on a main ditch include headgate repair, silt and debris removal, and replacement of deteriorating ditch banks.

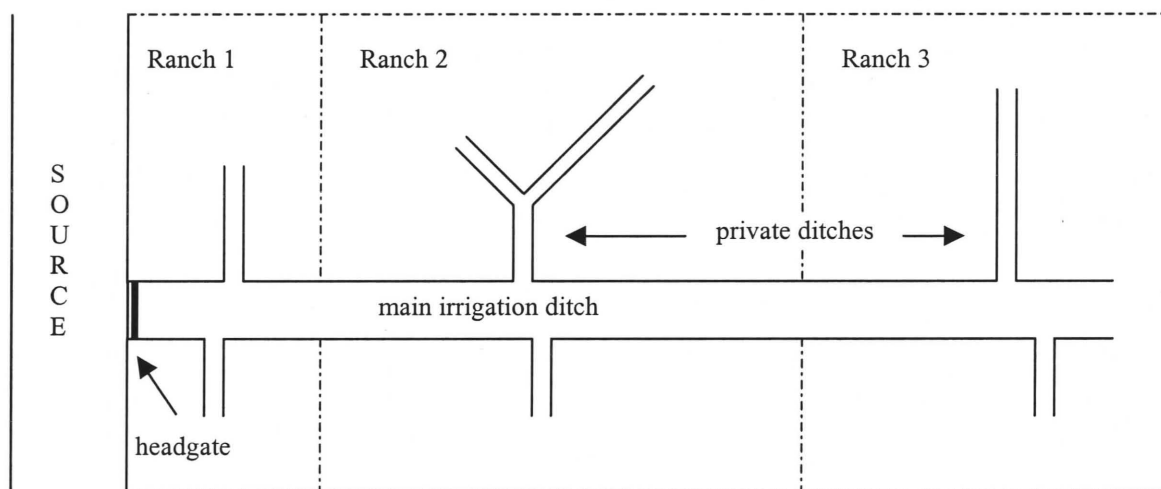


Figure 1.1

The data we have compiled from this sample of irrigation ditches provide a compelling framework for our study. Indeed, the cost-sharing rules employed on these ditches have typically been in place for many decades (often over a century), suggesting that if a rule were ill-behaved, it would likely have been discarded long ago. We are able to partition all rules in our

sample into either the *average* or *serial class*. A rule is in the average class if all agents pay according to an identical fixed “rate” for use of the irrigation ditch.<sup>2</sup> Serial rules apply this same principle, though do so in a serial fashion along the ditch. That is, the ditch is partitioned into a sequence of segments such that all agents require the first segment to be operational in order to receive water, all but the first agent on the ditch additionally require the second segment to be operational, . . . , all but the  $i^{\text{th}}$  agent additionally require the  $i+1$  segment to be operational, and so on and so forth. Each segment is then treated like a separate ditch whose costs are covered by having all agents requiring its use pay an identical fixed rate. An agent’s total obligation for access to the main ditch is thus the sum of its obligations on each of these individual segments. (The reader may note that in this context the resulting allocation is identical to that generated by the Shapley value, introduced in Shapley (1953), of the corresponding coalitional game.) We define the serial class to contain those rules that protect agents from the burden of costs incurred downstream from their property. Thus the serial class contains both true serial rules as well as “marginal rules” in which agents are individually responsible for maintaining portions of the main ditch lying on their property.

In addition to cost share rule classification, our dataset includes information on the benefits, costs, and distributional features associated with the irrigation ditches and the parcels of land they service. Our econometric analysis reveals that the selection of a cost share rule is far from arbitrary and that a reduced form of the structural environment has impressive explanatory power. Loosely speaking, we find that if environmental factors induce greater dependency on the cooperation of others, then a rule within the average class becomes more likely. If, on the other hand, environmental factors imply less need for cooperation, then an outcome in the serial

---

<sup>2</sup>This “rate” may be defined on a per capita basis, per irrigated acre basis, or on the basis of shares of stock owned in the ditch’s controlling interest. Further details are provided in section 2.

class becomes more likely. We also find factors that influence majority interests, create difficulties for interpersonal utility comparisons, or impact notions of “fairness” to be important pieces of the puzzle. These results present the first formal empirical analysis of the manner in which structural features influence the actual cost-sharing choices of economic agents. Our results also provide direction through uncharted territory in that previous theoretical analyses do not always offer a clear view of how structural features should be expected to affect the choice of cost allocation.

We further note that both the average and serial mechanisms have received considerable attention in the theoretical literature, a small sample of which includes Friedman and Moulin (1999), Koster et al. (1998), and Sprumont (1998). Even the specific context of irrigation cost sharing has been highlighted in works such as Aadland and Kolpin (1998) and Moulin (2001). These analyses suggest that, depending on one’s axiomatic perspective, either mechanism may be deemed “optimal.” The central axiomatic theme that distinguishes serial mechanisms from average mechanisms is the protection of those imposing small demands on the shared resource from those imposing large demands. In the context of our sample of shared irrigation ditches, the demands an agent places on the system are synonymous with the length of ditch that must be maintained to service the agent’s needs. Thus agents imposing small demands are located at the front of the ditch, while agents imposing large demands are located at the ditch’s tail. Empirically, we find that serial mechanisms are indeed prone to emerge when the pressure for such protection is most keen, indicating that the theoretical literature on the subject is reflective of real-world cost-sharing behavior.

The remainder of the paper is organized as follows. Section 2 introduces a theoretical model that serves to motivate our empirical analysis. We outline the data we have collected and the



sources from which it was derived in section 3. Section 4 presents our empirical analysis and results. Closing comments are found in section 5.

## 2. Theoretical Structure

We first consider a simple representation of shared irrigation costs. In this simple structure we assume that a finite number of agents  $N=\{1,\dots,n\}$  are ordered sequentially along an irrigation ditch from its beginning to its end. Given this ordering, the ditch can be partitioned into a sequence of uniquely defined segments. Segment 1 is the portion of ditch from the headgate to the last point required to service agent 1, segment 2 is the portion of ditch from the end of segment 1 to the last point required to service agent 2, . . . , segment  $i$  is the portion of ditch from the end of segment  $i-1$  to the last point required to service agent  $i$ , and so on and so forth. For each  $i=1,\dots,n$ , let  $c_i$  denote the annualized costs affiliated with segment  $i$  and let  $\mathbf{c}=(c_i)_{i \in N} \in \mathfrak{R}_+^N$  denote the vector of all such costs. The pair  $(\mathbf{c},N)$  will be referred to as a *simple irrigation game*.

Note that the aggregate costs of servicing any coalition  $S \subseteq N$  can be characterized by  $v(S)=c_1+\dots+c_{\max\{i \in S\}}$ , i.e., the aggregate costs on all ditch segments necessary to service the last member of  $S$  (and thus all of  $S$ ). A *cost allocation* for a simple irrigation game is a vector  $\mathbf{x}=(x_i)_{i \in N}$  that covers the total cost  $\sum c_i$ , i.e.,  $\sum x_i = c_{\text{total}} = \sum c_i$ . (Note that summation limits will be omitted when no confusion results.) Examples of cost allocations include:

*average cost sharing:*  $\mathbf{a} = (a_i)_{i \in N}$  where  $a_i = c_{\text{total}}/n$  for each  $i \in N$ ,

*serial cost sharing:*  $\mathbf{s} = (s_i)_{i \in N}$  where  $s_i = c_1/n + \dots + c_i/(n-i+1)$  for each  $i \in N$ .

Average cost sharing simply divides total costs equally between all agents. Serial cost sharing divides each segment cost equally between all agents who use the segment. Since agent  $i$  uses segments 1 through  $i$ , agent  $i$ 's aggregate cost share under the serial rule is the sum of  $i$ 's share of the costs  $c_1$  through  $c_i$ .

Real-world applications naturally have much more detail than is provided by simple irrigation games. For instance, on a given ditch each agent may irrigate different quantities of land, which may not be sequentially ordered, may have different seniority of water rights, or may use the water for different purposes. Moreover, ditches have different geographic locations, which may lead to variation in rainfall, erosion, land value, etc. All such details are potentially relevant in determining the cost allocation adopted on any given ditch. We shall define a *detailed irrigation game* to be a simple irrigation game paired with a profile of additional detail **d**. The central theme of this paper is to determine the manner and extent to which environmental details are capable of explaining the cost-allocation rule that is employed.

Detailed irrigation games offer new variations of cost-sharing rules, even for the specific examples of average and serial cost sharing rules. First, consider the average rule. Total costs might be distributed equally across each agent (as we have defined above), equally across each acre irrigated (so each agent pays a fixed price per acre), or equally across shares of stock owned in the ditch's controlling interest (so each agent pays a fixed price per unit of stock owned). The serial variants, on the other hand, divide costs equally across all acres requiring a given segment for irrigation on either a per capita, per acre, or per share of owned stock basis. Despite the wide array of possibilities, our survey data indicate that the vast majority of ditches employ a cost allocation rule that falls into one of these two general classes (each containing a substantial portion of our sample):

*average class*: total costs are distributed equally per capita, per acre, or per shares of stock owned.

*serial class*: total costs are either distributed serially per capita, per acre, or per shares of stock owned; or agents pay only for costs incurred on their property (recall the marginal

rule is also classified as “serial” as it too protects agents from the demands of downstream users).

Before turning to our empirical analysis, it is interesting to note that while cost sharing sometimes creates tension between irrigators, there is often great clarity of thought involved in the selection of a cost share rule. Consider, for instance, the following discussion provided by one of our survey respondents, outlining serial cost sharing and its advantages as implemented on the respondent’s ditch.

There are five shares with four people holding the shares. If a problem occurs at the head of the ditch, everyone pays the amount that their share would dictate. If the problem extends beyond the headgate of the first owner, the other four shareholders pay their share which of course would be the four shares. If the problem extends beyond the second headgate or shareholder, the other three shareholders take care of it and so on. This keeps ownership within the confines of his rightful share and the shareholder really doesn’t have a say in what happens below his headgate . . . . The owner at the end of the ditch has a fairly long area to take care of so if he wants to put money in it in cleaning or repairs, he can without having everyone agree to pay etc. so he does have some freedom in his own management. The cost is divided equally among the shareholders so everyone pays their share according to the way described above. No. 4 shareholder has two shares because of the acreage so he has two shares to pay for where the others have one share to pay. The cost at the head of the ditch would be divided by 5 shares to headgate No. 1, and the cost at headgate No. 2 and below would be divided by 4 shares and so on.

### **3. Survey and Other Data**

In this section, we describe the cost-sharing surveys, introduce the data from sources other than the survey, and define the variables to be used in the econometric analysis.

#### **3.1 Cost-Sharing Surveys**

We begin by noting that the irrigation ditches in our sample are typically small ditches (average of nine users) with an informal and unrecorded agreement on how costs will be shared. As a result, it was necessary to survey the irrigators to identify the cost-sharing rule employed on each ditch. We accomplished this through a sequence of two mail surveys. The first survey

presented the irrigators with the following options and asked them to identify the method of cost sharing that best describes the one used on their ditch:

1. All users pay equal amounts to cover total ditch maintenance costs.
2. All users on or below a maintenance project pay equal amounts to cover total project costs.
3. Each user pays only the cost of maintaining the portion of the main ditch located on their property.

We also presented respondents with per acre and per share-of-owned-stock variants to options 1 and 2. However, we choose to focus solely on the distinction between the average and serial class of rules, rather than on all their possible variants, because our data are insufficient to accurately distinguish between all possible variations of the average and serial mechanisms. We also included the option to “write in” other cost sharing rules. Even though the open-ended option allowed respondents to report rules that do not conform to either the average or serial classifications, all responses fit into one of these two classes.

Following up on the first survey, we sent out a postcard survey to the same set of irrigators asking them to either validate their responses to the initial survey or, if they had failed to respond to the first survey, provide information for the first time. The postcard survey expanded the cost-sharing questions slightly to ensure that the distinction between the average and serial rules was transparent:

1. Is it customary for each user of your ditch to help pay for maintenance projects on the main ditch, even if these projects are located downstream from them?
2. If maintenance costs are to be shared by some group of users on the main ditch, how are these costs distributed? (Check whichever fits most closely.)

\_\_\_ Everyone in the group pay equal amounts.

\_\_\_ Costs are never shared, everyone pays only for costs on their own land.

When combining the two surveys, we received a total of 270 usable responses on 98 ditches. To put this into perspective, there are a total of 169 irrigation ditches in Carbon and Stillwater Counties. Furthermore, four ditches in our sample and 10 ditches outside our sample are listed as “single-user” ditches in the MT state records. We, therefore, have in our sample the majority (94 of 155) of the state-listed, multi-user ditches in the two counties.

For both surveys, we generated our mailing list using water-rights information from the Water Resource Division of the Montana Department of Natural Resources and Conservation (DNRC) (<http://www.dnrc.state.mt.us/wrd/home.htm>). All irrigators are required by state law to file a *water right*, granting them a legal right to a specified amount of water. As part of the filing process, irrigators provide their names, mailing addresses, ditch name, and other specifics regarding their irrigation environment. We mailed the first survey to every irrigator holding a water right in Stillwater and Carbon Counties.

In some instances, respondents from the same ditch issued conflicting reports regarding their cost-sharing rule. We offer two possible explanations for this apparent inconsistency (certainly others exist as well). First, it could be that the irrigators genuinely disagree about the cost-sharing agreement (recall that the rules are not typically recorded in written form). Second, it could be that the location of the irrigators along the ditch influences their perception of the cost-sharing rule. Indeed, maintenance and improvement projects often occur on an irregular basis and irrigators at the head of the ditch (front-enders) may actually be unaware of costs incurred at the ditch’s tail. Should this be the case, front-enders may perceive serial cost sharing as indistinguishable from the average rule, while a tail-ender would not share this misperception.

Apparent inconsistencies in the stated cost-sharing rule are resolved through the following procedure:

- (1) assign to each ditch the rule stated by the majority of its respondents
- (2) break ties in (1) by assigning the ditch's majority response from the more detailed postcard survey
- (3) break ties in (2) by assigning the most common rule in the entire sample.

There were 18 ditches reporting some sort of inconsistency in the stated cost-sharing rule, of which, 14, 2, and 2 were settled using criteria (1), (2) and (3), respectively.

### **3.2 Other Data**

The remaining data include physical attributes of the irrigation environment and information from the irrigators' water-rights profile. We organize this section by the source of the data.

The majority of our data were made available through the Water Resource Division of the Montana DNRC. From the DNRC, we obtained water-rights information for every irrigated field in Carbon and Stillwater Counties. This produced approximately 2,840 individual parcels of irrigated land (covering approximately 150,000 acres) in our sample and approximately 900 irrigated parcels outside our sample. Each water-rights claim contains the owner's name and address, the name of irrigation ditch and its point of diversion, the purpose of water right and its date of priority, and the location and size of each parcel of land irrigated with the water right. The owner's name, address, and ditch name were used to initiate the mail surveys (as discussed above) and to identify each irrigator with a single ditch.<sup>3</sup> The purpose of the water right is almost always listed as irrigation, although a small percentage is listed as stock water, domestic

---

<sup>3</sup>Many irrigators owned water rights on multiple ditches. In our survey, we asked that they choose the multi-user ditch with the smallest number of users.

use, or lawn/garden use. The point of diversion refers to the place where the irrigation ditch is diverted from its primary source (see Figure 1.1). The priority date is an important date for irrigators. It determines how water is to be allocated among irrigators sharing the resource and is a legally binding in case of disputes over water allocation. The following is an excerpt from the Montana DNRC regarding water rights:

Water rights in Montana are guided by the prior appropriation doctrine, that is, first in time is first in right. A person's right to use a specific quantity of water depends on when the use of water began. The first person to use water from a source established the first right, the second person could establish a right to the water that was left, and so on. During dry years, the person with the first right has the first chance to use the available water to fulfill their right. The holder of the second right has the next chance.

Our survey respondents did indicate, however, that there is generally ample water for all users to irrigate their fields so that cost allocation (rather than water allocation) is their central concern.

The point of diversion and location of each field were recorded by county, range, township, section and quarter section. To aid in recovering other physical data (discussed below), we translated the township data into latitude and longitude coordinates using the TRS2LL program provided by Martin Welfald (<http://www.geocities.com/jeremiahobrien/trs2ll.html>). The TRS2LL program recognizes location down to the section level.

The second source of data is the GRAPHICAL LOCATOR, a program developed by Daniel Gustafson, a research scientist with the Department of Biology at the University of Montana–Bozeman (<http://www.esg.montana.edu/gl/cst/index.html>). The GRAPHICAL LOCATOR accepts longitude/latitude data as input and can be used to calculate “local roughness” for each irrigated field and the point of diversion. (Local roughness is discussed in more detail in the following section.)

The third data source is the pair of Soil Surveys for Carbon and Stillwater Counties, published by the United States Department of Agriculture in cooperation with the Montana

Agricultural Experiment Station. These surveys represent a detailed study and mapping of the chemical, physical, and environmental characteristics of soils present throughout these counties. We focus attention upon those characteristics that affect the benefits or costs derived from irrigation, and thus seem most likely to influence the cost-sharing procedure agents choose to adopt. (A discussion of the specific variables considered is found in the following section.)

The fourth source of data is a set of spatial climate maps generated by researchers at the Oregon Climate Service (OCS). These are the most detailed, highest-quality spatial climate data sets currently available (<http://www.ocs.orst.edu/>). OCS used the PRISM model to generate mean monthly precipitation estimates for the time period 1961-1990 (Daly et al. 1994; Daly et al. 1997). The data are measured in millimeters of rainfall per month and are reported in a spatial grid, where the reported values are an average across each cell. Each cell spans approximately 0.04167 latitudinal and longitudinal units (approximately 2 sections or 0.5 miles).

The fifth and final source of data is the office of the Secretary of State for Montana. For some of the ditches, the irrigators came together and filed articles of incorporation, making the ditch a formal company. Using information from the Water Resource Surveys for Carbon and Stillwater Counties (State Water Conservation Board, 1946 and 1966) and the Secretary of State's office, we were able to identify which ditches had filed articles of incorporation.

### **3.3 Variable Definitions**

In this section, we define and provide motivation for the variables to be used in the econometric analysis. Table 1 presents descriptive statistics for these variables over the 94 multiple-user ditches used in our sample. Our dependent variable, AVERAGE CLASS, is a ditch-level binary variable set equal to one for an average and zero for a serial cost-sharing classification. As Table 1 indicates, our sample is moderately unbalanced in the sense that the



majority (71%) of the ditches in our sample use cost-sharing rules within the average classification.

The explanatory variables of our econometric model are chosen to offer proxies for the following types of information: (1) the (absolute and relative) benefits derived from irrigating a specific parcel of land, (2) the (absolute and relative) costs incurred from maintaining a specific ditch, and (3) the (current and historical) distribution of agents along the ditch. Benefit and cost information are suggestive of the stakes involved in being a member of a given irrigation ditch, and as such, may indicate the compromises that agents may be willing to make. Distributional information presents insight as to what agents may collectively perceive as fair cost sharing, as well as what the majority would prefer in their own self-interest. Let us now turn to the specific variables we use to elicit benefit, cost, and distributional information.

First, TOWN is defined as the fraction of irrigators on a given irrigation ditch that have at least one field within a one mile radius of the center of a town.<sup>4</sup> Only 27 of the 94 ditches had any irrigators located within a one-mile radius of a town, and of those 27 ditches, the average value for TOWN was approximately 0.38. The presence of users within and near towns is likely to produce a disparity in the benefits associated with the irrigation water. Users within a town generally use the water to irrigate their lawns or gardens while users outside town generally use the water to irrigate their fields, which produce hay and crops often crucial to their financial livelihood. Furthermore, users near town may be irrigating land with a higher market value relative to those further away from towns and the extent of this disparity (real or perceived) may influence what cost-sharing rule is deemed to be fair.

---

<sup>4</sup>For Carbon and Stillwater Counties, the towns under consideration are Absarokee, Bridger, Columbus, Fromberg, Joliet, Red Lodge, and Roberts.

Second, ALTERNATIVE USE is defined as the fraction of users on a given irrigation ditch that either use the water from the main ditch for something other than irrigation (i.e., stock water, domestic use, etc.) or irrigate a field of less than half an acre. We choose half an acre because our own experience leads us to believe that fields less than half an acre are likely to be used for nontraditional purposes. Only 10 of the 94 ditches had non-zero values for ALTERNATIVE USE and of those 10, the average value was approximately 0.18. We expect that TOWN and ALTERNATIVE USE may be related to the choice of cost-sharing rule because they represent possible differences in benefits derived from irrigation. For instance, if ranchers irrigating a crop benefit more per unit of water used than do users that simply irrigate their lawns, then interpersonal utility comparisons are much less transparent. Although we are *a priori* unsure whether greater variation in use will push agents toward an average or serial class of rules, it seems plausible that it may nonetheless be influential.

Third, RAINFALL measures the total rainfall received during the growing months of May, June, July, and August. The more rainfall fields receive, the less beneficial is the irrigation water on the margin. As such, there may be less pressure for irrigators to fully cooperate in sharing the costs along all segments of the main ditch and thus push them toward the serial rule. RAINFALL is averaged over all fields on the ditch on a per-acre basis. That is, RAINFALL is the weighted sum of the rainfall for each field  $j$ , with the weights equal to the ratio of irrigated acres for field  $j$  relative to the total number of irrigated acres on the ditch. There is substantial variation in rainfall across the ditches in our sample, varying from a minimum of 116 millimeters to a maximum of 244 millimeters per growing season.

Fourth, ROUGHNESS is defined as the standard deviation of surrounding elevation values. This calculation uses the nearest 16 elevation values in the original 1-degree (3 arc second)

digital elevation model data, which corresponds to a radius of about 125 meters (Gustafson 2000). Each field is assigned a roughness value and then we take an acre-weighted average of these values across the entire ditch to form ROUGHNESS. Higher ROUGHNESS values have two important implications. First, higher values for ROUGHNESS imply ditches associated with a more contoured surface area, for which it is typically more difficult to effectively irrigate. Therefore, we would expect less benefit from irrigation, all else equal. Second, irrigation ditches located on steeper terrain generally are associated with higher construction and maintenance costs due to greater erosion of ditch banks.

Fifth, RUNOFF is a measure of the propensity of the soil to absorb water. Higher values for RUNOFF imply soil types that absorb less water (i.e., have more runoff), and as a result, are not as well suited for irrigation. This also may imply higher costs due to greater erosion of ditch banks. Higher costs associated with higher values of RUNOFF (and ROUGHNESS) may imply increased pressure for irrigators to fully cooperate by sharing costs along all ditch segments.

Sixth, NUMBER OF USERS is simply the number of irrigators distributed on a ditch. Some of the irrigation ditches filed for a single water right as an incorporated entity. For these ditches, it was not possible to directly identify the number of users, but only the number of irrigated fields. Therefore, to calculate the number of users, we used the average number of fields per irrigator for the remaining ditches in the sample (approximately 3.5 fields per user) to impute the number of users on the incorporated ditches. The number of users varies widely from only two users up to 61 users, with the “typical” ditch having approximately nine users. We anticipate that, all else equal, the more users there are on a ditch, the more likely it is that the rule will be average because the implied higher costs may necessitate a need to fully cooperate in sharing the costs. Furthermore, the prescribed average cost allocations are more transparent and typically

easier to calculate than serial allocations, a difference that is generally magnified as the number of users increases.

Seventh, SOURCE DISTANCE is the distance between the point of diversion and the first private ditch branching off the main irrigation ditch.<sup>5</sup> Ditches with large SOURCE DISTANCES were likely to have experienced large initial costs simply to get the water to the first user. In order to overcome this large initial expense, a critical number of users may be necessary to share the costs and therefore it is probably less likely that the ditch would develop piecewise (i.e., adding ranchers incrementally to the tail end of the ditch). To the extent that a more piecewise development is more likely to adopt a serial rule to accommodate new tail-end users, we would expect ditches with large SOURCE DISTANCES, all else equal, to be associated with average rules. Furthermore, this portion of the main ditch involves resources used by every irrigator on the main ditch. Therefore, the longer this segment is relative to the length of the entire ditch, the more average and serial allocations will tend to resemble one another (assuming costs are proportional to length and for a given number of agents). As a result, we expect that ditches with larger SOURCE DISTANCES will experience pressure to cooperate fully in sharing costs and thus be more likely to employ an average rule. As shown in Table 1, the average SOURCE DISTANCE is substantial; slightly less than one mile long.

Eighth, TAIL DIFFERENTIAL measures the distance between the last field on the “original” ditch and the last field on the “current” ditch relative to the number of current users. (Hereafter, original and current refer to the ditch as it stood near the date of the first filed water right and the

---

<sup>5</sup>In actuality, our dataset provides field locations rather than the locations where private ditches branch off the main irrigation ditches. We estimate SOURCE DISTANCE by assuming that segment 1 of the main irrigation ditch is approximately linear and that the first private ditch is: perpendicular to the main ditch, leads to the center of the first field, and is 1/4 mile in length (our results are robust to variations in this length). The Pythagorean Theorem is then applied to calculate SOURCE DISTANCE. (Inspection of the maps from the Carbon and Stillwater Water Resource Surveys suggest the linearity assumption is reasonable for all ditches except Gruell and Weast. For those two ditches we calculate SOURCE DISTANCE by summing the lengths of approximately linear subsegments).

date in which the survey was administered, respectively).<sup>6</sup> Again assuming that costs are proportional to distance, TAIL DIFFERENTIAL captures the incremental per capita costs associated with adding new users to the tail of the ditch. The larger is this value, the stronger the tendency may be for the original users to push for adoption of a serial rule as it approximates the increased cost shares the average rule would present to original users as compared to the serial rule. In this sense, TAIL DIFFERENTIAL also represents the degree to which original users may feel the need to be protected from demands imposed on the system by new users at the tail of the ditch.

Ninth, ORIGINAL CENTER OF GRAVITY ( $CoG^0$ ) characterizes the manner in which the irrigated acres are distributed along the original ditch. The  $CoG^0$  variable for the  $j^{\text{th}}$  ditch is calculated as follows

$$CoG_j^0 = \frac{\sum_{i=1}^{m_j} \left( (d_{i,j} - \min_i(d_{i,j})) * acre_{i,j} \right)}{\left( \max_i(d_{i,j}) - \min_i(d_{i,j}) \right) * \sum_{i=1}^{m_j} acre_{i,j}},$$

where  $d_{i,j}$  is the linear distance from the headgate to the  $i^{\text{th}}$  private point of diversion,  $acre_{i,j}$  is the number of irrigated acres associated with the  $i^{\text{th}}$  private point of diversion, and  $m_j$  is the total number of fields. Since the differences in the numerator and denominator both involve  $\min(d_{i,j})$ , this measure “nets out” the SOURCE DISTANCE.  $CoG^0$  is bounded between zero and one, with values near zero indicating ditches with a higher relative concentration of irrigated acres to the left of center (i.e., toward the top of the ditch) and vice versa. In theory, this measure could be

---

<sup>6</sup>More precisely, the original ditch is given by the ditch as it stood within the three-month window after the first filed water right, except for incorporated ditches which are treated as having been created at the time of incorporation. In calculating this window, we ignore the winter months of December, January and February because it seems unlikely that any ditch construction could take place during that time frame. We choose a three-month window based on the presumption that the individuals who originally share ditch resources may not all file their water right on the same date. Varying the length of this window up to one year does not qualitatively affect our results.

either negatively or positively correlated with AVERAGE CLASS. One might expect that a sense of fairness would drive irrigators with tail-heavy ditches (i.e.,  $\text{CoG}^0$  large) to choose a serial rule so that front-enders are not overly burdened by sharing costs from resources they do not use. However, it may also be that for tail-heavy ditches, tail-enders vote out of self-interest for the average rule in order to reduce their prescribed share of total costs.

Tenth, CoG DIFFERENTIAL is defined as the CURRENT CENTER OF GRAVITY ( $\text{CoG}^1$ ) less  $\text{CoG}^0$ .  $\text{CoG}^1$  is identical to  $\text{CoG}^0$  except that it pertains to the current profile of ditch users, rather than the original profile. Holding constant  $\text{CoG}^0$ , an increase in CoG DIFFERENTIAL implies a shift over time in the distribution of users toward the tail of the ditch. We anticipate that its direction of correlation with AVERAGE CLASS to be the same as that for  $\text{CoG}^0$ .

#### 4. Econometric Analysis

In this section, we introduce the econometric model and the estimation methods. The primary goal of this section is to build an empirical model of the cost-sharing environment that is capable of explaining the choice of cost-sharing rule.

##### 4.1 Econometric Model

We begin by assigning the unit of observation to be the irrigation ditch, which is indexed from  $i = 1, \dots, n$ . We assume that the irrigators on each ditch are restricted to choose from the two classes of cost-sharing rules; average or serial. The choice of rule is in turn assumed to depend on structural characteristics as indicated by the following equation:

$$Y_i = X_i\beta + \varepsilon_i, \quad (1)$$

where  $Y_i$  is a latent variable measuring the likelihood of choosing either the serial or average cost-sharing class of rule for ditch  $i$ ,  $X_i$  is a row vector of explanatory variables for ditch  $i$

thought to influence the choice of rule,  $\beta$  is a column vector of coefficients, and  $\varepsilon_i$  is a normally distributed error term. By assuming a normal distribution, we then form the likelihood function conditional on the observed data. Letting  $\Phi$  indicate the mean-zero normal cumulative density function, we can write the probability that the  $i^{\text{th}}$  ditch chooses a rule from the average class (indicated by  $\omega_i = 1$ ) as:

$$P_i \equiv \text{Prob}(\omega_i = 1) = \text{Prob}(Y_i > 0) = \text{Prob}(\varepsilon_i > -X_i\beta) = 1 - \Phi(-X_i\beta).$$

Since there are only two classes of cost-sharing rule, the probability that the  $i^{\text{th}}$  ditch chooses the serial rule ( $\omega_i = 0$ ) is given by  $1 - P_i = \Phi(-X_i\beta)$ . Then assuming independence of error terms, we can write the (log) likelihood function as

$$\ln(L) = \sum_{i=1}^n (\omega_i \ln(P_i) + (1 - \omega_i) \ln(1 - P_i)).$$

The problem of forming and maximizing the (log) likelihood function by choosing  $\beta$ , given normally distributed error terms, is referred to as the probit model. This procedure results in an estimation problem requiring nonlinear optimization techniques to generate estimates of the  $\beta$  parameters and the associated marginal effects (see Greene 2000).<sup>7</sup>

## 4.2 Discussion of the Results

The estimation results from the probit model described above are presented in Table 2. The estimated coefficients are nearly all statistically significant (at standard significance levels) and the signs are generally in agreement with our expectations. Moreover, the overall fit of the model is excellent. As shown in Table 2, the likelihood ratio statistic testing whether all the variables are jointly able to explain variation in the dependent variable equals 72.6 with a 5%

---

<sup>7</sup>The estimation was carried out in Gauss 3.5 using the Constrained Maximum Likelihood (CML) module and Newton's method for the nonlinear optimization.

critical chi-square value of 18.3. Furthermore, Table 3, which reports the number of correct and incorrect predictions, shows that we are able to correctly predict 64 of the 67 average rules and 23 of the 27 serial rules, for nearly a 93% overall correct prediction percentage. It is particularly impressive that the model is able to correctly predict 85% of the serial rules, given the unbalanced nature of the dependent variable. As Greene (2000) points out, in order for the model to predict the less common category, it “. . . may require an extreme configuration of the regressors.”<sup>8</sup> In sum, using a relatively parsimonious model based solely on physical attributes of the irrigation environment, we are able to accurately predict which cost-sharing rule irrigators will collectively agree to use.

Turning now to the individual estimated coefficients in Table 2, we find that all the coefficients other than the constant and ROUGHNESS are statistically significant at standard levels. Note the missing P-value and marginal effect for the ALTERNATIVE USE variable. Since every ditch with a non-zero value for ALTERNATIVE USE also employs an average rule, the coefficient is not identified and any arbitrarily large value for the coefficient will guarantee that the model always correctly associates the ALTERNATIVE USE ditches with the average rule. Therefore, although we omit the P-value and marginal effect for the ALTERNATIVE USE variable, it is important to recognize that it provides a substantial source of explanatory power. The signs on the coefficients also generally conform to our expectations. Higher values for all the variables except RAINFALL and TAIL DIFFERENTIAL imply greater likelihood of observing the average rule.

---

<sup>8</sup>We also investigated the performance of the semi-parametric maximum score (MS) estimator. The MS estimator chooses the coefficients ( $\beta$ ) to directly maximize the number of correct predictions. Using the MS estimator, we correctly predict only one more cost-sharing rule (88 of 94) than the probit model. Therefore, although the probit model does not directly maximize any traditional goodness-of-fit measure, it appears to fit the data nearly as well as a semi-parametric estimator that does.



It is also interesting to note the magnitude of a change in the explanatory variables on the probability of choosing a particular cost-sharing rule. The marginal effects in column three of Table 2 measure the change in probability of choosing the average rule for an incremental change in each variable (evaluated at the means). Several marginal effects stand out as noteworthy. First, while holding all other variables constant at their means, adding an additional user (increase from 9 to 10 users at the mean) increases the probability of choosing an average rule by 0.9 percentage points. Second, increasing SOURCE DISTANCE from approximately one to two miles, all else equal, increases the probability of choosing an average rule by 20.6 percentage points. Third, adding one mile to the tail of the ditch (i.e., increase TAIL DIFFERENTIAL from approximately 0.10 to 0.21 at the average number of current users) increases the likelihood of choosing the serial rule by approximately 4.0 percentage points, all else equal. Fourth and finally, increasing the *original* center of gravity from 0.5 to 0.6 (i.e., moving the center of gravity of irrigated acres toward the tail of the ditch) increases the likelihood of choosing the average rule by 4.4 percentage points, while a similar increase in the *current* center of gravity, for a fixed original center of gravity, increases the likelihood of choosing the average rule by 6.4 percentage points. Thus, our data support the conjecture that an increase in either  $CoG^0$  or  $CoG$  DIFFERENTIAL tends to increase the likelihood of observing a rule within the average class as tail-end irrigators vote out of self-interest for an average mechanism to reduce their prescribed cost shares.

## 5. Conclusion

At the outset, we posed the question of whether the choice of cost-sharing mechanisms is arbitrary or systematically related to the physical environment of the agents involved in sharing costs. Our results, using data from a sample of irrigators in south central Montana, indicate that

the chosen cost-sharing rules are far from arbitrary. In fact, detailed information on the variation in (relative and absolute) benefits and costs associated with irrigation, as well as the distribution of agents along an irrigation ditch, display impressive explanatory power in determining whether agents on a particular ditch will choose a rule from either the average or serial class of cost-sharing mechanisms. Moreover, our survey indicates that the majority of these rules are quite stable, in the sense that the rules have typically remained unchanged through the better part of the previous century. This suggests that agents collectively (though not necessarily individually) consider the prescribed cost shares from the rules to be reasonably equitable.

Our results are also supportive of the spirit underlying axioms appealed to in the theoretical cost-sharing literature. Indeed, one of the fundamental principles of serial cost sharing is the protection of those placing small demands on a shared facility from the burdens imposed by those with large demands. (See, for instance, Moulin and Shenker 1992 or Kolpin 1998.) We find that when there is greater pressure for “fully cooperative” efforts, an outcome in the average class becomes more likely. Conversely, when cooperative pressure is reduced, or in the extreme, when there is a mounting tension from the introduction of “high demand” agents (those at the tail of the ditch), it follows an outcome in the serial class becomes the more likely result.

Furthermore, our empirical results appear to be robust. We considered alternative specifications by incorporating other theoretically reasonable explanatory variables such as the yield ratio between irrigated and non-irrigated land, ditch length, maximum ditch flow, total number of irrigated acres, variation in irrigated acres across users on a given ditch, gradient of the land, propensity for soil erosion, elevation, and a measure of cost savings to front-enders caused by the addition of new tail-enders. In addition to experimenting with other explanatory variables, we also examined (1) other tie-breaking rules for the few cases where irrigators

appeared to disagree about the existing cost-sharing rule; (2) a model allowing the irrigator, as opposed to the ditch, to be the unit of observation (allowing us to directly incorporate information on differing perceptions of the cost-sharing agreement); and (3) the possibility that the cost-sharing rules may display some degree of spatial clustering. Our overall conclusion is that our empirical results are not an anomaly, but rather representative of a stable relationship between the physical irrigation environment and the chosen cost-sharing rule.

Finally, we note that the results from this study may be useful in determining equitable and stable resource allocation mechanisms in other applications. Examples may include allocating resources across academic units at a university, sharing the costs stemming from increasing electrical output to a regional power grid, or determining a protocol for sharing costs associated with reducing the production of green house gases. While the structural parameters of such settings are quite different from those examined here, many of the same tensions and pressures between the partners of a cooperative venture remain.

## References

- Aadland, David and Van Kolpin (1998). "Shared Irrigation Costs: An Empirical and Axiomatic Analysis." *Mathematical Social Sciences* 35:203-218.
- Daly, C., R.P. Neilson, and D.L. Phillips (1994). "A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain." *Journal of Applied Meteorology* 33:140-158.
- Daly, C., G.H. Taylor, and W.P. Gibson (1997). "The PRISM Approach to Mapping Precipitation and Temperature." In reprints: *10th Conf. on Applied Climatology*, Reno, NV, American Meteorological Society, 10-12.
- Friedman, Eric and Hervé Moulin (1999). "Three Methods to Share Joint Costs or Surplus." *Journal of Economic Theory* 87:275-312.
- Greene, William (2000). *Econometric Analysis*. Fourth Edition. Prentice Hall, Upper Saddle River, NJ.

- Kolpin, Van (1998). "Equitable Nonlinear Price Regulation: An Alternative Approach to Serial Cost Sharing." *Games and Economic Behavior* 22:61-83.
- Koster, Maurice, Stef Tijs, and Peter Borm (1998). "Serial Cost Sharing Methods for Multi-Commodity Situations." *Mathematical Social Sciences* 36:229-242.
- McFadden, Daniel (1974). "The Measurement of Urban Travel Demand." *Journal of Public Economics* 3:303-328.
- Moulin, Hervé (forthcoming). "Axiomatic Cost and Surplus-Sharing." In *Handbook of Social Choice and Welfare*, Arrow, Sen, Suzumura eds., North-Holland.
- Moulin, Hervé (2001). "Fair Division and Collective Rationality." Mimeo.
- Moulin, Hervé and Scott Shenker (1992). "Serial Cost Sharing." *Econometrica* 60:1009-1038.
- Shapley, Lloyd (1953). "A Value for n-Person Games." In *Contributions to the Theory of Games, Vol II*, H. W. Kuhn and A. W. Tucker, eds., Ann. Math. Studies 28, Princeton Univ. Press, Princeton, NJ.
- Sprumont, Yves (1998). "Ordinal Cost Sharing." *Journal of Economic Theory* 81:126-162.
- State Water Conservation Board (1946). Water Resources Survey: Stillwater County, Montana. Helena, MT.
- State Water Conservation Board (1966). Water Resources Survey: Carbon County, Montana. Helena, MT.
- Thomson, William (forthcoming). *The Theory of Fair Allocation*. Princeton Univ. Press, Princeton, NJ.

Table 1. Descriptive Statistics

Variable	Statistics				
	Mean	Standard Deviation	Minimum	Maximum	Sample Size
Average Class	0.713	0.455	0.000	1.000	94
Town	0.382	0.336	0.033	1.000	27
Alternative Use	0.181	0.146	0.040	0.500	10
Rainfall	198.791	25.460	116.306	243.946	94
Roughness	3.777	3.246	0.000	18.716	94
Runoff	1.408	0.451	0.000	2.333	94
Number of Users	8.848	10.416	2.000	61.417	94
Source Distance	0.998	1.045	0.000	5.403	94
Tail Differential	0.101	0.211	0.000	1.342	94
Original CoG	0.497	0.144	0.140	0.859	94
Current CoG	0.514	0.125	0.192	0.859	94

Notes: For the *Town* and *Alternative Use* variables, the reduced sample size reflects only ditches with positive values for the variables. The *Number of Users* variable has a non-integer maximum because the number of users was not listed in the state records. Therefore, we imputed the number of users for the incorporated ditches using the sample ratio of fields per user for unincorporated ditches (the number of fields was available for incorporated ditches).

Table 2. Probit Estimates (Average Rule = 1, Serial Rule = 0)

Variable	Statistics		
	Coefficient Estimate	P Value	Marginal Effect
Constant	-2.570	0.248	--
Town	5.419**	0.037	0.376
Alternative Use	86.355	--	--
Rainfall	-0.025*	0.061	-0.002
Roughness	0.076	0.137	0.005
Runoff	1.421**	0.023	0.099
Number of Users	0.125**	0.031	0.009
Source Distance	2.971***	0.000	0.206
Tail Differential	-5.259***	0.001	-0.365
Original CoG	6.301**	0.012	0.437
CoG Differential	9.156***	0.002	0.636
Sample Size		94	
Likelihood Ratio Statistic		72.627	
McFadden's Pseudo R <sup>2</sup>		0.644	

Notes: The marginal effects are evaluated at the mean. (\*), (\*\*), and (\*\*\*) indicate significance at the 10%, 5%, and 1% level, respectively. The *Alternative Use* coefficient is not identified as every ditch with positive values for the variable employ the average rule. In this sense, it is a perfect predictor of the cost-sharing rule and any arbitrarily large coefficient would generate the same goodness-of-fit.

Table 3. Number of Correct and Incorrect Predictions

	Actual		Totals	
		Average		Serial
Predicted	Average	64	4	68
	Serial	3	23	26
Totals		67	27	94

Notes. 64 of the 67 average rules (96%) and 23 of the 27 serial rules (85%) were predicted correctly. Overall, 87 of the 94 rules (93%) were predicted correctly.