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Coping with Asymmetries in the Commons: Self-Governing Irrigation Systems Can Work

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Common-pool resources are natural or man-made resources where exclusion is difficult, and yield is subtractable (Gardner, E. Ostrom, and Walker, 1990).[1] They share the first attribute with pure public goods; the second attribute, with pure private goods. Millions of common-pool resources exist in disparate natural settings, ranging in scale from small inshore fisheries, irrigation systems, and pastures to the vast domains of the oceans and the biosphere.

The first attribute—difficulty of exclusion—stems from many factors, including the cost of parceling or fencing the resource and the cost of designing and enforcing property rights to exclude access to the resource. If exclusion is not accomplished by the design of appropriate institutional arrangements, free-riding related to the provision of the common-pool resource can be expected. After all, what rational actor would help to provide the maintenance of a resource system, if noncontributors can gain the benefits just as well as contributors? The extent to which a common-pool resource will be provided is a complicated problem, depending on how preferences are articulated, aggregated, and linked to the mobilization of resources.

The second attribute—subtractability—is the key to understanding the dynamics of how the "tragedy of the commons" can occur. The resource units (like acre-feet of water, tons of fish, or bundles of fodder) that one person

[1]Our definition of common-pool resources focuses on the structure of the *resource* while Seabright's paper in this issue focuses on the *property regime* related to a resource (or other common property). Most farmer-organized irrigation systems fit Seabright's conception of a common-property regime.

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appropriates from a common-pool resource are not available to others. Unless institutions change the incentives facing appropriators, one can expect substantial overappropriation. For example, those who fish from a lake derive all the benefit from catching additional fish. However, the depletion of the fishery is a cost shared with other fishermen. The private gain is thus very likely to overbalance any single fisherman's share of the social loss. Or, to put it another way, no single fisherman can prevent depletion of the fishery by restricting his personal catch. The fishery is thus likely to be pushed to the brink of extinction unless institutions counteract these incentives.

In prevailing theories, the temptation to free-ride on the provision of key infrastructures is viewed as a major deterrent to successful economic development. David Freeman (1990, p. 115) concisely describes this problem in relation to irrigation:

> The logic of the individually rational utility seeker may not coincide with the logic of the community. If, for example, farmers individually observe that their leaky and misaligned water course requires improvement, they will not invest in corrective action on individually rational grounds. Assuming a sizable number of farmers, each will calculate as follows. If one farmer invests time, energy, and money required to improve the channel going through his or her own land and other farmers do not make comparable corrective investments in a coordinated fashion, then the payoff in improved water supply and control (the collective good) is negligible.
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> However, if many farmers undertake the improvement effort on each of their sections, and one individually rational decision-maker does not do so, she or he will still enjoy a substantial share of the benefit provided by the work of others, at no personal cost. Therefore, the rational, calculating individual will choose to do nothing either way. The collective good will not automatically evolve, even though the individuals in question may possess full and accurate information about the potential benefits of improving the channel and may have the required know-how and resources to do so.

To make matters even more difficult, maintaining an irrigation system over the long term requires immediate and costly contributions of labor or fees, while benefits are hard to measure and dispersed over time and space. Whatever allocation rules that officials and/or farmers establish for an irrigation system, there is the temptation to cheat by taking more water than authorized, by taking water at an unauthorized time, or by contributing less inputs than required for provision of one's given water allocation. For example, rice farmers prefer to keep their rice paddies flooded continuously, since rice is intolerant to drying and highly tolerant to excess water. Extra water keeps weeds under control on those paddy fields that obtain the water, but could be used more efficiently to yield a larger quantity of rice.

Empirical evidence from field and experimental settings amply demonstrates that, without effective institutions, common-pool resources will be underprovided and overused (Cordell, 1978; E. Ostrom, Gardner, and Walker, forthcoming 1993; Clark, 1974; Larson and Bromley, 1990). Substantial controversy exists, however, concerning how to remedy the problem. Many analysts presume that common-pool resource appropriators are trapped in a Hobbesian state of nature and cannot themselves create rules to counteract the perverse incentives they face. The logical consequence of this view is to recommend that an external authority—"the" government—take over the commons. Further, where technical knowledge and economies of scale are involved, it is presumed that this external force should be a large, central government. Central governments are seen as necessary agents of change to break the control of powerful individuals in rural areas who underinvest in collective action and obtain a disproportionate share of whatever is generated. Of course, recommending government action can lead to a wide range of policy interventions, from having the government impose a market, to recommending that national governments manage common-pool resources themselves.

The theoretical presumption that an external, central government is necessary to supply and organize forms of collective action, such as providing irrigation works, has been reinforced by the colonial experience. During the colonial period in many parts of Asia and some parts of Africa, large-scale governmental bureaus were established to develop previously unirrigated areas. Such areas were opened for settlement and oriented toward the production of cash crops for export. The resulting centralization of governmental power over the supply of irrigation water has been continued, in most instances, by the governments that were created as colonial powers left the scene. In much of the developing world, irrigation development "has been highly distorted by the process of state concentration of investments and governance, and the concomitant demise of local rights and initiatives" (Barker et al., 1984, p. 26).

National governments in many parts of the developing world have come to be perceived as the "owner" of all water, as well as other natural resources (Sawyer, 1992). From this viewpoint, national governments become the only agency that should or could invest in constructing and managing irrigation systems. This orientation toward the necessity of central authority is intensified by a second presumption that supplying irrigation requires considerable technical expertise, which is unlikely to be found locally. Together these lead to a belief that "scarce technical expertise is best located in a powerful state bureaucracy where it can be effectively dispensed" (Barker et al., 1984, p. 26). International aid agencies reinforce this predilection toward professional, central control over the supply of irrigation water by their inclination to work directly with the central ministries of the national government to whom aid funds are extended.

Considerable recent research has challenged the assumption that appropriators cannot set rules affecting the use of common-pool resources (Bardhan, forthcoming). Considerable empirical evidence from field and experimental settings holds that appropriators frequently do constitute and enforce their own rules, and that these rules work.[2] The initial research has focused primarily on groups where most of the relationships among participants are relatively symmetric with regard to assets, interests, and the physical situation, and on situations where the problems they face are relatively simple to overcome. In such situations, appropriators do take "time out" from operational decisions to design rules that improve the joint yield that they can obtain (E. Ostrom, 1990; E. Ostrom, Gardner, and Walker, forthcoming 1993; Berkes, 1989; V. Ostrom, Feeny, and Picht, 1993; Berkes et al., 1989; McCay and Acheson, 1987; Wade, 1988; Bromley, 1992). In Valençia, Spain, Hirano, Japan, and Törbel, Switzerland, for example, local appropriators have designed, monitored, and enforced their own rules to sustain intensive use of local common-pool resources for many centuries (Maass and Anderson, 1986; McKean, 1992; Netting, 1981).

Now more difficult questions can be posed. These tougher questions center on whether individuals who differ substantially—in regard to their economic or political assets, their information, or their physical relationship—can craft rules that enhance joint output, distribute output equitably, or both (Johnson and Libecap, 1982; Keohane, McGinnis, and E. Ostrom, 1993). Of course, the answer to this question will likely be: "It depends." So the task of this research agenda is to develop a coherent understanding of the set of conditions that enhance or detract from self-organizing capabilities when individuals differ substantially from one another.

For the sake of concreteness, this paper focuses on the asymmetry present on most irrigation systems between those who are physically near the source of water (the headenders) and those who are physically distant from it (the tailenders). This paper first explores the interaction between head-end and tail-end farmers, particularly their decisions about whether to devote resources to the upkeep of the irrigation system, and how bargaining between the parties can benefit all sides. Finally, we examine empirical evidence from a study of irrigation institutions in Nepal, and discuss the broader practical significance of our findings.

An Irrigation "State of Nature" Game

In large-scale, centrally constructed irrigation systems, the headenders and the tailenders are in very different positions. Narrowly selfish headenders would ignore the scarcity that they generate for those lower in the system. But if the headenders get most of the water, those at the tail end have even less reason to want to contribute to the continual maintenance of their system. All common-pool resources generate both appropriation and provision problems.

[2] This research is closely related to the more general question of how institutions evolve and perform (Calvert, forthcoming 1993; Knight, 1992; V. Ostrom, 1991; Milgrom, North, and Weingast, 1990).

In an irrigation common-pool resource, the appropriation problem concerns the *allocation* of water to agricultural production; the provision problem concerns the *maintenace* of the irrigation system. In addition, irrigation common-pool resources also have an asymmetry between headenders and tailenders, which increases the difficulty of providing irrigation systems over time.

We model the strategic interaction between headenders (player 1) and tailenders (player 2) of an irrigation system as follows. There is a temporary structure, a headworks, at the very beginning of the system, which brings water into the system. This structure has to be rebuilt annually. The total amount of water (W) brought into the system depends on how much labor headenders (L_1) and tailenders (L_2) provide. The decision to provide labor is taken simultaneously under the condition of complete information. Once water starts flowing, headenders, who get first crack at it, take the lion's share of it (75 percent), while tailenders get what is left (25 percent). The opportunity cost of providing a unit of labor is constant throughout the system, and equal to 1.

Since the payoffs to each end of the system depend on what both ends do, the situation they face is a game of strategy. However, the incentives facing the two ends of the system are very different. The headenders have a physically advantageous position, and get most of the water. The first order condition on headenders' labor says that the marginal product of labor equals its opportunity cost ($.75\ \partial W/\partial L_1 = 1$). The first order condition on tailenders' labor says that the marginal product of their labor also equals opportunity cost ($.25\ \partial W/\partial L_2 = 1$). Under the usual concavity assumptions, these first order conditions imply that headenders supply more labor than tailenders. We should observe a pattern over time in which headenders contribute more labor and get more water.[3]

This model is illustrated by the Thambesi irrigation system in Nepal, organized by farmers, where the Thambesi River provides a source of water that is easy to channel and requires little annual maintenace (unlike most farmer-organized systems). The headworks of the Thambesi system is a simple brush and stone diversion works that is easily adjusted each year to fit changes in the course of its source (Yoder, 1986, p. 179). Routine maintenance carried out prior to the monsoon rains requires "only four to five hours of work with all the members participating" (p. 180). As a result, it is possible for some of the farmers alone to keep this system going. "The members with holdings in the tail cannot force those with land above theirs to deliver water to them equally by not participating in maintenance and other system activities" (p. 179).

Thambesi is one of the few farmer-organized systems where headenders have clearly established prior rights to water over those lower in the system. Farmers at the head of each rotation unit "fill their fields with water first before those further down the secondary are able to take water" (Yoder, 1986, p. 292). During the pre-monsoon seasons, farmers at the head of the system grow water-intensive rice. Consequently, no one lower in the system can grow an

[3]Corner solutions are also possible, but we still have $L_1 > L_2$.

irrigated crop during this season. If the headenders were to grow wheat instead of rice, an area nearly ten times as large could be irrigated during the pre-monsoon season (p. 313).[4] In this system, measured crop yields are correlated with distance from the headworks. Substantial land that could benefit from irrigation depends entirely on rainfall.

The game equilibrium with headenders contributing more than tailenders has undesirable properties, in the sense that production will be less than optimal and the system will be undermaintained. The tailenders work less for less water, and the whole system suffers. These considerations suggest that irrigators have good reason to leave the state of nature and reconstitute their system, crafting better rules to follow. Indeed, when the equilibrium is most seriously inefficient, the incentives to seek out a new system are greatest. The next section takes up the issue of bargaining over the rules of the game.

Bargaining Over the Rules of the Game

If their rights to govern and manage their own irrigation system are recognized, or at least not interfered with, farmers on systems that require much more labor input than Thambesi can take a "time out" between seasons and attempt to add or reform rules that improve their system outcome (Gardner and E. Ostrom, 1991). The annual meetings of irrigators to decide on the rules affecting appropriation and provision activities can be modeled as a bargaining problem. If no agreement is reached in these annual meetings, the irrigators return to the equilibrium of the state of nature game discussed in the previous section.

The challenge to bargaining is to find an outcome that benefits both parties, relative to the prevailing state of nature equilibrium. After all, if either party is not improving themselves, they will not accept the bargain.

We illustrate these ideas with a simple numerical example. The water production function is $W = 2(L_1^{0.5} + L_2^{0.5})$. The objective function for the entire system is to maximize water less the opportunity cost of labor, that is, maximize $W - L_1 - L_2$. The optimum is achieved when the marginal product of labor at each end of the system equals its opportunity cost, 1. Solving the resulting first order conditions, we find that each end of the system supplies 1 unit of labor, producing 4 units of water. By contrast, in the equilibrium in the state of nature, the headenders would supply .56 units of labor; the tailenders, .06 units; and only .2 units of water are produced.[5] Labor is seriously

[4] Yoder's (1986) research also demonstrates that where the farmers own shares of the water system and can sell these shares, the incentives faced by headenders are entirely different. In such a property-rights regime, headenders can capture part of the capitalized value of the benefits of allocating more water to those lower in the system. Thus, a change in the institutional arrangements related to a physical environment dramatically changes the incentives of participants and the efficiency and equity of outcomes.

[5] In the state of nature, the first order condition for headenders is $.75\,\partial W/\partial L_1 = 1$; for tailenders, $.25\,\partial W/\partial_2 = 1$. Since $\partial W/\partial L_1 = L_1^{-0.5}$, we get $L_1 = (.75)^2$. Similarly, we get $L_2 = (.25)^2$.

underprovided, and water is a fraction of what it should be. Of this flow of water, 75 percent (1.5 units) would go to the headenders; 25 percent (.5 units), to the tailenders.

A bargain in this situation would consist of a water-for-labor exchange. That is, the headenders would agree to work more, as would the tailenders. In exchange, the tailenders would get a lot more water. One possible bargaining solution would be as follows. The head end works .86 more; the tail end, .98 more. This gets them up to 1 unit of labor each, the optimal labor input. Extra water is proportional to extra labor, so the tail end gets $.94/(.44 + .94) = 68$ percent of the additional water produced. The water reaching the tail end rises from .5 to $.5 + .68(2) = 1.86$ while the head end comes out of this bargain with $1.5 + .32(2) = 2.14$ units of water. Everyone comes out ahead.[6]

This bargaining solution has an important empirical implication. Notice that the difference in the quantity of water allocated to the head end and the quantity allocated to the tail end has shrunk, due to the bargain struck. In the state of nature, the head-tail difference was $1.5 - .5 = 1$; in the bargain, the difference is only $2.14 - 1.86 = .28$. Although there is still a difference, it is considerably lower (36 percent). A reduction of the difference between head-tail water allocation of this magnitude should show up empirically. In the next section, we test the hypothesis that head-tail water differences are reduced in those systems where farmers are authorized to devise agreements between the two ends of the system.

Several factors in the field can affect the bargaining problem between headenders and tailenders. For instance, the presence of a permanent headworks, which reduces overall labor required, will favor headenders over tailenders in the event that negotiations break down. Headenders may even maintain the system all by themselves, and take all the water they want. Such a production asymmetry reinforces the locational asymmetry. On the other hand, if there is real mutual dependence, and the productivity of labor of the tailenders offsets the distributional advantage of the headenders, then the asymmetries tend to offset one another and the bargains struck are relatively symmetric.

In instances of symmetry, an entire family of rotation rules are used in practice that enable the irrigators to split the water and the labor about evenly. As examples, here are two rotation rules that suffice to transform the state of nature game into a game with a symmetric bargaining solution.

In *Rotation Rule A*, in odd-numbered years, water goes first to the headender and in even-numbered years water goes first to the tailender. Both headenders and tailenders work side-by-side for any days devoted to maintaining the system. An example of a similar rule, based on season rather than year, is found on the Marpha farmer-organized system in the Mustang District of

[6]There are many solutions to this bargaining problem. Well-known solutions, such as those of Nash and Kalai-Smorodinsky, yield predictions qualitatively similar to this one.

Nepal, where barley is planted in the winter and buckwheat is planted in the summer. Fields devoted to barley were watered from the top of the system to the bottom, while the ordering for buckwheat was reversed so that the tail-end fields received water first (Messerschmidt, 1986).

In *Rotation Rule B*, all water in the system is allocated to the headenders for even days of the seasons and all to the tailenders for the odd days of the season. Headenders maintain the canal for one time period and tailenders maintain the canal for an alternative, but equal, time period. This rule is illustrated by the Yampa Phant system described below.

Both of these rules result in an equal split of the rights of appropriation and the duties of provision. Whether written or unwritten, rotation rules of this sort are the common knowledge of all participants on a farmer-governed system. Further, farmers actively monitor each others' conformance to these rules (Weissing and E. Ostrom, 1991, 1993).

Over time, these rules can easily be adapted to a situation where both water and labor are allocated in an unequal but proportional manner. For example, Rotation Rule A might be amended to say that in years not divisible by 3, water goes first to the headender, while in years divisible by 3, water goes first to the tailender. Headenders devote twice as much labor as tailenders on side-by-side workdays devoted to maintaining the system. The analogous version of Rotation Rule B would state that all water in the system is allocated to the headenders for days of the seasons not divisible by 3. All water in the system is allocated to the tailenders for days of the season divisible by 3. Headenders maintain the canal for twice the time period that tailenders do.

Of course, the rules as actually discovered in field settings are rarely this cut-and-dried. The rotations involved are often quite a bit more complicated. Rules that relate to routine maintenance frequently differ from those that relate to emergency repairs. Also, the proportionality may be multidimensional: water allocated is proportional to one variable, while labor provided is proportional to another. The set of variables upon which proportionality is based can include landholding, total labor in the household, labor relative to land held, physical capital, and votes held in a voting system. When rules are based on a clear principle of proportionality and all participants recognize that the rules enable them to reach better outcomes than feasible in the "state of nature" game, and all are prepared to punish rule breakers, more productive equilibria are reached and sustained over time. Although the details of any given irrigation system can appear bewildering, the strategic principles we have identified above are recurring regularities in data drawn from the field. It is to these data that we now turn.

Empirical Evidence

It is difficult to conduct empirical tests of these kinds of theoretical findings. One should expect to observe a wide diversity of outcomes, regarding the level of net benefits achieved, their distribution between the head and tail portions of irrigation systems, their persistence over time, their efficiency, and their equity. The real world offers any number of potentially confounding variables, raising the risk that any seeming failure of the theory might be justified, after the fact, by introducing a new explanatory variable. Until recently, no large-scale data set with the appropriate variables existed that could be used for this purpose. However, the discovery of a large number of case descriptions of farmer- and government-operated irrigation systems in one country, Nepal, has led to the development of the Nepal Institutions and Irrigation Systems database, in which data for 127 systems has been coded (E. Ostrom, Benjamin, and Shivakoti, 1992).

Nepal has an area of about 141,000 square kilometers, slightly larger than England. Its 18 million inhabitants are engaged largely in agriculture. Of the approximately 650,000 hectares of irrigated land, irrigation systems operated by farmers cover about 400,000 hectares, or 62 percent (Small, Adriano, and Martin, 1986). The remaining irrigated land is served by a variety of agency-managed irrigation systems, many of which have been constructed since 1950 with extensive donor assistance. On some of the agency-managed systems, farmers have organized themselves and do participate in second-level, choice-of-rule games, but they are far more active in devising appropriation and provision rules in farmer-managed systems.

Irrigation occurs extensively in the hills (frequently quite steep), in the river-valleys (the terrain is more undulating), and in the flat and more fertile Terai, located in the southern part of the country, which has only been devoted to extensive agriculture since the successful eradication of malaria. In the hills, irrigation systems have several plateaus where it is very easy for farmers on the first plateau to get most of the water to their fields before any water goes on to the second or third plateau. Thus, one would expect that the problem of physical asymmetries would be easier to deal with in the Terai than in the hills.

In Nepal, farmer-managed irrigation systems achieve a high average level of agricultural productivity. Of the 127 systems in the Nepal database, we have productivity data for 108. The 86 farmer-managed irrigation systems average 6 metric tons per hectare a year; the 22 agency-managed irrigation systems only 5 metric tons per hectare, a statistically significant difference ($p = .05$). Farmer-managed irrigation systems tend also to achieve higher crop intensities.[7] A crop intensity of 100 percent means that all land in an irrigation system is put to full use for one season, or partial use over multiple seasons amounting to the

[7]It should be noted that farmer-managed systems are on average smaller than agency-managed irrigation systems, but the size of the system is not significantly related to agricultural productivity when we control for the type of governance and for other physical attributes controlled by governance, like the presence of permanent headworks and at least partial lining of the irrigation channels (Lam, Lee, and E. Ostrom, forthcoming). Some farmer systems as large as 15,000 farmers have sustained themselves for very long periods of time. Scale is, however, an important fact affecting the cost of organizing these (or agency-operated) systems.

same crop coverage. Similarly, a crop intensity of 200 percent is full use for two seasons; 300 percent, full usage of all land for three seasons. Farmer-managed irrigation systems achieve a higher average crop intensity (247 percent) than do agency-managed irrigation systems (208 percent). Again, the difference is statistically significant.

The agricultural yields and crop intensities that farmers obtain depend on whether they can be assured of water during the winter and spring seasons, when water becomes progressively scarcer. A higher percentage of farmer-managed irrigation systems in Nepal are able to get adequate water to both the head and the tail of their systems across all three seasons, as shown in Table 1. During the spring when water is normally very scarce, about 1 out of 4 farmer-managed irrigation systems are able to get adequate water to the tail of their systems, while only 1 out of 12 agency-managed irrigation systems get adequate water to the tail of their systems. Even in the summer monsoon season, only about half of the agency-managed irrigation systems get adequate water to the tails, while almost 90 percent of the farmer-managed irrigation systems get water to the tail of their system. It is pretty clear that most of the farmer-managed systems have engaged in substantial bargaining to get out of the state of nature game and achieve higher equilibria possible by adopting their own commonly understood rules.

To further address why farmer-managed irrigation systems are more likely than agency-managed systems to distribute water more equitably between head and tail, we conduct a regression analysis. This shows how physical variables and type of governance structure combine to affect the difference in water availability achieved at the head and the tail of irrigation systems.

The dependent variable in our regression is called "water availability difference." This variable compares the availability of water at the head of the system minus the availability of water at the tail of the system, averaged across three seasons. We measured water availability on a scale with three possibilities: adequate, receiving a score of 2; limited, with a score of 1; and scarce or nonexistent, with a score of zero. Thus, an overall score of zero indicates that for all three seasons, the level of water adequacy was the same in the head and tail sections of the system. A score of .33 indicates that in one season, the head received adequate water and the tail received limited water or that the head received limited water and the tail received scarce water.[8]

The independent variables in the regression include the length of the canals in the system (measured in meters); the labor input (measured by the number of labor days devoted to regular maintenance each year, divided by

[8]For the 118 systems for which we have data, the difference score ranges from −.66 to 1.66. The regression presented in the text is based on data for 76 systems for which we had data on all variables in the regression equation. A parallel analysis using multinomial probit estimates yields parallel findings concerning the direction and significance of permanent headworks and type of system, but the negative relationship between terrain and the difference score does not reach statistical significance.

Table 1
Water Adequacy[a] by Type of Governance as Arrangement and Season

Season of Year	*% of FMIS with Adequate Water at the Head*	*% of FMIS with Adequate Water at the Tail*	*% of AMIS with Adequate Water at the Head*	*% of AMIS with Adequate Water at the Tail*
Monsoon	97	88	92	46
Winter	48	38	42	13
Spring	35	24	25	8

[a]Water adequacy was measured on a four-point scale from adequate to nonexistent based on structured coding of field visits and case studies.

the number of households served); four dummy variables, for the presence of permanent headworks, lining of the canals, whether the system is in the Terai, and whether the system is farmer-managed; and a constant.

We have data on all of these variables for 76 of the irrigation systems.[9] The length and labor input variables are not significantly different from zero. However, the coefficient on headworks (.34) and whether the system is farmer-managed (−.32) were both significant at the 95 percent level, while the coefficients on the lining of canals (−.14) and whether the system was in the Terai (−.10) are both significant at the 90 percent level. The regression also contained a constant term of .64, significant at the 95 percent level. However, the R^2 for the regression was only .28. At this point, we treat these results as initial and tentative. Field teams are collecting data from a larger set of systems during the summer of 1993, so additional analyses will be conducted on a larger data set in the future.

This preliminary analysis raises questions about how the physical characteristics of an irrigation system affect the capacity to distribute the gains from mutual cooperation equitably. The difference in water availability achieved at the head and the tail of these Nepali irrigation systems is significantly and negatively related to being in the Terai, presumably because the headender advantage is less marked in the plains than in the hills. The presence of permanent headworks—which are frequently considered as one of the hallmarks of a modern, well-operating, irrigation system—is positively related to a inequality between the water availability achieved at the head and the tail. Presumably, one reason is because permanent headworks increase the bargaining position of headenders, relative to tailenders. Lining of canals, on the other hand, preserves more water for tailenders and reduces water availability differences. Finally, the difference in water availability is significantly reduced at the tail of farmer-managed irrigation systems, as compared to that of

[9]This subset of 76 systems does not appear to differ on any relevant variable from the larger data set.

agency-managed irrigation systems, presumably because farmer-managed systems are more likely to reach bargaining solutions about their own operational rules that more effectively take tailender interests into account.

The construction of a permanent headworks has frequently been funded by external sources, with farmers not required to repay the cost of this investment. This type of external "aid" substantially reduces the need for mobilizing labor (or other resources) to maintain the system each year, a reduction that has normally been interpreted in project plans entirely as a benefit. However, this claim of undiluted benefit is made too quickly; the construction of extensive infrastructure facilities without requiring that capital investment be paid back by beneficiaries has two adverse consequences. First, without a realistic requirement to pay back capital investments, farmers and host government officials are motivated to invest in rent-seeking activities and may overestimate previous annual costs to obtain external aid (Repetto, 1986). Second, this form of aid can change the pattern of relationships among farmers within a system, reducing the recognition of mutual dependencies and patterns of reciprocity between headenders and tailenders that have long sustained the system. By denying the tailenders an opportunity to invest in the improvement of infrastructure, external assistance may prevent those who are most disadvantaged from being able to assert and defend rights to the flow of benefits (Ambler, 1990). Let us offer an example of these distressing consequences, as they occurred in an agency-managed irrigation system.

The Kamala Irrigation Project, located in the Terai, illustrates the problem of building sophisticated and expensive capital structures without paying attention to the design of institutions that will bring appropriation and provision decisions into close juxtaposition. Kamala was constructed during the 1970s by the Department of Irrigation (then called Department of Irrigation, Hydrology and Meteorology). It was originally designed to serve 25,000 hectares in a section of the Terai where farmers had practiced rain-fed agriculture, but had not been previously organized to provide their own irrigation systems. A permanent, concrete headworks and a fully lined canal were constructed with the financial assistance of the Asian Development Bank. The system was completed during the 1983–84 agricultural year. Since then, no water fees have been imposed or collected. The system has never been able to supply irrigation water to all of the lands within its official service area.[10] The Kamala Project staff is financed from the general revenues of the central government and few funds have been collected to the continued operation and maintenance of the system. Project personnel spend most of their time operating and maintaining the huge concrete headworks that divert water from the Kamala River to the main and branch canals, and very little time maintaining the rest of the system. Few field canals have been constructed and farmers have broken through the branch canals to obtain water.

[10] This could be due to an overoptimistic estimate of the service area in the first place, a problem that happens frequently when a positive benefit-cost ratio is required in the project design phase.

Neither government nor farmers have undertaken responsibility for operating or maintaining the system below the headworks. The absence of organization at the water use level has generated a high level of conflict and led to an inequitable water distribution pattern. As described by a field research team (Laitos et al., 1986, p. 147):

> Water allocation is primarily first come, first served. Thus, farmers at the head... tend to get all the water they need, while farmers at the tail often receive inadequate and unreliable amounts of water. This situation has often led to conflict between head and tail farmers. Sometimes hundreds of farmers from the area near the middle village of Parshai will take spears and large sticks and go together to the head village of Baramajhia to demand that water be released. At Baramajhia, farmers are often guarding their water with weapons. If water is released, Parshai farmers have had to maintain armed guards to assure that the... canal remains open.

Even with all of the investment made in physical works, this irrigation system is operating in a "state of nature" with regard to the establishment of rules to allocate water or provision responsibilities. The agricultural yields obtained in this system vary dramatically, depending on water availability, but crop intensity is generally below average: at the head, 180 percent; at the tail, 150 percent.

In marked contrast to the Kamala Irrigation Project is another agency-managed irrigation system, the Pithuwa Irrigation Project, also located in the Terai. While the Department of Irrigation invested in constructing and lining 16 branch canals, it did not attempt to build a permanent intake structure. The system was designed to serve about 600 hectares, but farmers have extended the system to serve 1,300 hectares of land by rotating the fields devoted to rice during the monsoon on an every-other-year basis. The location of many of the larger landowners near the tail of the system (which is also near to the east-west highway and thus low cost transportation of produce to markets) is a fortuitous circumstance that counterbalanced the lack of attention by the government to the design of complementary allocation and resource mobilization rules. Even with many absentee landowners and sharecropping arrangements, this system has managed considerable self-organization.

While there are many effective farmer-managed irrigation systems in its district, the area served by the Pithuwa system depended on rain-fed agriculture and was not organized prior to canal construction. In the early days of project operation, water distribution was based on a "might is right" principle and there were many conflicts and feuds similar to those that still exist on the Kamala Project. The origin of the current high level of farmer participation at Pithuwa is interesting as it evolved from organization on one branch at the tail of the system to the organization of the entire system (Laitos et al., 1986, pp. 126–27).

> . . . one prominent farmer took the initiative to organize the other farmers on Branch 14 into a committee, which formulated rules for water allocation and distribution along Branch 14. With farmer participation in committee activities, conflicts over water sharing along the branch canal decreased in a short time. Other branches started to follow the example set by the farmers of Branch 14. Eventually, all of the branch farmers created branch committees for water allocation and distribution. . . . Once the branch canal committees were working satisfactorily, a federation of the branch canal committees created a general assembly of farmers and a main canal committee.

From this initial organization, a two-tier system now covers the entire system and governs many aspects related to the operation of the overall system, as well as individually crafted rules to operate each of the 16 branches. The main canal committee is responsible for allocating water among the 16 branch canals. During the monsoon season when water is abundant, all branches receive water. Given the crop rotation, half the farmers plant rice, while the other half plant vegetables, seeds, and fibers.[11] This crop rotation, which is tantamount to a water rotation, allows a doubling of the irrigated area. When water is scarce, however, the "committee arranges a rotation system. They then allocate water to the tail outlets first for a set number of days, and then to the head outlets" (Laitos et al., 1986, p. 130). Each branch committee determines its own allocation rules and the rules differ substantially from branch to branch.

> In branches 1 and 2, four hours of water per *bigha* (0.66 hectare) are allocated, whereas in branches 3 and 16, two hours per *bigha* are allocated. The time for allocation is based on the nature of the soil, the size of the fields, the volume of water available, and the frequency of watering required for the crop. On some branches, daytime water is allocated for transplantation, and nighttime water is allocated for fields that are transplanted. Each committee has adopted rules that suit their soil, crops, and the availability of water in the branch canal.

Further, adequate representation of the head and tail sections of each branch is assured by a rule that if the chairman of a branch commmittee comes from the head portion of that branch, the secretary must come from the tail, and vice versa (Giri and Aryal, 1989, p. 15).

Given the strength of the branch and system committees, the Department of Irrigation has gradually turned over the maintenance and operation of this system to the farmers. Repairing the intake structure each spring before the monsoon season is a huge task, implemented with the assistance of a

[11]Crop rotations such as this require the full cooperation of farmers since they are foregoing choice about what to plant on the land they own. Once established, they are easy to monitor.

government bulldozer and a budget to purchase the fuel for the bulldozer. The responsibility for cleaning the branch canals has been assigned to each branch canal committee using several methods. Some branches "contract out" the cleaning of their canals based on a competitive bidding system, whereby the lowest bidder is awarded the contract for a year. The funds to pay for this maintenance are raised by the farmers through an assessment imposed by the farmers' committee based on the size of a farmers' holding. On other branches, the farmers themselves clean the canals and the rules for labor mobilization are determined by that branch.[12]

Agricultural practices on this system are considered to be among the best of the agency-managed irrigation systems. The average crop intensity achieved at the tail end of the system (228 percent) is slightly higher than at the head end (221 percent), which is explained by the location of larger farms at the tail of the system and the strong incentives created by the proximity of the tail to an all-weather road. Soils and other factors are similar throughout the system. Even though this is formally an agency-managed irrigation system, the farmers have nearly the same local authority as in a farmer-managed irrigation system.

On farmer-managed irrigation systems, the diversity of appropriation and provision rules adopted is substantial and closely related to the types of labor requirements needed to keep the systems operational. The owner-operators of the Yampa Phant irrigation system, a very old 40-hectare system located in the hills, for example, do not need to invest in massive resource mobilization during the spring to build or repair their headworks, as they and a neighboring system have built a permanent storage structure to retain water from a perennial spring. They are, however, concerned about the daily upkeep of their 12 outlets during the monsoon rains and have devised a labor rotation system during the period of peak labor demand (Laitos et al., 1986, p. 97).

> During the summer paddy season, maintenance responsibility is rotated among the 12 outlets daily. One laborer per day per outlet is required. After 12 days, responsibility shifts back to the farmers served by the first outlet. Within each field channel served by an outlet, farmers also rotate the responsibility for main system maintenance. Each farmer takes a turn inspecting the main canal and making necessary repairs. Everyone participates during an emergency.

During periods of water abundance, water is available on demand. During the winter season of water scarcity, the upper six outlets receive water for one 24-hour period and the lower six outlets receive water for the next 24-hour period. The farmers of Yampa Phant have thus devised a set of rules that is

[12]Farmers are allowed to register for more irrigation water than the land they have. This requires such farmers to invest more in maintenance but also to obtain more water in proportion to their contribution. "Water rights earned through this are saleable. Any farmer who has excess water rights in a particular year can sell his water to potential buyers" (Giri and Aryal, 1989, p. 43).

remarkably like stylized Rule B noted earlier. These farmers average 7.75 metric tons per hectare per year. Most farmers at both ends of the system grow three crops every year, so the difference between head and tail end production is negligible.

The farmers of the Kerabari irrigation system, in the Terai, face a different type of resource mobilization problem and have adapted a different set of rules. Constructed by farmers during the 1970s, this farmer-managed irrigation system draws water from a stream (the Khadam Khola) that carries a large quantity of sediment from the foothills during the monsoon rains. Even though the main canal built by the farmers is considered by outsiders to be "quite an engineering feat," several attempts by the farmers and by the government to build a permanent intake structure have been washed away (Laitos et al., 1986, p. 217). Thus, despite past government efforts to help the farmers of Kerabari economize on the annual effort required by a temporary headworks, the farmers must continue to deal with floods and washouts. During the spring of 1985, for example, 150 farmers had to work for 15 days to repair the main canal (Laitos et al., 1986, p. 219). Two branch canals serve the upper Khadam and lower Khadam farmers. All farmers on this system own their own land and land is relatively equally distributed.

When this farmer-managed irrigation system was first organized, there was one committee for both subsystems, but the "lower Khadam farmers felt that the upper Khadam farmers were less active and enthusiastic about system maintenance and operation. They divided the committee into the upper and lower Khadam committees, but agreed to have one common chairman [who owns land in both systems] for both committees" (Laitos et al., 1986, p. 22). When water is abundant, each farmer withdraws whenever desired. During the spring when water is scarce, decisions about cropping patterns are made within the two branch committees and rotation systems are devised that ensure that water is adequate for the cropping patterns that have been jointly established.

All households owning less than two *bighas* (1.32 hectares) of land—about two-thirds of the owner-operators—send one laborer for each day of maintenance decided upon by the joint committee. Those owning more than two *bighas* of land contribute one laborer for each two *bighas* owned. Given that many farmers own much less than one *bigha* of land, this rule places a heavier burden on small landowners than on large landowners.[13] The joint committee

[13]Donald Curtis (1991, p. 76) provides a fascinating account of the change in rules for the Bansbote system on the Sewar River as it evolved from a system originally organized by a Zamindar, a local land-owning tax farmer. Under the Zamindar, each area of this system was required to send a fixed number of laborers whenever the system needed maintenance. When a farmer's committee took charge of the system, they changed the labor mobilization rule to each household sending one laborer (so households owning land in different areas were relieved of their double or triple obligations). Next, the small landowners prevailed on the large landowners to provide labor at the rate of one laborer per *bigha*. "Since in local terms this is still a fairly large unit of land the pressure is now on to have the rules changed again to require labour contributions on the basis of a smaller unit of land. But this move has not yet succeeded."

has mobilized cash from the farmers to line the canal, and has sought external assistance to try to address the headworks issue. At least 90 percent of the fields located in both the upper and lower sections are planted during each of the three growing seasons. Farmers have adopted high yield varieties and good agricultural practices and produce about 9.1 metric tons per hectare per year —well above average.

Implications

Asymmetries among participants facing common-pool resource provision and appropriation problems can present substantial barriers to overcoming the disincentives of the "state of nature" game between head-end and tail-end farmers. However, these asymmetries are frequently overcome in settings where farmers are made aware of their mutual dependencies; after all, head-enders may need the resources provided by tailenders when it comes to maintaining the system over time. Moreover, such bargaining over new rules can only work if the players have some assurance that the efforts they make to devise and enforce new appropriation and provision rules will not be undercut by external authorities. In a monetized and self-financed system, for example, tailenders are unwilling to contribute their water fees unless they obtain sufficient, reliable water so that the increased yield obtained by taking water is greater than the fees assessed on them.[14]

What is striking from an examination of the farmers in Nepal, the Philippines, Indonesia, and in other developing countries where they have been effectively allowed to self-organize, is the diversity of rules that result from the tough bargaining that farmers engage in during their annual meetings (Coward, 1980; Geertz, 1980; Hunt, 1989; Korten and Siy, 1988; E. Ostrom, 1992; Siy, 1982; Tang, 1992). As would be expected from our theoretical analysis, not all of these bargaining efforts achieve rules that enhance efficiency and/or equity.[15] But as long as mutual dependencies are clear to all participants, and they expect to relate to one another for a long time into the future, farmers in the developing world demonstrate substantial capabilities to craft

[14]Svendsen (1992) analyzes the effects of imposing a water fee on users by the National Irrigation Agency of the Philippines, that was in turn assigned primarily to that agency rather than the general treasury. Since the fees were to cover the full costs of the project, one effect was the reduction of the subsidy given by the national government to the irrigation sector. A second major effect is a significant increase in the service areas of government systems and in the equity of water distribution. The evidence from Svendsen's study strongly indicates that the imposition of a user fee improved the situation of the more disadvantaged who could refuse to pay user fees unless they obtained adequate water for their investment.

[15]The survival rate of farmer-governed systems is obviously not as large as that of government-owned systems that can draw on coerced taxation (and donor aid) to survive. It is, thus, not too surprising that farmer-run systems are more efficient than government systems given selection pressures to eliminate the less efficient.

rules that lead to higher yields and to a reduction in the asymmetry of results—and to enforce those rules as well. Many government agencies have wanted to impose the type of cropping patterns that exist on the Pithuwa and Kerabari systems, or the monetary fees that are collected by the Pithuwa farmers, but have not been able to gain sufficient cooperation from farmers to implement such policies.

Much of the emphasis in the development literature has been on the importance of physical technology to improve irrigation and agricultural performance, rather than institutions. There is little question that appropriately designed modern irrigation works can enhance the agricultural yield and efficiency of many farmer-organized systems. But interventions designed by outsiders that ignore the potential disruption of the mutual dependencies and reciprocal relationships among farmers may cause more harm than good. For example, aid in the form of grants (or loans that are never paid back by those who directly benefit from them) used to invest in the physical capital of irrigation systems may remove any need by headenders to recognize the needs of tailenders for water. In the ensuing state-of-nature battle over water, if no one pays fees or contributes labor to maintain the system, then the supply of irrigation may decline, even in the presence of outside aid.

Belief in the capability of external agencies to solve common-pool resource problems should be balanced with a recognition that external agencies can sometimes be disruptive. There is much more to learn about the capabilities and limits of various institutional arrangements to cope with diverse problems, but self-governing common-pool resource communities have demonstrated their ability to perform at very high levels of efficiency and equity.

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