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Locational asymmetry and the potential for cooperation on a canal

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Abstract

Illegal water diversions and lax rule-enforcement are common on irrigation canals. We present a mathematical programming model of a watercourse, calibrated to a canal in Maharashtra on which farmers voted to cooperate to control water theft. The model solution computes the crop choices and profits of individually optimizing farmers who differ in their location. It reveals the spatial distribution of gains and losses from cooperation. It illuminates why voluntary bargaining will rarely achieve an efficient water allocation. It also shows that landless laborers might well be against local cooperation, if the expropriated water nurtures labor-intensive crops.

JEL classification: Q2
Keywords: Canal irrigation; India; Cooperation; Enforcement

1. Introduction

The sustainable use of common property resources, which contribute so significantly to production and to consumption in poor countries (Dasgupta, 1993; Jodha,

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1986), often depends on cooperation among their users. Cooperation is, however, difficult to achieve in the presence of wealth, influence, or information asymmetries (Bardhan, 1993; Dayton-Johnson, 2000). Cooperation on irrigation canals is especially problematic. On a canal, even identically endowed and informed farmers are heterogeneous, because gravity imposes asymmetry on them. When might cooperation emerge among farmers who are differently located along a canal? Which farmers would be willing to cooperate, and which would not?

Cooperation implies a set of water allocation rules that are widely understood, and enforced, by the farmers themselves. These rules could emerge by majority vote, or by voluntary negotiations between coalitions on the canal.[1] The rules could be concerned with setting prices, rationing seasonal quantities, encouraging (or limiting) informal trades, and policing use. Of course, specific rules and their prospect of enforcement exist in a wider context of laws and societal norms. In this article, we focus on the rule-enforcement aspect of local-level cooperation.

Locational asymmetry arises because, as water flows down from the head of a canal to its tail, it seeps, spills, evaporates, runs off, and is illegally diverted. Such losses in transit disproportionately affect farms at the tail-end. For example, a case study from north India showed that the loss through seepage was a significant factor in the spatial allocation of canal water, and therefore of crop patterns (Vander Velde, 1980). And Chambers (1980, pp. 36–37), in a comparison of irrigation systems in India and Sri Lanka, observed:

> The physical position of fields relative to the channels is critical. In the absence of countervailing custom, social sanction, or physical force, the privileged top-enders satisfy their own needs first before allowing water to flow on down a channel . . .

Upstream–downstream asymmetries are central to analytical models of efficient water allocation. It has been shown that efficiency in the face of seepage could require downstream farmers to use less water but to pay more for it (Chakravorty and Roumasset, 1991). Alternatively, should upstream farmers' use leave downstream farmers with very salty water, an efficient allocation would have upstream farmers consume less (Quiggin, 1988). Optimal investments in conveyance (e.g. canal lining) and in farm irrigation technology are also spatially asymmetric on account of losses in transit (Chakravorty et al., 1995). These papers conclude that collective action may be necessary for efficient water allocation. If hydrologic elements such as return flow are significant, spatial interactions and optimal pricing are even more difficult to determine (Griffin and Hsu, 1993).

[1] "Cooperation" can also be thrust upon farmers by state agencies that no longer wish to manage canal water allocation. The results of such devolution have been mixed (Vermillion, 1997). Here we are not concerned with forced management transfers, but with farmer-initiated efforts.

Although locational asymmetry is a natural feature of all canals, it is generally not modeled as a determinant of local-level cooperation.[2] Using mathematical programming, we have developed a farming system model of a hypothetical watercourse with thirty farms. A watercourse is a subsystem with the same layout as the parent canal system, but compact enough to be a feasible unit of cooperation. We depart from the previous literature in two significant ways. One, we consider primarily the impact of illegal water diversions, and seepage losses only secondarily. Two, we focus on distributive equity rather than spatial efficiency. As we shall argue, relative equity under different allocation rules is key to the emergence of farmer-initiated cooperation.

We principally compare two versions of our model. The first is an unregulated allocation regime marked by unauthorized irrigation and cash payments to silence the field guards (minimal enforcement, or the status quo). The second is a regulated one, without such "theft", achieved by local monitoring of each farm's water use (complete enforcement, or cooperation). We also analyze an intermediate government-run regime, with some monitoring and higher fines for unauthorized irrigation (partial enforcement). In all versions of the model, the farms are spatially linked to one another by seepage and by the water use on upstream farms. By explicitly modeling these linkages, we can relate locational asymmetry to the potential for cooperation on the watercourse. That is, we can make the dividing line between top- and tail-enders endogenous to the water allocation regime.

Under each rule-regime and given the total water supply, the model solves for the spatial distribution of water, and of crops and net profits, down the watercourse. The model solutions provide insights into the likelihood of farmer-initiated cooperation. Is the status quo distribution of net revenues efficient? If not, can decentralized bargaining between field neighbors achieve efficiency? Is the status quo with water theft equitable? If not, which farmers are likely to support a change to local-level enforcement? If at least 51% of the farmers are worse off with water theft than under a new regime, the necessary (though not sufficient) conditions for cooperation do exist.[3]

When water deliveries are inefficient and inequitable, many studies recommend that collective action be encouraged. When farmers do not cooperate to improve their situations, the literature frequently concludes that cooperation "fails" because of asymmetric power relations, trust and coordination problems, or some version of the prisoner's dilemma (see e.g. Bardhan, 1995; Baland and Platteau, 1996).

[2] In an irrigation game with theft, Weissing and Ostrom (1991) derive equilibrium rates of stealing and monitoring. But this model has no location effects and all farmers can steal equally. Upstream–downstream asymmetries have been incorporated into a two-player game of canal maintenance (Ostrom and Gardner, 1993).

[3] We therefore assume that local cooperation need not be jointly and individually rational for all possible subsets of the farmers. It can be imposed by a simple majority, unless the transaction costs are too high.

The farming system model reveals that cooperation may not emerge even if there are no asymmetries in power, wealth, or information. A water allocation regime could be inefficient and inequitable, yet a clear majority of the farmers could be better off that way.

In Section 2 we provide evidence for the influence of location on cooperation, from an actual watercourse in the Indian state of Maharashtra. In Section 3, we describe the main features of the farming system model, calibrating the model with data collected on that watercourse. In Section 4 we compare the spatial distribution of water and net revenues with and without water theft. The implied preferences toward local enforcement accord with what happened on the study watercourse. We show that the interactions among agriculture, location, and rule-regime determine the likelihood of cooperation, and that a farming system methodology is well suited to the analysis of such complex interactions.

The solutions to the farming system model strongly indicate that cooperation is more likely to emerge by majority vote than by either consensus or Coasean-style negotiations among groups of farmers. Private bargaining between field neighbors cannot overcome the costs of negotiation and the risk of broken agreements, given the sensitivity of particular crops to lack of water.

In Section 5 we explore an alternative to local enforcement, in the form of higher government-imposed fines for farmers caught using water out of turn. A high penalty should discourage stealing, but does the higher “price” for stolen water encourage or discourage the transition to cooperation? We conclude with a summary of the results. The appendix draws on the case study to explain how a local cooperative might enforce its rules.

2. Cooperation on a canal

The nearly universal treatment of canal water as a common property resource leaves unresolved many issues of management and implicit property rights. On long canals that irrigate thousands of fragmented fields, volumetric pricing is rarely a feasible option (Perry, 1996). Politically, too, full-cost pricing of such a crucial resource has proved impossible, from the Philippines to Egypt (Repetto, 1986). Therefore, rationing by institutional means is the norm, usually through irrigation rules conceived of and implemented by distant government entities.

Most policy analysts, however, have come to believe that a bureaucratic state agency is not capable of regulating canal water allocation by itself. The information required to balance the twin goals of efficiency and equity is high (Kulkarni, 1986); government enforcement budgets are small (Azhar, 1993; Agarwala, 1985); and too many field-level officials are corruptible (Mookherjee and Png, 1995; Wade, 1982). In such circumstances, anarchy reigns, with bitter conflicts over irrigation turns or the appropriation of all the water by a few. The problem is less one of ill-defined property rights than one of property rights that are known but not enforced.

Conflicts over irrigation turns and payments for “black market water” were well known to the farmers on the study watercourse.[4] Until 1989, the management institution on this watercourse was the state-run Irrigation Department (ID)—as it still is in most of Maharashtra. Officially, each farmer was entitled to an equal number of irrigation hours per acre. Officially, the ID’s field-level employees supervised the flow of water to a sequence of watercourses and farmers. In reality, the overworked and badly paid canal inspectors had some discretion in disbursing scarce water. For the monsoon and winter cereal crops, the water supply was adequate for most farmers. But from April to June, when the water demand for sugarcane peaks and the clay soils crack from the heat, it was more profitable for a canal inspector to overlook illegal water diversions—or even to facilitate them—than to ensure that the water reached the legitimate users.

In 1989, encouraged by a local think-tank, several farmers on the watercourse started a campaign to form a water users’ association (WUA). The WUA would buy a volume of water from the ID. Then the WUA and not the ID would allocate the water, and its own canal inspectors would enforce the allocation rules. The leadership of the putative association, as well as the ID, agreed that a majority of the farmers should vote for this proposal before the ID turned over the watercourse. However, the ID wanted a two-thirds majority for a change of this significance, and some of the larger farmers argued for votes weighted by landholdings. The men behind the campaign thought that a simple unweighted majority should suffice.[5] They prevailed, and the WUA became a legal entity with the votes of 60% of the landholders along the watercourse.

Not debated was compensating the likely losers from the management turnover. Some farmers would be unhappy to lose their ready access to water, of course, and might even try to sabotage the new WUA.[6] Eventually they, too, would understand that local control of water was best for the entire watercourse. Or so it was said. The allocation rules themselves were not debated either. Almost everyone accepted the principle of fixed hours per irrigated acre, which is the official allocation rule on most modern canals in India. The primary goal of the cooperative was to enforce the existing rules regarding irrigation turns.

[4] Because some information, especially regarding the intrigues and intricacies of irrigation in Maharashtra, was given in confidence, we can be no more specific about the study site. We take this opportunity to express our gratitude to the agronomists, engineers, and farmers who made this research possible.

[5] “In India you can be a Minister with 51% of the vote”, they said. “If you can run the country with 51%, why can’t you run a watercourse?”

[6] In the first two irrigation seasons, the WUA inspectors were instructed to be especially vigilant of the openly unhappy farmers. They were to get their water exactly on time, their complaints were to be handled tactfully, and they were not to be reminded that they had “lost”.

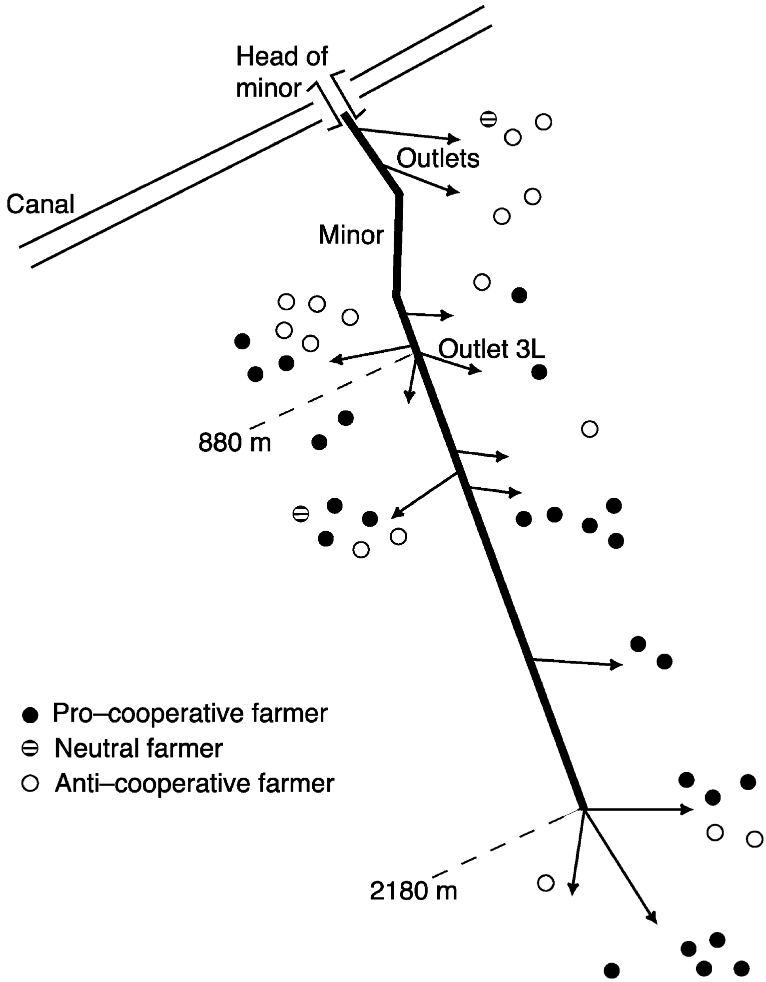


Fig. 1. Location and attitudes towards cooperation.

Fig. 1 examines a sample of 43 farm households on this watercourse, where the plot sizes varied from 0.7 to 40 acres.[7] It relates their positions on the channel to their attitudes towards the proposed WUA.[8] Fig. 1 shows that location is indeed a

[7] This sample represents a third of the households who used canal water for the whole year of the study. Several households contained more than one nuclear family, such as brothers who owned and farmed separate but neighboring plots of land.

[8] These "attitudes" represent the farmers' votes, as reported by them after the WUA had started operating. The actual voting was by secret ballot, although most people had known how their neighbors and family members would vote.

Table 1
Determinants of farmers' votes for the WUA

	Coefficient	t-statistic	Elasticity at means
Constant	−0.760	−1.42	−0.359
Outlet down canal	0.215	3.27	0.919
Landholding (acres)	−0.0789	−1.56	−0.266

Number of observations = 41 (the two neutrals ignored).
McFadden pseudo-R^2 = 0.24; normalized success index = 0.30.

good indicator of a farmer's support for a water users' association. On this watercourse, the cutoff point appears to be Outlet 3L, at 880 m, about 40% of the distance from the watercourse gate. Above Outlet 3L, 10 of the 15 households in the sample were against the formation of the cooperative, 1 was undecided, and only 4 were in favor. Below this outlet, there were 28 farmers in the sample. Twenty-one were in favor of the cooperative, one was neutral, and six were against it.

Because influence and wealth in Indian villages are strongly correlated, large farmers might be expected to negotiate a generous water supply for themselves. Recent evidence from 48 villages in south India, for instance, strongly indicates that social and economic heterogeneity undermine the formation of WUAs (Bardhan, 2000). So it is not surprising that, of the six farmers in Fig. 1 who were unfavorably located but did not support the cooperative, four were influential landholders with more than 15 acres each.[9] These four farmers all expressed satisfaction with the status quo, saying that extra water had been released through the outlets especially for them, and that they had paid the canal inspector Rs 150–200 per acre of unauthorized water.[10]

We do not dispute the advantages of wealth on this or on any other watercourse. In certain cases, a few farmers will be rich and powerful enough to force their self-interest on everyone else. There is, nevertheless, a significant range of inequality over which the wealthy are influential, but cannot prevail over the concerted actions of the numerically superior small and median farmers (Banerjee et al., 1997). The extent of this range is, of course, an empirical question, as is the relative importance of location. For the study watercourse, Table 1 reports the results of a probit analysis of the votes for cooperation, regressed against the

[9] These acres were consolidated in one or two holdings. Unlike in Kotapalle (Wade, 1988) or in the Philippine *zanjeras* (Coward, 1979), large landholders in this area do not usually have scattered holdings.

[10] Because these four large farmers were downstream, they also had to monitor the watercourse to make sure no one tried to steal from their (illegally sanctioned) water supplies. "I slept near my outlet," said one of them. "I thought, I paid so much for this water, no one else should take it away. I didn't like this cooperative business. I still don't like it. But I sleep in my own bed now".

positions of farmers' outlets and their landholding sizes. Although the landholding size variable has the expected sign, location is the statistically and economically significant variable. In other words, even where asymmetry in wealth does not undermine cooperation on a canal, asymmetry in location can.

3. The farming system model

To examine the consequences of location for cooperation, we have developed a mathematical model of a watercourse, written in the GAMS programming language. The numerical parameters are derived from interviews conducted with farmers, agronomists, engineers, and employees of the Irrigation Department in Maharashtra, but the structure of the farming system model is quite broadly applicable. The details of the model have appeared elsewhere (Ray and Williams, 1999), so here we just review its main features, and extend it to the analysis of cooperation.

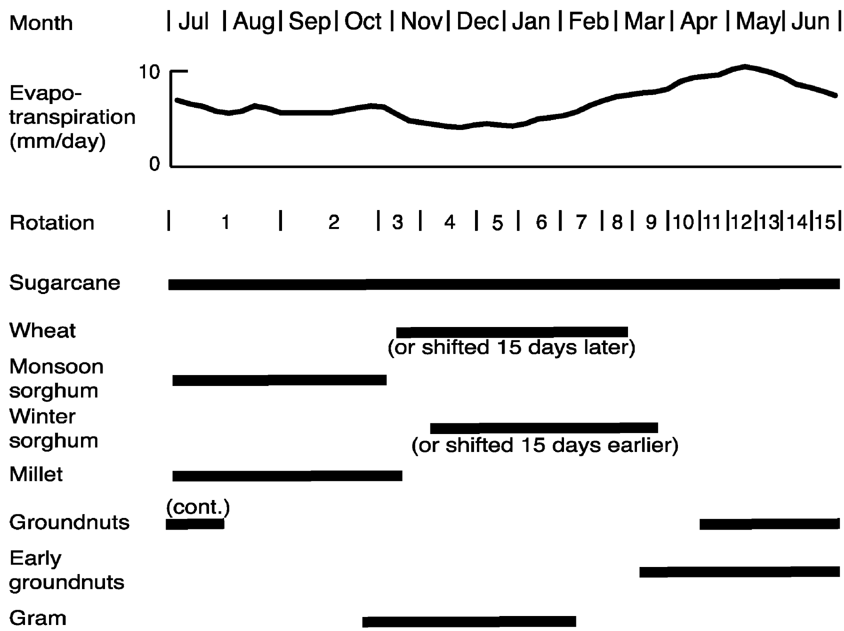
A simple watercourse is modeled, with 30 farms arranged sequentially along it. Although a watercourse in India normally serves between 100 and 300 farm households, 30 farms are enough to establish the effects of locational asymmetry. These farms can be thought of as individual holdings, or as proxies for strips of land containing clusters of farm households. Each farm is identical except for its position on the watercourse—a simplification that allows the model to isolate the effect of location. Because the water supply to each farm is determined by the actual water use and accumulated seepage above it, the entire watercourse rather than a single farm is the appropriate unit of analysis.

The farm household chooses its annual crop combination from eight crops, some of which have overlapping growth periods (Fig. 2). Each crop can be irrigated at between four and six water-supply levels, with yields increasing at decreasing rates at each successive level.[11] With relatively short growing seasons, the same plot can support two or even three crops in one year. An annual cropping pattern could be winter wheat followed by summer groundnuts; or, if water and labor supplies permit, a 12-month standing crop of sugarcane.

The watercourse is given a (known) volume of water over 15 irrigation turns, or "rotations", in the course of one agricultural year.[12] In effect, there are 15 water inputs, each defined by its volume and time of delivery. The crop-water requirements are also specified for each rotation, and vary according to the crops' growth stages (IARI, 1977). The farm family has 4 acres of land, a male and a female

[11] Counting each crop yield–water applied combination as a separate crop, we get 42 crop activities in the programming model. This piecewise segmentation of the normally concave crop–water response functions allowed us to keep the model of an individual farm linear.

[12] There is not enough water in most major systems to allow continuous irrigation. At any given time, some watercourses are shut off, while others run full (Gandhi, 1981).



Evapotranspiration was measured fortnightly in 1990. The rotation schedule shows the maximum number of releases of water. The crops' typical growing times as shown would need a further few days for preparing the ground.

Fig. 2. An annual crop calendar.

laborer, and the water that reaches it at each rotation. The land, family labor, and water are the endowments of the farm family; their supply constraints are separately specified for each rotation period.

The farmer is modeled as a price-taking maximizer of net revenues from farming plus wages earned from hiring out its own labor. Therefore, the one-year objective function for an optimizing farmer k is

$$Z = \sum_j C_j A_j + \omega(l - l^{\mathrm{h}}) - c^{\mathrm{c}} \qquad (1)$$

subject to per-rotation endowment constraints, where C_j denotes the revenue minus variable input costs for an acre of crop j; A_j denotes the acres of crop j; ω is the wage rate per day (in rupees); l and l^{h} denote the labor days hired out and in, respectively;[13] and c^{c} is the total cost of canal water used by the farm.

[13] The model separately specifies male and female wages and male and female labor days.

Extra labor can be hired in from a (finite) landless population, generally from within the watercourse, and at a higher cost from outside it during periods of peak demand. Underemployed farmers can also hire themselves out to any landholders who are net buyers of labor. The reservation wage for a landholding laborer is a positive function of his or her crop net revenues, while that for a landless laborer is zero. An employer, however, always pays at least the minimum wage. In short, male and female laborers are tradable within each rotation, while land and water are not. All other inputs are freely tradable at their market prices; their supply constraints are annual.

For most of the year, there is an excess supply of labor on the watercourse. The programming model iterates until the labor supply, including any farmers hiring themselves out, is equal to the labor demand, in each of the fifteen rotation periods. It does this by adjusting the probability of employment (and hence the expected wage) downwards whenever there are too many laborers looking for too few jobs, until there is effectively no more excess supply.[14]

Two water allocation institutions are modeled. Each farmer in each rotation of the watercourse is given an irrigation time slot, proportional to his or her landholding. As water is released at the head of the channel, the farmers irrigate their field turn by turn, by making a breach in the earthen bank and redirecting the flow. Each farm family can use all the water to which it is entitled, only some of it, or none at all, depending on the crop water needs for that particular rotation.

In the first case, a central canal authority is officially in charge of water distribution, but is unable (or unwilling) to implement its own rules. In this unregulated regime, a farmer uses his allotted water, and, if he wants more, he takes it illegally. If a canal inspector notices him using water out of turn, he has to pay a fine. This fine can be interpreted as the official penalty to be paid to the authority or as a bribe to the field level staff as an inducement to remain officially undetected (Wade, 1982; Datye and Patil, 1987).[15] The farmer takes the expected fine (δP) as the price of unauthorized water—a price that, under the status quo, is only slightly higher than the price for legally sanctioned water. In the second, regulated regime, the farmers cooperate effectively to monitor water distribution on their watercourse. Their local water board perfectly enforces the rules; it is as if δP is infinite. Each irrigated acre receives equal time, but not equal water, because seepage losses accumulate from the head towards the tail.

[14] It was not possible to balance the overall water demand and supply, as well as the overall labor demand and supply, within the same set of numerical iterations. Water is allocated sequentially among the farms, but the farmers do not take turns to hire labor. The model is therefore solved within two "loop" commands—an inner loop in which the total water supply is divided among the farmers, and an outer loop in which the labor supply and demand are balanced over the entire watercourse, in each of 15 rotations.

[15] In the words of an upstream farmer: "Of course I know that the inspector is corruptible. I made him corrupt. You think he works for the Irrigation Department? No, no, he works for me".

Under each water regime, and for each individual farmer, the programming model solves for optimal water use, and therefore net revenues, from the head of the watercourse to its tail. At the end of the solution for farmer F_k, the water supply parameters are reassigned to inform the model that for farmer F_{k+1}, the starting supply must be lowered by seepage and, if applicable, stealing. The equations of motion in the model are

$$w_{kr} = w_{k-1,r}\left(1 - s(w_{k-1,r})^{f}\right) - w_{kr}^{c} \quad \forall r = 1,\ldots,15 \quad \forall k = 1,\ldots,N-1 \tag{2}$$

$$w_{Nr} \geq 0 \quad \forall r \tag{3}$$

where w_{kr} denotes the canal water passed down from Farm k to $k+1$ in rotation r; s is a seepage parameter; f is a flow parameter; and w_{kr}^{c} is the canal water used by F_k in rotation r. In the model with theft, w_{kr}^{c} has a legitimate and an illegitimate component; in the cooperative version, an additional constraint restricts w_{kr}^{c} to the legitimate share. Conceptually, w_{kr}^{c} in the cooperative model can be relaxed to allow some slippage—after all, some evasion is likely even in the most vigilant cooperative. Eq. (2) is the model's only non-linear constraint; Eq. (3) ensures that more water is not used than is available.

Because water flows down a canal in one direction only, the equilibrium over space is analogous to a sequential equilibrium over time, with the seepage rate the analogue of the discount rate. This seepage is a deadweight loss, because the model does not allow for recharge or return flows. For optimal allocation, the water would be divided such that its marginal value to F_{k+1} is just high enough to offset the seepage loss from F_k to F_{k+1}. But the outcomes under the status quo of theft or of cooperation are not equivalent to a classic dynamic optimization. They are equilibria reached by a series of static optimizations. Nor is the cooperative version of the model efficient in the sense that the total net revenue on the entire watercourse is maximized. A constant hours-per-acre rule is not efficient in the face of seepage, but equity rather than efficiency is the allocation principle on most canals in Asia (Bromley et al., 1980).

4. The watercourse with and without theft

In this section, we compare the spatial distribution of water and net profits under the assumptions of water theft versus no theft. We also use the model solutions to argue that local-level cooperation is more likely to emerge by majority vote than by consensus. This is a consequence of locational asymmetry alone.

4.1. The spatial distribution of water and profits

The model solutions with and without water theft are dramatically different. In the unregulated first-come-first-served case, the water use and net revenues decline down the channel, in a series of steps. The solution shows that the first eight farmers simply buy extra water during the warm weather period from mid-April to mid-June, when potential evapo-transpiration is high (Fig. 3). These farmers consume fully a third of their annual water over just eight weeks. They use it all for sugarcane, the premier cash crop of Maharashtra. This pattern of stealing only during the summer, and only for sugarcane, is exactly as reported by farmers in the study area.

The farmers along the lower two-thirds of the watercourse never steal. They are virtuous less out of instinct than out of opportunity. Little or no water comes down to them during the summer months (Fig. 3), which constrains their crop choices such that they need no extra-legal water at any other time. The middle farmers (F_9 to F_{19}) follow a monsoon–winter cycle of sorghum and wheat, with only a small portion of their land under summer crops. (This pattern is in fact common in Maharashtra). The last 10 farmers do receive some water, but only during those rotations when its marginal value is negligible. It is more profitable for them to abandon farming and hire themselves out to the more favorably located farmers.[16]

Fig. 4 compares the farm-level profits down the watercourse with and without theft. The net profit curve with theft shows sharp discontinuities, because (i) during the peak-demand rotations all the water disappears upstream, and (ii) this water has a higher average value than that available downstream in other rotations. In fact, the availability or scarcity of water in a single, critical, three-week period drives the cropping pattern (and therefore profits) over the entire year (see Fig. 2). Should the farmers cooperate to eliminate illegal water use, the distribution of water, and therefore of profits, declines much more gradually.[17] Fig. 4 shows that, on this watercourse and with these parameters, a clear majority is better off under, and so would opt for, a no-stealing regime. The support for a change from the status quo would be concentrated below the top third of the watercourse.[18]

[16] In the study area many farmers had wells, which they used to supplement their canal water supplies. To keep the location story simple, however, we have not included wells in this article (unlike in Ray and Williams, 1999). When the model is run with wells, all the farmers are much better off than in Fig. 4, and they all farm their land. The groundwater option might have reduced the need for stealing canal water, but the solutions show that the cropping patterns adjust to the greater water supply by becoming even more sugarcane-intensive. Therefore, the number of farmers who illegally divert water is the same with or without wells.

[17] The gradual decline without theft between Farmer 1 and Farmer 30 is due to seepage. Some of the seeped water is undoubtedly retained as soil moisture, and some of it should re-enter the system lower down as return flow (Molden, 1997). Some fraction of it is a deadweight loss to the local economy, a loss borne primarily by the tail-enders.

[18] From Fig. 4 the cutoff point for viable cooperation can easily be read off. If the requirement for a WUA is a simple majority, or even a 67% majority, this watercourse can support cooperation. If the requirement is a 75% vote in favor, it will not be possible. With different numerical parameters, even a 67% requirement might be too stringent. In general, the bigger the required vote, the smaller is the number of qualifying watercourses.

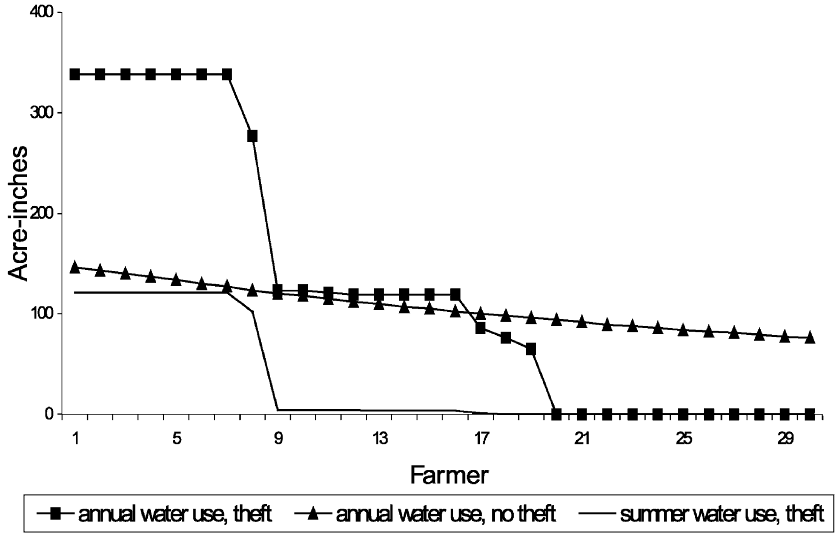


Fig. 3. Canal water use, with and without theft.

Would this institutional change, if it took place, be efficient? It is a challenge to measure efficiency in a system of subsidies, tariffs, support prices, minimum wages, and extra-legal payments. One possible way is to compare the gross agricultural revenues on the watercourse, with and without theft. Such a measure

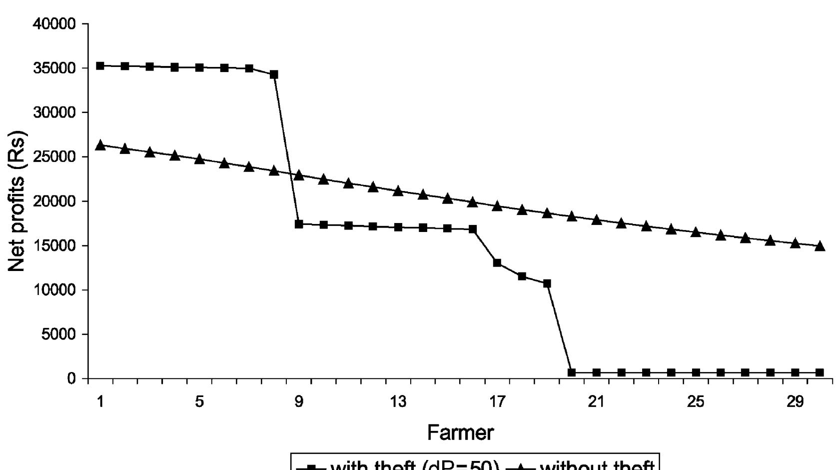


Fig. 4. Net profits with and without theft.

may be appropriate when there are very few alternative uses for agricultural inputs. A second way is to consider the net surplus to the local economy, i.e., the watercourse. Any payments made to local entities, such as farmers' profits, wages earned by (landed or landless) local labor, fees paid to the water board, and extra-legal payments to individuals within the board, are counted in. Any payments sent out, such as water delivery and system maintenance costs that the water board owes to the central Irrigation Department, bought inputs such as seeds and fertilizer, and wages paid to outside labor, are subtracted out. What remains after these payments is the *net local surplus*, and this is the measure we adopt here. It is the return to the land, labor, and water endowments of the local economy.

Table 2 shows the net local surplus, the farmers' net profits, the on-watercourse labor cost, the illegal water payments, and the costs of enforcement and maintenance to the water board, with cooperation and without. (It does not include the start-up costs of forming a WUA.) The annual net local surplus with theft is only 91% of that without theft. From the farmers' point of view, the aggregate welfare gain is 25%—and this is the more relevant figure for their motivation to cooperate.[19] So on this watercourse, and with these parameter values, theft appears to be inefficient and inequitable enough to warrant a move to a regulated regime. Had the individual benefits for most farmers not been high, cooperation would not have been feasible even in this socially and economically homogeneous irrigators' group.

The two versions of the model highlight the contrast between the de jure and the de facto property rights on the canal. The de jure rights are, and are known to be, equitably distributed along the watercourse command. The de facto rights belong to the upstream farmers, who, by accident of location, can use all the water they need before letting the downstream farmers irrigate. Looked at in a broader context, the de facto situation is analogous to de jure distributions elsewhere. For example, on some rivers in France, those upstream have the right to take all the water they want. In California, USA, farmers with "senior rights," who might be downstream, can take as much water as their rights permit before farmers with "junior rights" can irrigate. Studies on California's canals indicate that there are net gains to be made from transferring water from the seniors to the juniors, because the marginal value of water on the seniors' land is low (Zilberman et al., 1997). In India, many upstream farmers are like senior rights holders, by location and by historical use, even though not by law.

[19] Even 25% is small compared to some previously reported results. Chakravorty et al. (1995) project gains of 100% from conveyance efforts and efficient pricing in California. However, their optimal solution includes a 200% increase in canal length and a 100% increase in the water supply. It also assumes that all locally saved water translates into system-wide savings (but see e.g. Seckler, 1996). Our more modest gains are from a change in the allocation rules alone—retaining the same seepage rates, water supply, and canal length.

Table 2
Net local surplus with and without cooperation, on 120 acres

	With theft (the status quo) (in rupees)[a]	With cooperation (in rupees)[a]
Total profits of 30 farmers	459,651	609,484
Maintenance and enforcement[b]	(−)15,000	(−)25,000
Male wages (of landless)	6460	6760
Female wages (of landless)	2136	390
Illegal water cost	87,700	Not applicable
Net local surplus	540,947	591,634

[a] US$1 = Rs 30 approximately, in 1991.
[b] The exact figures in this row would depend on how much maintenance is done by entities inside or outside the watercourse, and on the extent to which the board chooses to subsidize canal water for the farmers. The social cost of enforcement is higher with cooperation, since it includes the disutility from monitoring actually carried out. These figures are adapted from a watercourse that was turned over to the farmers, who then had to finance operation, maintenance, and monitoring from water user fees and flat per-acre contributions (Lele and Patil, 1991).

4.2. How would cooperation emerge?

Once the irrigators decide to cooperate—if they do so at all—cooperation could emerge by a formal vote in favor of it, or through informal negotiations among the farmers. The WUA on the study watercourse was formed by a majority vote, following which the Irrigation Department recognized it as an autonomous legal entity.[20] This mode of cooperation need not be Pareto-efficient, because a 51% (or, where relevant, a 67% or 75%) majority can hold 100% of the power.[21]

By contrast, cooperation by informal negotiation has to be both individually and jointly rational; it cannot accommodate Pareto-inefficient changes. Unless cooperation has become “habit-forming” (Seabright, 1993), only those individuals who expect to gain from cooperating will agree to do so. Therefore, the potential losers have to be compensated in cash, kind, or labor services.[22] Such decentral-

[20] “There is nothing we can do now”, said an ID employee. “They tell us, we want this much water next month. We deliver it. Then we leave.”

[21] It might be asked why the result of such a vote is accepted. There are three classes of answer: one, once the voting (or any decision-making) mechanism has been established, acceptance is a Nash equilibrium. Two, behavioral norms are internalized by people over time, and one such norm is the authority of majority decisions. Three, repeated actions (such as acts of voting on various issues), backed by sanctions for deviating from cooperation, sustain norms (see Dasgupta, 1993, pp. 208–212). By arguing that the WUA had the right to allocate water and penalize rule-violators, we implicitly accept the third rationale.

[22] Without locational asymmetry, voluntary cooperation might have been sustainable without compensatory side-payments. For example, there could have been uncertainty about, or year-to-year changes in, the identities of winners and losers from cooperation. In that case, the expected gain from cooperation might have been positive for all the users.

ized cooperation, or bargains, could take place between two field neighbors on a watercourse or between groups of farmers in a non-zero-sum game. The most plausible informal negotiations can be considered as comparisons of the model under different conditions.

4.2.1. The pair-wise bargain

One can imagine a series of two-party bargains on the watercourse in which each farmer agrees not to steal from his or her downstream neighbor in exchange for some compensation. Without protracted negotiating costs (Coase, 1960) or privately held information (Farrell, 1987), such decentralized negotiations between neighbors should lead to an efficient allocation—an idealized market allocation, in fact. Although market-like transactions are rare on canals (Young, 1986), they have been observed (Murgai et al., 1998).

To see whether these pair-wise bargains are feasible, we compare the net profits of Farmers 8 and 9 first with theft, and then with the model modified for efficient reallocation between them alone.[23] All the farmers above F_8 get as much water as they want, so they need not initiate negotiations. Below F_9 no one steals, so there is nothing to negotiate over. Should F_8 and F_9 strike a bargain, F_8 might negotiate with F_7 and F_{10} with F_9, and so on.

If F_8 steals, the joint profits for F_8 and F_9 are Rs 70,938. If F_8 does not steal (because F_9 says “I’ll pay you not to steal from me”), their joint profits rise to Rs 76,018. It appears that a Coasean bargain is possible between them. Nevertheless, more than 85% of this difference would have to be given to F_8 to compensate him, leaving F_9 with a net gain equal to 3% of her pre-cooperation profits. This hardly seems worth her negotiating time, considering associated transaction costs.[24] More critically, the model solution shows that, if F_9 expects more water, she alters her cropping pattern completely. Her new crop (sugarcane) is profitable, but dependent on year-round irrigation. If there is even a small probability of F_8 reneging on the agreement, F_9 will be much worse off than without the pair-wise bargain.

Under theft, F_8 and F_9 are the neighbors with the largest difference in net profits between them, and the most (jointly) to gain from a bargain. Because a bargain is not economically feasible between them, it is unlikely to be feasible between any other pair.

4.2.2. The coalition bargain

A second possibility is to form two bargaining parties on the watercourse, grouping those who would gain from equitable reallocation versus those who

[23] Note that we do not compare the theft model to the cooperative model for this thought experiment. We compare theft to an optimal allocation in which the joint surplus for F_8 and F_9 is maximized.

[24] Costs related to water transfers are high on watercourses dominated by small farms (Easter and Feder, 1997), even if illegal water diversions are not the norm.

would lose. From Figs. 3 and 4, this translates to the lower 22 farmers offering side-payments to the upper eight for restraining themselves, and for staying within the equal-time-per-acre rule. From Table 2, it is clear that the gains from cooperation are high enough to support these side-payments. So would compensated cooperation, which would be feasible, consensual, and Pareto-efficient, emerge on this model watercourse? Why did it not emerge on the study watercourse?

For that matter, when faced with the threat of a majority-imposed WUA, why wouldn't the upper eight farmers buy the votes of just seven middle-reach farmers? Such a strategy on the study watercourse would have created a blocking coalition against the cooperative movement. Fig. 4, as well as the second column of Table 3, shows that Farmers 1 to 8 could co-opt F_9 to F_{15}, and still be better off than under the rules of the WUA.[25]

Measured by net profits, coalition bargains appear financially viable. In practice, however, a compensation scheme on a watercourse would face formidable transaction costs. First, the downstream farmers would strongly resist having to buy off the stealers, since the de jure right to water is as much theirs as it is the upstream farmers'. This is a crucial point—the initial assignment of the property right influences the costs of negotiation, and so changes the efficient equilibrium (Baland and Platteau, 1997). Second, implementing the scheme would require calculating each farmer's share of the gains (or losses) from cooperation, since differently located farmers gain (or lose) differently from cooperation. The net benefit from a grand coalition to F_{30} is Rs 14,290, for instance, whereas for F_{15} it is Rs 3406. In such circumstances, both equal and unequal assessments would invite resentment. Third, these agreed-upon side payments would have to be enforced. And finally, the crop patterns on the watercourse would have to be monitored, because each farmer would still have a short-term incentive to steal from his downstream neighbor. For example, F_8 can support 2.38 acres of sugarcane if he steals water, but less than 1 acre if he does not. F_9 has to know the upstream crop choice by January, if she is to avoid a crippling holdup in May (see Fig. 2).

Policing and enforcement are almost always necessary to maintain a cooperative effort, as evidenced by both the theoretical and empirical literatures (e.g., Ostrom, 1990; Baland and Platteau, 1996). Even though WUAs formed by majority vote face some such costs, negotiated cooperatives face additional bargaining, monitoring and enforcement costs, especially in the presence of locational asymmetry. These costs are probably the reason why there is no documented example of negotiated cooperation with side payments from watercourse-level communities. We conclude that a canal-based WUA is more likely to

[25] The area between the net profit curves with and without theft is larger for Farmers 1 to 8 than is the comparable area for Farmers 9 to 15.

Table 3
Net profit gains from cooperation with side-payments

Type of bargain	Grand coalition (F_1–F_8 vs. F_9–F_{30})	Blocking coalition (F_1–F_8 vs. F_9–F_{15})
Joint profit; cooperation (Rs)	609,483	350,505
Joint profit; theft (Rs)	459,650	400,355
Difference (Rs)	149,833	49,850

form by majority vote than by voluntary negotiation, at least in countries where voting has already acquired political legitimacy.

5. Enforcement and cooperation

A farmer-managed irrigation association is not the only route to controlling theft. The central Irrigation Department, concerned about high levels of illegal irrigation, could increase its monitoring efforts, its penalty for unauthorized use, or both.[26] We are not aware of any field-level evidence that could reveal the impact of higher penalties on theft, and by extension on the support for local cooperation. The farming system model can be used to conduct this sensitivity analysis.

In any particular season, the fine for stolen water the farmer expects to pay has two elements: δ, the probability of being caught, and P, the penalty per unit of water stolen. In the model, the expected penalty δP is exogenous, and despite differing by season, is the same for each unit of water. The penalty for the first stolen unit and the last stolen unit is the same, although the first is certain to have a higher marginal value. If the constant P is interpreted as the fine levied by the water board, it is conceptually analogous to the higher tier in a two-tier rate structure. If P is interpreted as a bribe, it can be looked on as a bargained outcome between the farmer and the canal inspector. The farmer prefers to pay less than the official fine set by the water board. The canal inspector does not want to ask for so much money that the farmer becomes indifferent to paying him or paying a fine to the water board. Nor is the inspector's monitoring proficiency high enough to charge farmers unit by unit, as a discriminating monopolist could do. Therefore, in practice, a *going rate* range becomes established, varying seasonally in response to the seasonal average value of water.

Whether P is paid as a fine to the water board or as a side-payment to the canal inspector, it is just the price of extra water to the farmer. The higher the price, the lower the quantity demanded by any individual, not surprisingly. But the less the

[26] The official fine is a ceiling for the unofficial bribe; as the one goes up, we assume that the other will, too.

upstream farmers demand, the more they send downstream, so more farmers have a chance to siphon off extra water. The higher price of water alters the degree of spatial heterogeneity.

At any δP that is insufficient to deter all theft, the distribution of water, and therefore of profits, down the channel is more inequitable than in a no-stealing regime. Fig. 5 shows the location of the last farmer to benefit from stealing at three levels of δP. When the expected penalty for water theft is a low, Rs 50 per acre-inch, eight head-end farmers use up the entire canal water supply during the hot weather season.[27] All the other farmers are worse off than they would be under cooperation, and so, if given a choice, would vote in favor of a no-stealing regime. At $\delta P = 100$, 23% less water is stolen overall, although more farmers steal. Because 18 farmers are worse off than under cooperation, cooperation would still be feasible. If $\delta P = 150$, even less water is stolen overall. The combined profits of the 30 farmers are also lower: Rs 511,059 with moderate theft as against Rs 609,484 with no theft. But now Farmers 1 through 16, a bare majority, can all steal a bit, and so are better off than they would be with no theft at all. The minimum conditions for cooperation would no longer be present, because of the Irrigation Department's very effort to reduce theft.

In general, by reducing illegal irrigation through more intensive monitoring and higher fines, the ID could increase the number of rule-violators. It could lock the watercourse into an uncooperative equilibrium in which a WUA could not be supported. The middle farmers emerge as the swing vote in this analysis—a tendency we could not have identified without modeling the interactions between location and the farm-by-farm crop choices.

The cost of theft is only one of the many variables that can affect the potential for cooperation. Others are input prices, output prices, crops' water needs, and the seepage and soil moisture recharge rates. In such a complicated, interwoven system, even large changes in some parameters (ceteris paribus), might have no impact on the water management institution. Or a small change in some parameter, similar to δP rising from 100 to 150, could cause the watercourse to shift from a situation where a majority of farmers support regulation to one where they do not. For that matter, institutional change could be a response to several small simultaneous shifts in parameters, as might occur for policy, climatic and technological reasons. In such circumstances, it could be difficult to relate any one factor causally to an observed shift from anarchy to cooperation or from cooperation to anarchy.

[27] In the study area, a farmer, if detected, paid (approximately) Rs 50 per acre-inch of extra water. This was almost always an unrecorded transaction, and was lower than the official fine, but in line with the charge for (legal) sugarcane water. The Government of Maharashtra does allow the farmers to petition for extra sugarcane water by filling out a "Form no. 7." But, said the farmers, "It's much easier to fill out Form no. 2." There is no Form no. 2. In idiomatic Hindi, "no. 2" means "under the table."

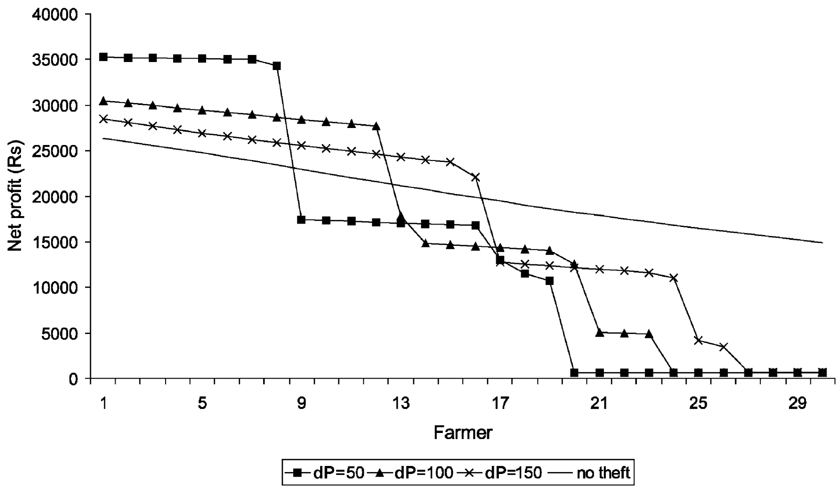


Fig. 5. Net profits; varying theft levels.

5.1. Welfare, employment, and the level of enforcement

The 30 farmers with land along the watercourse are not the only stakeholders in cooperation or the lack of it. There are those who collect the water charges, including not just the official water board but also the individuals who offer protection to unlawful water users. There are landless laborers, who are the most vulnerable segment of rural society, but whose interests are almost never mentioned in the literature on WUAs. If we add the earnings of these two groups to the farmers' net revenues, and subtract the operating costs of the water board itself, the net local surplus with a high degree of theft is Rs 540,947. With no theft at all it is Rs 591,634, as was shown in Table 2. With a high-penalty-induced moderate degree of theft, it is even higher at Rs 626,625.

The efficiency consequence of sending water downstream depends on the balance between seepage losses downstream versus diminishing returns to more water used upstream. With a lot of theft, all the water is used for upstream sugarcane, even when it would have been more valuable lower down. With (almost) no theft at all, the allocation is equitable, but water turns are of fixed duration regardless of efficiency. With some theft, the upstream–downstream water allocation is more efficient, and generates more revenue to the local economy, than either extreme.

The model solutions show that when no water is stolen, the 30 landowners are either fully employed on their own land, or their reservation wages are high enough to price them out of the labor market. When the extent of theft is very high and concentrated upstream—our status quo model—the farmers on the lower half of the watercourse compete with the landless for work. Even Farmers 11 to 16 hire their family members out during the summer months. However, when less water is stolen overall, but by more farmers, there is more land under labor-intensive crops such as winter wheat and groundnuts. In this situation, almost all the upper- and middle-reach farmers are occupied on their own land, and yet their demand for labor is high. Therefore more landless laborers are hired in, especially males for land preparation and plowing.

Fig. 6 demonstrates that the optimal amount of theft is not zero, and that the effect of theft on the system is not monotonic. It plots the total profits for the 30 farmers, and the net surplus to the local economy, at varying levels of water theft. (The extent of theft decreases from left to right on the horizontal axis, in response to its rising cost.) The secondary vertical axis shows the total wages earned by landless males hired in one year on the watercourse. With very low penalties for unauthorized irrigation, the resulting high levels of theft are neither efficient nor equitable. Most farmers would benefit from a change to local enforcement, where their collective net profits are highest. At higher levels of official enforcement and moderate levels of theft, there would not be a majority of farmers willing to cooperate to eliminate theft. Even so, this lack of cooperation may not be a negative outcome. For the local economy, and especially for the landless, there appears to be some intermediate level of theft that is more beneficial than a farmer-run cooperative.

The unexpected impact of cooperation on the landless is analogous to the third-party effect in the irrigation literature. Those who are not part of a water

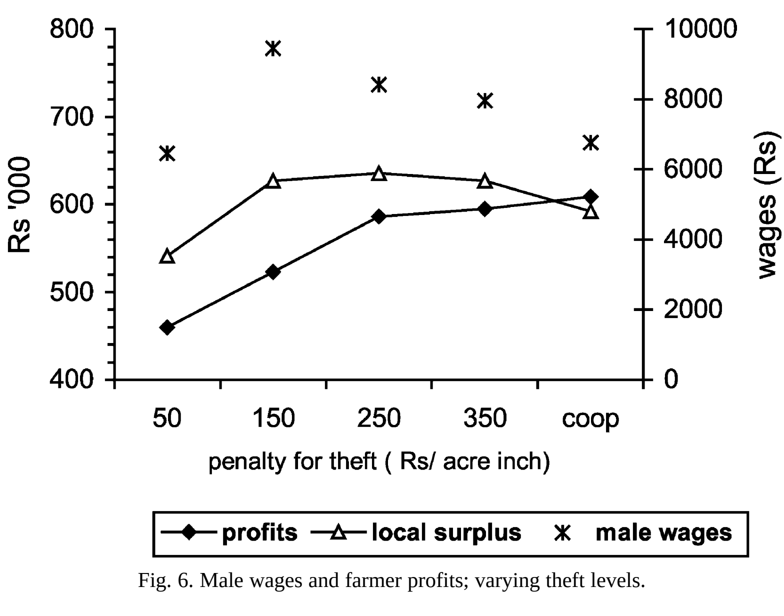


Fig. 6. Male wages and farmer profits; varying theft levels.

transfer—“third parties”—can be negatively affected by water trades or changes in water use. Such third-party effects can hold up water market reform (Rosegrant and Binswanger, 1994), or can justify restrictions on water transfers (Colby, 1990). However, water users’ associations would almost never consider the interests of the landless, who by definition are not irrigators, in a decision to cooperate among themselves. The landless would not get to vote.

6. Conclusion

Canals carry water to millions of otherwise dry-farmed acres, converting precarious subsistence into profitable farming in many developing countries. In the absence of effective irrigation bureaucracies or water markets, farmer-level cooperation could be the best guarantor of efficiency and equity in water management. But both seepage losses and excessive upstream water use impose unidirectional harm on downstream users, and so reduce farmers’ incentives to cooperate with one another.

The programming model presented here links the farmers on a watercourse spatially by seepage and by theft. Given a set of rules of water allocation, a farmer’s location determines the volume and timing of the water she receives. Given the wedge between the de facto and the de jure rules, location is a key predictor of who will, and who will not, cooperate to enforce the de jure rules. The model solution indicates whether or not most farmers stand to benefit from regulation rather than anarchy, and where on the watercourse the cutoff location is likely to be.[28]

The regime of partial enforcement, between the extremes of flagrant theft and no theft at all, has some surprising implications. At some intermediate level of penalty for water theft, enough farmers benefit from theft so that local rule-enforcement is no longer possible. At this point the interests of downstream farmers and those of the landless may be in sharp conflict. The water- and labor-intensive crop patterns supported by moderate theft regimes may well be advantageous for the landless laborer, who is dependent on wages earned on other peoples’ land. This conclusion is an uncomfortable one for countries whose policies include fostering rural cooperation as well as increasing rural employment.

[28] To make quantitative predictions in particular instances, one would have to relax the assumption of identical plots of land. It is simple to incorporate a distribution of land sizes into this programming model. If the seasonal water and labor supply constraints remain the same, the cropping patterns down the watercourse are essentially unaltered. The labor market, despite its transaction costs, can neutralize most of the inefficiencies from unbalanced land holdings. Therefore the physical cutoff point is at almost the same location. However, the number of farmers above (and below) the cutoff point changes. Without land asymmetry, it does not matter whether the voting rule is one vote per household or per acre. With land asymmetry, the rule would matter.

In general, the mode of forming a cooperative is more critical for canals than for other common resources, because locational asymmetry creates geographically concentrated winners and losers from any institutional change. Canal-based cooperation is more likely to emerge where the voting system is developed and its results are accepted, so that the farmers, either in pairs or in groups, do not have to negotiate a consensual agreement. As the model solution reveals, even pair-wise bargaining over water must proceed in the face of uneven gains from trade and the threat of holdups in key seasons.

The farming system methodology allows water to be modeled as a commodity whose value varies significantly over time and space. Its time of arrival, its delivery frequency, and the seasonal nature of the crops' water requirements, combine with the supply of labor, seepage down the channel, and the costs of stealing water, to determine the potential for cooperation in complex, and sometimes surprising, ways. Local heterogeneity in these conditions could well be responsible for the success of cooperation on one watercourse, but its failure on another, on the same canal system. These rich interactions could never be captured in a model seeking a closed-form solution, because many more simplifications and restrictions would be necessary to keep such a model solvable.

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Appendix A. How does a local cooperative reduce stealing?

The farming system model represents the cooperative as eliminating theft. Water theft cannot be eliminated with cooperation, but only significantly reduced. It can be shown that, as long as the marginal value of water remains positive, there will never be a zero stealing equilibrium (Weissing and Ostrom, 1991). Even if enough farmers vote to cooperate, or all the farmers negotiate cooperation, temptations to steal water remain.

To some extent, a local organization can rely on social and economic factors to sustain informal cooperation. A rich body of literature has shown that these factors include a group of users who have a history of interaction with one another (Axelrod, 1986); the existence of shared norms in other aspects of life (Elster, 1989); and a nuanced system of escalating sanctions for rule-violators (Ostrom, 1990). However, these characteristics can enable, but cannot secure, self-enforcing cooperation.

Rather than rely on the self-enforcing potential of cooperative agreements, WUAs, once in place, typically hire one or more guards. They then have to find ways to keep the guards honest and the farmers cooperative, when the guards might still be tempted by bribes, and the irrigators might still be tempted to siphon off extra water. The accountability of the guards to the irrigators' group, and the transfer of ownership from the government to the farmers, gives a local association enforcement options that more bureaucratic government departments do not have.

Discussions with the irrigators on the study watercourse revealed that if the legitimate irrigator knew that his supply was being interrupted, he expected the WUA's guard to find out why, and blamed him if there was no resolution. He blamed the guard even if he, the irrigator himself, detected the violator.[29] Policing the watercourse was not his job:

> I would think, what is that useless man doing to earn his salary? He gets too much money as it is. He is our man, he'd better keep an eye on our water.

Therefore the guard had a strong incentive to be vigilant, since the inability to detect potential stealers was bad for his reputation. Unlike the Irrigation Department guards, the cooperative's guards were accountable to the community of irrigators, and could jeopardize their jobs if they were obviously inefficient or corrupt. The guard still had a short-term incentive to allow stealing, but he knew that his future stream of earnings was at risk:

> Our *patkaris* (canal inspectors)—I don't think they could be corrupted. They work well, they are happy with their pay. They know there are others in the village who would like their jobs. They know that, believe me.

Once the WUA controlled the water allocation, peer pressure and the proximity of one's field neighbors was also a constraint on individually optimizing behavior:

> Well, I don't mind telling you that I would *like* to take more water sometimes. Only sometimes, okay? But I'm afraid to. People talk, they see you and then they talk. It looks bad.

A majority of the farmers on the study watercourse preferred the peer pressure method of deterrence to a cash penalty:

> I don't like the idea of fines. It's not nice. If someone doesn't want to cooperate, we will convince him that our rules must be accepted. But by persuasion and not by force.

[29] In fact, the farmers on this watercourse were less forgiving of a lazy guard than of other farmers who might try to take water out of turn. This temptation was considered wholly understandable—it is why they needed a paid guard in the first place.

As a last resort, the WUA committee could withhold water from a repeat violator. This was an extreme step, and had never yet been necessary, but “it’s in our by-laws”.

The accountability of the guards, the vigilance of the irrigators, the perceived right to demand fairness, and the peer pressure a small community can bring to bear on one of its members, are all advantages of decentralized decision-making. The collective enterprise of watchfulness, social sanctions, and performance-contingent job security made the “shadow penalty” for theft, or for overlooking theft, quite high in this newly formed cooperative.

Stealing under these circumstances cannot drop to zero. It will be occasional—more a seized chance than a regularity. It will also be locationally more random. The village-level canal inspector may sometimes “help” his friends or family members. The expectation for a typical farmer in a normal rainfall year is to steal with low, but positive, probability. This is the best feasible outcome for an effective cooperative.

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