



Choosing rules to govern the commons: a model with evidence from Mexico[☆]

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Received 5 October 1998; received in revised form 25 February 1999; accepted 5 October 1999

Abstract

I develop a model to assess *distributive rules* observed in field data on 48 Mexican farmer-managed irrigation systems. Households decide whether to contribute maintenance effort, the aggregate amount of which affects the level of output. Distributive rules with congruence between the sharing of collective costs and benefits elicit the highest level of effort; empirically, however, incongruent rules dominate the surveyed systems. I argue that transaction costs offset some efficiency benefits of congruent rules. I estimate a model of rule choice: inequality and the age of the water users' association strongly increase the likelihood that a system chooses proportional water allocation. ©2000 Elsevier Science B.V. All rights reserved.

JEL classification: D70; O12; O13; O17; Q25

Keywords: Common property; Institutional choice; Irrigation; Mexico; Rules

1. Determinants of rules on the local commons

Management of the local commons — small-scale common-pool resources such as in-shore fisheries, forests, pasturelands, and irrigation systems — is critically important to economic well-being and environmental conditions in the rural sector of developing economies. Moreover, the study of commons management can shed light on the determinants of institutional choice. What circumstances favor the appearance and evolution of these regulatory regimes? What characteristics of resource-using communities lead to the adoption of particular rules?

Ostrom (1990, p. 92 and *passim*), argues that successful institutions to manage local commons frequently exhibit *congruence* between cost-sharing and allocation rules: 'appropriation rules restricting time, place, technology and/or quantity of resource units are

[☆] This paper is based on a chapter from my doctoral dissertation in economics from the University of California, Berkeley.

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Table 1
Joint distribution of characteristics of distributive rules in 49 Mexican farmer-managed irrigation systems.^a

	Cost sharing		Water master		Canal cleaning	
	Proportional rule	Equal-division rule	Present	Absent	Collective	Household
<i>Water allocation</i>						
Proportional rule	8	23	25	6	11	18
Equal-division rule	1	17	10	8	9	8
<i>Cost sharing</i>						
Proportional rule			8	1	0	8
Equal-division rule			27	13	20	18
<i>Watermaster</i>						
Present					12	21
Absent					8	5

^aEach cell reports the number of irrigation systems with that pair of characteristics. (Three systems have different canal-cleaning regimes; therefore the numbers in the fifth and sixth columns sum only to 46.) Source: Dayton-Johnson (1999).

related to local conditions and to provision rules requiring labor, material, and/or money.’ This ‘congruence hypothesis’ — namely, that governance regimes for the commons with equivalent rules for cost sharing and benefit allocation perform better and endure longer — is echoed in field studies of irrigation. Chambers (1980, p.41), drawing on his experience in South Asia, asserts that “. . . communal labor is most likely to be effective . . . where labor obligations are proportional to expected benefits”. Siy (1987) shows that under the *atar* distributive rule in the successful Philippine *zanjeras* (irrigation societies), the ratio of individual benefits to labor contributions is roughly equal for all members of a given organization.

The case-study literature provides detailed accounts of regulatory regimes in farmer-managed irrigation systems. (Dayton-Johnson (1998) and Tang (1994) provide surveys.) These studies, however, have too few degrees of freedom to establish empirical regularities linking structural characteristics (e.g., the age of the water users’ association or asset-holding inequality among its members) and the selection of institutions. Tang (1992, 1994) has culled research from a large number of case studies in order to establish such patterns. Nevertheless, there is a need to systematically document the statistical association between organizational characteristics of irrigation societies and exogenous parameters regarding participants in those groups.

This paper explores, with theory and econometric analysis of field data, how the self-governed Mexican irrigation societies known as *unidades de riego* choose *distributive rules*: rules that govern the distribution of costs and benefits of cooperation among the members of the water-using community. I surveyed farmers and inspected the canal infrastructure in farmer-managed irrigation systems in the central Mexican state of Guanajuato during 1995 and 1996.¹ Table 1 presents the distribution of selected institutional characteristics across the irrigation systems in the Mexican field study. Forty-nine of the 51 operational irrigation

¹ The design and results of the survey are summarized in Dayton-Johnson (1999). Other larger-scale surveys of irrigation organization include Lam’s (Lam, 1998) study of systems in Nepal, and Bardhan’s (Bardhan, in press) analysis of systems in South India.

systems in the sample can be classified into one of four distributive rules. (Table 1 also presents information on the presence of a water-master — charged with the physical distribution of irrigation water to parcels — and the labor-mobilization regime for canal-cleaning, either carried out collectively, or individually by each household.)

Water is allocated, in each *unidad*, either (a) proportionally to each household's land-holding, or (b) in equal shares to all households. Similarly, maintenance and repair costs are shared either (a) proportionally to land-holding, or (b) equally among all. Combining the two water-allocation arrangements and the two cost-sharing arrangements generates four distributive rules: (i) *proportional* division of both irrigation water and maintenance labor; (ii) *equal division* of both water and labor; (iii) proportional allocation of water and equal division of costs (the *proportional-allocation rule*); and (iv) equal division of water and proportional division of costs (the *proportional-cost-sharing rule*).² In the parlance of Ostrom and others, the proportional and equal-division rules are congruent. From the perspective of the congruence hypothesis, the puzzle to be explained in Table 1 is the presence of 24 irrigation systems — a nonnegligible fraction of the sample — with incongruent rules. (Twenty-three exhibit the proportional-allocation rule, and one, the proportional-cost-sharing rule.) More generally, I attempt to explain the heterogeneity of institutional choice.

The paper is organized as follows. Section 2.1.1 presents a simple model of individual incentives in the farmer-managed irrigation system. With this model I verify the congruence hypothesis in the absence of side-payments and transaction costs: the proportional and equal-division rules always mobilize at least weakly more cooperative maintenance effort than the proportional-allocation rule. In Section 2.1.2, I consider transaction costs — costs of record-keeping and accounting, of monitoring compliance with the rules, and of negotiation — that differ from rule to rule. I derive conditions under which system-wide returns, gross of transaction costs, under the proportional-allocation rule are greater than under the proportional rule. Simple cross-tabulations from the field data are consistent with these results. Nevertheless, any such system would have still higher returns under the equal-division rule. Finally, in Section 2.1.3, I discuss the possibility that unequal bargaining power among farmers may lead to the adoption of the sub-optimal (in the absence of side-payments) proportional-allocation rule rather than the equal-division rule; such forces are more likely to arise the greater is land-holding inequality.

The basic question raised by the model in Section 2.1 is not so much why an irrigation system would choose the proportional-allocation rule over the proportional rule, but rather why a system would choose either over the low-transaction-cost equal-division rule. Accordingly, in Section 2.2, I estimate a logit model of the likelihood that a system has chosen either a proportional or proportional-allocation rule, rather than the equal-division rule. Economic inequality and the age of the water users' association are quantitatively the most important determinants of that probability: groups with more-unequally distributed land-holding and older water users' associations are more likely to have chosen a proportional/proportional-allocation rule.

Section 3 summarizes the results and discusses the relationship of the paper to other analytical work on common property and pre-market economic organization. The conclusion

² Other water-allocation and cost-sharing rules from the field-study literature are assessed in Dayton-Johnson (1998).

also considers extensions of the model, including how the static theory might be generalized to a dynamic setting.

2. The farmer-managed irrigation system: theory and evidence

2.1. Theory

The irrigation system comprises a set of n farming households $i = 1, \dots, n$; let $I = \{1, \dots, n\}$. Each household i is endowed with an amount of irrigable land ℓ_i . The users collectively have access to reservoir water for irrigation. The quantity of water captured by the reservoir is W . Let $L \equiv \sum_{i \in I} \ell_i$ be the aggregate land in the system; thus ℓ_i/L is i 's share of the reservoir's command area. ($\ell_i/L > 0$ for all $i \in I$: households with no land are not members of the water users' association.)

Each household i must contribute, at a unit cost to the household of c , an amount of canal-maintenance labor x_i . The collective-maintenance activities typically required in small irrigation systems include constructing and maintaining canals and field channels, and desilting, weeding and stopping encroachments in reservoir beds. The sum of these contributions X , $X \equiv \sum_i x_i$, together with the water captured W , determines the 'effective water supply' XW . That is, collective effort multiplicatively increases the supply of water available for irrigation. Better maintenance, for example, leads to lower losses from filtration, leakage through broken control structures, and sedimentation.³ The high and constant marginal benefit to cooperative labor implied by the multiplicative function XW is a good approximation of the reality observed in the Mexican field study. Cooperative effort certainly exhibits diminishing returns beyond some point; in practice, however, the marginal return to cooperative effort at levels of X observed in the Mexican *unidades* is probably quite high, as high-return maintenance tasks such as the repair of broken sluice-gates are frequently not performed. \bar{X} is the upper bound on aggregate cooperative effort X .

The *distributive rule* consists of a cost-sharing arrangement and a water-allocation arrangement and functions as follows. The labor contributions required of each household are defined in terms of this upper bound \bar{X} : household i must provide $\gamma_i \bar{X}$, where $0 < \gamma_i < 1$ for all $i \in I$, and $\sum_{i \in I} \gamma_i = 1$. Thus, if each member of the water users' association were to provide the labor required of it, the group would attain the maximum level of cooperative effort \bar{X} .⁴ The vector of shares $\{\gamma_i\}_{i \in I}$ is the irrigation system's *cost-sharing arrangement*.

³ Some of the collective-labor tasks that are performed, such as work on the canals that channel run-off into the reservoir, can directly increase W , which is treated here as exogenous. Strictly speaking, then, W should denote the potentially capturable run-offs or river flow. A further complication: the timing of the game in this paper assumes that maintenance effort is provided after W is known; any work undertaken to increase capture will affect W in a future that does not exist in the model. I make the simplifying assumption that all work done only affects effective water supply XW during the same period, since these between-period effects are of secondary importance.

⁴ \bar{X} is largely determined by the physical extension of the canal network and the average productivity of labor. I do not consider whether \bar{X} is itself optimal. Would the members of the water users' association choose an optimal target \bar{X} , leaving aside the question of whether or not the group could mobilize that level of effort? In an argument well-known in the engineering literature, Levine (1987) argues that negligence of maintenance is an economically rational strategy for a group of water users, particularly if that group can reasonably expect the state to rehabilitate canals and structures every 20–30 years.

Each household i with $x_i \geq \gamma_i \bar{X}$ receives $\alpha_i [X_{-i} + \gamma_i \bar{X}]W$, where $X_{-i} = \sum_{j \neq i} x_j$, and $0 < \alpha_i < 1$ for each i , and $\sum_{i \in I} \alpha_i = 1$. A household that contributes $x_i < \gamma_i \bar{X}$ is penalized by the water users' association: it receives no water and earns zero income.⁵ I assume that the probability of detecting non-contributors is one; this is a reasonable assumption in the context of village economies. The vector of water shares $\{\alpha_i\}_{i \in I}$ and the stipulation that non-contributors not receive their shares, is the irrigation system's *water-allocation arrangement*. In the vocabulary of Ostrom et al. (1994), $\{\alpha_i\}_{i \in I}$ regulates *appropriation* and $\{\gamma_i\}_{i \in I}$ regulates *provision*.

Two types of cost-sharing arrangements are observed in the field data: *equal-division*, wherein each household must contribute an equal amount of effort toward canal-cleaning and other collective maintenance tasks (i.e., $\gamma_i = 1/n$ for all i); *proportional to land-holding*, wherein those with more land ℓ_i must contribute proportionally more collective effort ($\gamma_i = (\ell_i/L)$ for all i). Similarly, the water-allocation arrangement can be one of two types: *equal-division*, under which each contributing household receives an equal amount of reservoir water for irrigation ($\alpha_i = 1/n$ for all i); *proportional to land-holding*, under which those with more land ℓ_i receive proportionally more reservoir water ($\alpha_i = \ell_i/L$ for all i).⁶ Thus, there are four possible distributive rules:

1. *Equal-division*: costs and water are equally divided: $\alpha_i = \gamma_i = 1/n$, for all $i \in I$.
2. *Proportional*: costs and water are allocated proportionally to land-holding: $\alpha_i = \gamma_i = \ell_i/L$, for all $i \in I$.
3. *Proportional-allocation*: water allocation is proportional to land-holding and costs are equally divided: $\alpha_i = \ell_i/L$, $\gamma_i = 1/n$, for all $i \in I$.
4. *Proportional-cost-sharing*: cost sharing is proportional to land-holding and water is equally divided: $\alpha_i = 1/n$, $\gamma_i = \ell_i/L$, for all $i \in I$.

I assume that water and land are complementary inputs to crop production and that farmers are water-constrained: for any increase in water availability to household i in the relevant range, the marginal product of water is positive. I assume therefore the very simple production function $q_i = \alpha_i [X_{-i} + \gamma_i \bar{X}]W$. Crop output is sold at price p , and all households are price-takers.

Although the model only requires that households contribute at least $x_i = 0$, the distributive rule ensures that they will always choose either $x_i = 0$ or $x_i = \gamma_i \bar{X}$. For contributions

⁵ In practice, households in the Mexican field study that do not contribute the required labor must pay a fine equal to the cost of hiring a worker on the spot labor market to perform the work. Many households in the surveyed systems — those headed by elderly widows, or whose younger members work in the United States, for example — simply hire one or more workers during the canal-maintenance period. If the household does not pay the fine, it receives no water. The zero-payoff assumption in this instance is a convenient normalization: many such households can in fact produce (at a relatively lower level of output), using only rainfall.

⁶ In the cases of both water allocation and cost sharing, of course, proportional-to-land holding and equal-division arrangements could be mixed. Thus, for example, the cost share of household i could be

$$\gamma_i = \zeta \frac{1}{n} + (1 - \zeta) \frac{\ell_i}{L}$$

for some $\zeta \in (0, 1)$. My field data are too coarse to distinguish among cases of ζ not equal to zero or one. Farmers were asked if those with more land bore proportionally greater costs. Cost-sharing arrangements in those systems where farmers responded affirmatively are called 'proportional.' Thus, the cost-sharing arrangement in any system with $\zeta < 1$ is called proportional, and similarly for water allocation.

between zero and $\gamma_i \bar{X}$, i 's water share is unchanged at zero, while its cost increases; for contributions greater than $\gamma_i \bar{X}$, i 's water share is unchanged at $\alpha_i [X_{-i} + \gamma_i \bar{X}] W$, while its cost increases.⁷ Two assumptions are embedded in this set-up: first, that there is perfect information (and hence, perfect monitoring of compliance with the rules), as noted above; and second, that there is perfect enforcement of the rules. Both are convenient simplifications. In fact, there are many ways to shirk: farmers may contribute maintenance effort one day, but they skip a day every once in a while, or arrive late. It is likely that such shirking is common knowledge in many systems, but far less likely that it is successfully sanctioned.

This is a one-shot, simultaneous-move game, so there is no meaningful 'sequence' of moves; however, describing the following timeline makes the workings of the model more transparent:

1. At some point prior to the playing of the game, the governing council of the water users' association chooses the maximum number of hours of collective labor (\bar{X}) and the water-allocation and cost-sharing arrangements ($\{\alpha_i, \gamma_i\}_{i \in I}$) that specify each irrigating household's share of the costs and benefits of system-maintenance efforts.
2. A second set of variables exogenous to the model is chosen each period by Nature: the water captured in the reservoir this season (W); the output price (p); and the unit cost of cooperation (c). The values of these parameters are known to all.
3. All irrigating households i that are members of the water users' association choose contribution levels of canal-cleaning and maintenance effort x_i from the set of choices $\{0, \gamma_i \bar{X}\}$: either the amount stipulated by the cost-sharing arrangement, or nothing. This is i 's strategy set. (Household i is not restricted from choosing other nonnegative amounts of x_i , but only the two values mentioned here would ever be selected.) The total amount of cooperative effort is thus determined: $X \equiv \sum_{i \in I} x_i$, given the Nash-equilibrium level of effort chosen by each household.
4. Payoffs are realized: the effective water supply XW is distributed according to the water-allocation arrangement. Each household i that contributed the required amount of canal-cleaning in the previous stage receives $\alpha_i [X_{-i} + \gamma_i \bar{X}] W$, and all others receive nothing.

Although this is a one-period model, in practice, steps #2 through #4 are repeated year after year; step #1 might be revisited irregularly.

As is customary (though not necessarily justified) in the research on local regulation of the commons (Johnson and Libecap, 1982; Kanbur, 1991), I assume that side payments are impossible. Households that benefit from collective canal-cleaning cannot transfer income to equilibrium non-contributors in exchange for canal-cleaning effort by the latter. Perhaps the transaction costs of monitoring and enforcing such transfers preclude their use. In practice, transfers are not observed in an explicit form in the Mexican irrigation systems in the field study. Although it is difficult to rule out that more complicated social relations within the village effectively substitute for explicit water-related income transfers, as a first approximation I follow the literature and rule them out.

⁷ This specification implies that if some households choose not to contribute to maintenance effort, there is water left over in the reservoir. Say that $J \subset I$ is the set of equilibrium contributors; then $\sum_{j \in J} \alpha_j XW$ is the volume of effective water units distributed and $\sum_{j \in J} \alpha_j XW \leq \sum_{i \in I} \alpha_i XW = XW$.

2.1.1. Analysis of the model

This section uses the framework developed above to characterize the equilibrium outcome under each of the distributive rules. Whatever the distributive rule, a social planner would require that every household contribute its stipulated maintenance effort if $pW \geq c$; in that case $X = \bar{X}$ is the socially-optimal level of maintenance effort. I assume that this condition is met. In this section, then, the criterion by which each rule is judged is its success in eliciting compliance with the rule, thereby increasing aggregate cooperative effort and production.

Lemma 1 establishes that both congruent distributive rules — the proportional and equal-division rules — elicit complete compliance ($X = \bar{X}$) in equilibrium in any case when complete compliance is socially-optimal. Lemma 2 shows that partial compliance is never an equilibrium outcome under the congruent rules. Lemma 3 demonstrates that partial compliance can emerge as an equilibrium outcome under the proportional-allocation rule even if full compliance is socially-optimal. These lemmas are combined in Proposition 1, a formalization of the Ostrom–Chambers congruence hypothesis.

Lemma 1. *Complete compliance ($X = \bar{X}$) is an equilibrium outcome under either the proportional or equal-division rule if and only if $pW \geq c$.*

Proof. Suppose all households other than i contribute the maintenance labor required by the rule. Consider first the proportional rule ($\alpha_i = \gamma_i = \ell_i/L$). Then if i contributes $(\ell_i/L)\bar{X}$, its payoff is

$$\frac{\ell_i}{L} p \bar{X} W - c \frac{\ell_i}{L} \bar{X} \tag{1}$$

If i contributes nothing, its payoff is 0. Thus, it must be that the expression in Eq. (1) is greater than or equal to 0. Since $(\ell_i/L)\bar{X} > 0$ always, Eq. (1) is at least 0 if and only if $pW \geq c$. Now consider the equal-division rule ($\alpha_i = \gamma_i = 1/n$). If all households save i contribute, and if i also contributes its required labor $(1/n)\bar{X}$, its payoff will be:

$$\frac{1}{n} p \bar{X} W - c \frac{1}{n} \bar{X} \tag{2}$$

If i contributes nothing, its payoff is 0. The payoff (2) is at least 0 if and only if $pW \geq c$. □

Lemma 2 establishes that there is no other equilibrium outcome under either congruent distributive rule such that some households contribute maintenance effort and some do not.

Lemma 2. *Under the proportional or equal-division rule, there is no equilibrium level of aggregate cooperative effort X such that $0 < X < \bar{X}$.*

Proof. I will prove this by contradiction.

Case (I): Proportional rule. Suppose first of all that there exists a strict subset J of I such that all households in J contribute in equilibrium, and all those not in J do not. Then for all $j \in J$, the payoff to contributing, conditional on contributions by all other members of J , must be nonnegative:

$$\frac{\ell_j}{L} p \left[\sum_{j \in J} \frac{\ell_j}{L} \bar{X} \right] W - c \frac{\ell_j}{L} \bar{X} \geq 0$$

Simplifying, this condition is equivalent to

$$\sum_{j \in J} \frac{\ell_j}{L} \geq \frac{c}{pW} \quad (3)$$

Now for $i \notin J$, it must be that playing $x_i = 0$ yields a higher payoff than playing $x_i = (\ell_i/L)\bar{X}$ when all members of J comply with the cost-sharing arrangement:

$$\frac{\ell_i}{L} p \left[\sum_{j \in J} \frac{\ell_j}{L} \bar{X} + \frac{\ell_i}{L} \bar{X} \right] W - c \frac{\ell_i}{L} \bar{X} \leq 0$$

This condition simplifies (dividing by \bar{X} , and exploiting the fact that $(\ell_i/L) > 0$ for all i) to

$$\sum_{j \in J} \frac{\ell_j}{L} + \frac{\ell_i}{L} \leq \frac{c}{pW} \quad (4)$$

But by (3), $\sum_j \ell_j/L \geq c/pW$, and $(\ell_i/L) > 0$ for all i , so that

$$\sum_{j \in J} \frac{\ell_j}{L} + \frac{\ell_i}{L} > \frac{c}{pW}$$

a contradiction.

Case (II): Equal-division rule. The proof is very similar to that of Case (I). Suppose that the lemma is not true. Then there is some strict subset of households $J \subset I$ that contributes cooperative effort; its complement does not. Suppose that there are n_J households in J . For all $j \in J$, the payoff to compliance must be nonnegative:

$$\frac{1}{n} p \frac{n_J}{n} \bar{X} W - c \frac{1}{n} \bar{X} \geq 0$$

This condition simplifies to:

$$\frac{n_J}{n} \geq \frac{c}{pW} \quad (5)$$

For $i \notin J$, it must be that noncompliance is at least weakly better than complying when the members of J comply. If $i \notin J$ cooperates, its payoff is

$$\frac{1}{n} p \left[\frac{n_J + 1}{n} \bar{X} \right] W - c \frac{1}{n} \bar{X} \quad (6)$$

If the payoff (6) is nonpositive, then (dividing by $(1/n)\bar{X}$ and rearranging):

$$\frac{n_J + 1}{n} \leq \frac{c}{pW}$$

But by (5)

$$\frac{n_J + 1}{n} > \frac{c}{pW}$$

a contradiction. □

Lemmas 1 and 2, then, establish that the congruent distributive rules always elicit maximum cooperative effort when that level is socially optimal. Lemma 3 demonstrates that under the proportional-allocation rule there can be equilibrium outcomes in which some households contribute and others do not. This contrasts with the characteristics of the equilibria under the congruent rules.

Lemma 3. *Under the proportional-allocation rule, there exists an equilibrium in which a strict subset J of n_J households contributes maintenance effort if and only if*

(a) *for all $j \in J$,*

$$\frac{\ell_j}{L} \geq \frac{1}{n_J} \frac{c}{pW}$$

(b) *for all $i \notin J$,*

$$\frac{\ell_i}{L} \leq \frac{1}{n_J + 1} \frac{c}{pW}$$

Proof. If some group J of n_J households contributes maintenance effort, then for any $j \in J$, compliance must at least weakly dominate noncompliance:

$$\frac{\ell_j}{L} p \left[\frac{n_J}{n} \bar{X} \right] W - c \frac{1}{n} \bar{X} \geq 0$$

This condition simplifies to condition (a) of the lemma (dividing through by $(1/n)\bar{X}$ and rearranging). For any household i not in J , conditional on J 's contributions, contributing labor provides a nonpositive payoff:

$$\frac{\ell_i}{L} p \left[\frac{n_J + 1}{n} \bar{X} \right] W - c \frac{1}{n} \bar{X} \leq 0$$

This condition simplifies to condition (b) of the lemma. □

By substituting I for J in Lemma 3, Corollary 1 gives the conditions under which the maximum level of aggregate cooperative effort is attained in equilibrium under the proportional-allocation rule.

Corollary 1. *Complete compliance ($X = \bar{X}$) is an equilibrium outcome under the proportional-allocation rule if and only if for all $i \in I$*

$$\frac{\ell_i}{L} \geq \frac{c}{pW} \frac{1}{n} \tag{7}$$

Another corollary to Lemma 3 shows that whenever there is an equilibrium in which the contributors form a strict and nonempty subset of the group, contributors and non-contributors can be wealth-ranked: any contributor has larger land-holding than any non-contributor. This is because there is a ‘threshold share’ of land-holding above which the household contributes cooperative effort. This threshold is a function of the set of contributors: the

larger the number of contributors, the lower is the wealth threshold. The wealth threshold is also related (inversely) to W , the water captured in the reservoir.⁸

Corollary 2. *Consider any equilibrium under the proportional-allocation rule such that contributors form a strict subset of households. Then for any equilibrium contributor j and any equilibrium non-contributor i , $\ell_j > \ell_i$.*

Proof. From conditions (a) and (b) of Lemma 3,

$$\frac{\ell_i}{L} \leq \frac{c}{pW(n_J + 1)} < \frac{c}{pWn_J} \leq \frac{\ell_j}{L} \quad (8)$$

so that $\ell_j > \ell_i$. □

(A series of results similar to Lemma 3, Corollaries 1 and 2 can be established for the proportional-cost-sharing rule. Given that this is the least-frequently-observed rule in the Mexican field study, I have omitted them to save space.)

Lemmas 1–3 can be combined into the principal result of the model, a formalization of the Ostrom–Chambers congruence hypothesis. The equilibrium outcome of the congruent rules (proportional or equal-division) is complete compliance whenever that is socially-optimal. The proportional-allocation rule can lead to less-than-complete compliance in equilibrium, even assuming perfect monitoring and enforcement.

Proposition 1. *The congruent distributive rules — proportional or equal-division — always elicit at least weakly more cooperative maintenance effort than the incongruent proportional-allocation rule.*

2.1.2. Transaction costs

The model analyzed in Section 2.1.1 raises the question of why nearly half of the surveyed irrigation groups in Mexico chose the dominated proportional-allocation rule. In this section, I add transaction costs to the model. Specifically, assume that there are aggregate monetized costs G associated with proportional water allocation, while the transaction costs associated with equal-division water allocation are normalized to zero. Similarly, the monetized transaction costs associated with proportional cost sharing are H , while the transaction costs associated with equal-division cost-sharing are zero. I assume that $G > 0$, $H > 0$, and $H > G$.

Consider first G , the differential transaction costs incurred by moving from equal-division to proportional water allocation. Under an equal-division water-allocation arrangement, there are no complicated calculations to be made, no special accounting requirements, and no differences in delivery amounts, given that all households receive an equal share of water. If some users are to receive more water, the costs of running the system are greater. Record-keeping costs are not prohibitive, but in a setting (such as Guanajuato) where many agents are unable to read or write, they are nevertheless important. There must be verification

⁸ Dayton-Johnson and Bardhan (1996) analyze conservation and inequality in a fishery. That model also features a wealth threshold above which the agent cooperates. The threshold in the fishery model is inversely related to the regeneration rate of the fish stock, which plays a role formally similar to that of the irrigation supply W in this irrigation model.

that those demanding more water are indeed entitled to it (because they have more land ℓ_i). Distribution of water is no longer uniform: the person charged with delivery must monitor different delivery volumes for different households. Thus, $G > 0$.

In practice, water in the Mexican irrigation systems in the field study is distributed by a watermaster (variously referred to as the *canalero*, *presero*, *llavero*, *juez de aguas*, *jefe de aguas*, *repartidor*, as well as other more colorful terms). A watermaster distributes irrigation supplies in two-thirds of the surveyed systems (36), and in four-fifths of those cases (29), the watermaster is paid a wage by the water users' association (refer to Table 1). The additional work created by changing from an equal-division to a proportional arrangement falls upon the watermaster. Because he is paid, and in particular because he is paid for each day he works, there is no special difficulty in getting him to perform the additional work. Thus, G largely comprises record-keeping and water-delivery costs.

Now consider H , the differential transaction costs incurred by moving from equal-division to proportional cost-sharing. Monitoring and enforcement of equal division of costs are not complicated under the two most common forms of mobilizing canal-cleaning labor, *household labor mobilization* and *collective labor mobilization* (refer to Table 1). In 48% of the surveyed systems (26), each household is assigned a portion of the canal to clean. The monitor — the watermaster, or the president of the water users' association — inspects the canal network before irrigating, and can sanction non-contributors if their portion has not been cleaned. In 37% of the surveyed systems (20), canal-cleaning is performed by all households collectively and simultaneously, and the monitor simply takes roll of those who appear on the canal-cleaning day or days.⁹

Under the collective labor-mobilization regime, it is a simple matter to enforce an equal-division cost-sharing arrangement by ensuring that all water users show up and leave at the same times on canal-cleaning days. Furthermore, irrigators can more easily monitor one another's effort level under this form of organization; this intensity of monitoring is more difficult when irrigators clean different portions of the canal individually. Farmers report a moral-hazard problem of sorts under the household labor-mobilization regime: one can clean a section of the canal so that it looks reasonably well-maintained but in fact has not been suitably repaired. Once water is in the canals there might be filtration or structural failure in that section, but it is difficult to ascribe blame for these problems to the household responsible for maintenance in that portion of the network.

Therefore, a proportional cost-sharing arrangement requires significant changes in the monitoring regime relative to equal division: wealthier households will have to send more canal-cleaners, or clean canals for more hours, either of which changes increases the complexity of accounting for the monitor. If the household labor-mobilization regime is in place, switching from an equal-division to a proportional cost-sharing arrangement adds increased costs of determining the portions to be assigned to each household, and negotiating those portions among all parties. In many systems that employ the household regime, the negotiation of the portions is revisited, acrimoniously, every season. Thus, H comprises

⁹ In three other systems, there are elements of both labor-mobilization regimes: e.g., all households must provide labor to clean the primary canal for three days, and the secondary canal system and field channels are cleaned according to the household labor-mobilization regime.

record-keeping and labor costs, like G , but also coordination and negotiation costs borne by irrigators in the form of longer or more frequent assemblies.

Both G and H likely increase with inequality in land-holding: this raises the complexity of record-keeping, and the scope for negotiation every year. G and H likely decline in the age of the water users' association, if farm households can learn over time to use proportional rules at less cost.

Systemwide costs under the proportional-allocation rule when the conditions of Lemma 3 are met are as follows:

$$pW(\bar{X} - X) + cX + G \quad (9)$$

where X is the actual amount of cooperative effort supplied in equilibrium. The first term in (9) is the value of output lost relative to the proportional rule (where $X = \bar{X}$). The second term is the aggregate maintenance cost, and the last term is the transaction costs associated with record-keeping and water delivery. If the same irrigation system were to adopt the proportional rule, its costs would be $c\bar{X} + G + H$. The total costs associated with the proportional-allocation rule are lower than those of the proportional rule if $H > (pW - c)(\bar{X} - X)$. (This does not require that $H > G$.) Using the notation of Lemma 3, X can be written as $(n_J/n)\bar{X}$, so that this condition can be rewritten in the form given in the following proposition.

Proposition 2. *Systemwide costs are lower under the proportional-allocation rule than under the proportional rule if*

$$H > (pW - c)\frac{\bar{X}}{n}(n - n_J) \quad (10)$$

Condition (10) from Proposition 2 generates a series of comparative-static predictions regarding the proportional- and proportional-allocation-rule systems. Table 2 compares the mean values of various indicators across the three most common distributive rules in the Mexican field study. Comparison of the values for four variables—age of the

Table 2
Mean values of structural characteristics for 48 irrigation systems, for each of three distributive rules

Variable	Distributive rule					
	Proportional rule ($N = 8$)		Proportional-allocation rule ($N = 23$)		Equal-division rule ($N = 17$)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Gini coefficient	46.8	10.3	36.8	23.0	5.0	12.3
Households	169	178	157	163	62	36
<i>Ejidors</i>	2.1	2.5	2.2	1.7	1.1	0.5
WUA age	53.1	29.4	44.4	20.6	34.4	18.5
Lined %	13.6	26.1	13.3	26.6	13.6	27.1
ℓ_{\min}	1.03	1.0	2.72	7.1	2.08	2.7
Wage	25.3	3.4	28.7	8.2	24.7	3.1
ℓ_{\min}/wage	0.040	0.038	0.100	0.259	0.086	0.109
Water depth	809.9	316.2	530.4	548.9	1066.0	1137.1

water users' association, irrigation supply, local wage, and minimum parcel size — for the proportional- and proportional-allocation-rule systems lend support to Proposition 2.

If the water users' association is older, then H is lower, and, *ceteris paribus*, the total costs of the proportional rule are more likely to be lower than the costs of the proportional-allocation rule. Thus, proportional-rule systems are more likely to have older water users' associations. Indeed, the average age of the water users' association is 44 years for the proportional-allocation-rule systems, and 53 years for the proportional-rule systems. If irrigation supply (W in Eq. (10)) is low, then the return to greater cooperative effort is lower, and condition (10) is more likely to hold. Table 2 verifies that water depth (a measure of irrigation supply measured in millimetres, where $1\text{ mm}=10\text{ m}^3/\text{ha}$) is lower in proportional-allocation-rule systems (530 mm) than in proportional-rule systems (810 mm). If the unit cost of cooperation — for which the local wage is a reasonable approximation — is high, then once again the return to greater cooperative effort X is lower, and condition (10) is more likely to hold. The average wage in proportional-allocation-rule system is 29 pesos per day, versus 25 in the proportional-rule system. The higher the minimum land-holding size, the more likely that all households will be above the wealth threshold given in Corollary 1, in which case complete compliance is an equilibrium outcome under the proportional-allocation rule, and there is no output shortfall associated with that rule. (In terms of Eq. (10), $n = n_J$.) Table 2 shows that the average smallest parcel size (ℓ_{\min}) in the proportional-allocation-rule systems is 2.7 ha, versus 1.03 ha in the proportional-rule systems.

The effect of inequality is ambiguous. Greater land-holding inequality raises H , and makes the proportional-allocation rule less costly relative to the proportional rule. On the other hand, greater inequality makes it less likely that many households' wealth will lie above the contribution threshold from Corollary 1, making the proportional-allocation rule relatively more costly. Table 2 shows that inequality (measured by the Gini coefficient calculated on the basis of irrigated parcel sizes) is higher among the proportional-rule systems (47%) than among the proportional-allocation-rule systems (37%). This evidence is consistent with the interpretation that the wealth-threshold effect of increased inequality on individual household incentives is greater than the transaction-cost effect.¹⁰

2.1.3. Inequality and bargaining power

While transaction costs reported by the Mexican farmers can explain why an irrigation system, if it is minimizing costs, might select the proportional-allocation rule rather than the proportional rule, such costs cannot explain why all systems would not choose the equal-division rule. Transaction costs are lowest under that regime, and complete compliance is an equilibrium outcome. A likely explanation is that the evolutionary mechanism

¹⁰ As is customary in transaction-cost analysis, I have restricted attention to comparison among a limited set of relevant institutional forms (Williamson, 1991). This analysis begs a further question: why are other institutional forms not included in the set of relevant options? In two of the sample irrigation systems dropped from the analysis in this paper, the water users' association simply collects cash from its members and hires the necessary laborers. Why is this arrangement observed in so few systems? A referee suggests that when a tax is in the form of labor, the farmer knows exactly how the tax is allocated. If money is contributed, there is less certainty that all of the money is actually spent on maintenance.

whereby irrigation societies choose distributive rules might not always minimize costs. North (1990) proposes that economic institutions evolve in the direction of ever-greater efficiency; even if this is true for the Guanajuato *unidades*, one cannot presume that these systems currently exhibit the steady-state distribution of institutional forms. Moreover, a given system's rules might reflect the balance of political forces within the community, rather than efforts to optimize levels of maintenance and irrigation supply.

Compare the gains from the proportional-allocation rule, relative to the equal-division rule. For households with land-holding wealth above the mean level, those gains rise with inequality in the land-holding distribution: the higher a household's land-holding lies above the mean, the larger the difference between its water share (α_i) and its maintenance-labor share (γ_i). For those group members with wealth below the mean, however, the attractiveness of the proportional-allocation rule is decreasing in inequality: as a household's land-holding size drops, its share of water benefits drops, while its labor contribution remains constant. How the actual rule choice reflects these different preferences toward adoption of the proportional or proportional-allocation rule depends on the mechanism that aggregates households' preferences. Assume for the moment that, as is plausible in a hierarchical agrarian social order, the will of the larger landholders is more highly weighted by this mechanism. Then increased inequality will be associated with a higher probability of observing the proportional-allocation rule. This outcome could emerge even if the proportional-allocation rule performs miserably in terms both of mobilizing maintenance effort and minimizing transaction costs, if the wealthier households can impose their preference for that relatively inegalitarian rule on the group. This process is consistent with Ostrom's (Ostrom, 1996) interpretation of evidence regarding bargaining over rules in a group of irrigation systems in Nepal.¹¹

The factors that lead to adoption of the proportional rather than the equal-division rule might respond to the same pressures. Both rules elicit maximum cooperative effort, but the proportional rule will give more water to the wealthier landowners. If the marginal product of water is not constant (as the model implies), the wealthier landowners may press for the proportional rule.

The discussion of transaction costs and of the political process that aggregates preferences over the choice of rules suggests that land-holding inequality is quantitatively important to rule choice. Furthermore, transaction costs might play a role in the choice between the proportional and proportional-allocation rules, but the factors that lead a system to choose either of those rules over equal-division are fundamentally similar.

2.2. Evidence

In this Section, I analyze the Mexican field data in light of the theoretical discussion. I drop the single adopter of the proportional-cost-sharing rule from the analysis dataset, so that only the remaining three rules are represented. Since there are then only 48 observations, of which only eight are proportional-rule systems, I collapse the proportional- and

¹¹ This raises the question of why the poorer households cannot pay off the wealthy to switch to a better-performing rule.

Table 3
Summary statistics of selected structural characteristics of 48 irrigation systems^a

Variable	Units	Mean	S.D.	Minimum	Maximum
Gini coefficient	%	27.18	24.59	0.00	74.71
Households	No.	125	140	15	676
<i>Ejid</i> os	No.	1.8	1.6	0.0	8.0
WUA age	years	42.3	22.1	4.0	113.0
Lined portion	%	13.44	26.10	0.00	100.00
ℓ_{\min}	ha	2.2	5.2	0.07	35
Wage	pesos/day	26.7	6.4	13.5	45
ℓ_{\min}/wage	Ratio	0.085	0.190	0.003	1.273
Water depth	mm	766.7	810.0	53.0	4722.6

^aThese variables are used in a logit model to explain the choice of a distributive rule.

proportional-allocation-rule systems into a single category. I estimate a logit model of the probability that a system falls into this collapsed category (Section 2.2.2). Every irrigation system in this collapsed category has adopted a water-allocation arrangement with higher transaction costs than the alternative, the equal-division rule. The other analytical strategy, collapsing the systems with proportional and equal-division rules, could be justified given that both elicit similar patterns of cooperation in the theoretical model. However, the different levels of organization implied by these two rules, and the transaction costs that they imply, argue against this option. Finally, a review of the characteristics of the systems under the three rules — summarized in Table 2 — reveals more similarities between the proportional- and proportional-allocation-rule systems than between the proportional- and equal-division-rule systems. Thus I ask, what structural factors lead the members of a water users' association to choose the proportional or proportional-allocation rules, rather than the simpler equal-division rule?

2.2.1. Group characteristics and distributive rules

What relationships do we expect to observe between structural characteristics and rule choices? I consider several candidate explanatory variables. Some are chosen in light of the model introduced in Section 2.1; others are suggested by the literature on collective action. Table 3 lists the summary statistics for these variables.

Economic inequality. Section 2.1.3 argued that greater land-holding inequality increases pressure from relatively wealthy households to adopt proportional/proportional-allocation rules.

Number of households. Olson (1965) argued that collective-action is less likely to succeed in groups with large numbers of members. Institutional choice reflects the outcome of collective action; is group size in the *unidades* associated with the choice of distributive rules? Table 2 shows that the largest groups choose the proportional/proportional-allocation rule; those that choose the equal-division rule are significantly smaller.

Number of ejidos. I interpret the number of *ejidos*—the quasi-communal farming communities created by the agrarian reform in Mexico—represented in a given system as a measure of social heterogeneity: to a first approximation, *ejidos* correspond to

villages.¹² This measure of social heterogeneity, I propose, increases transaction costs H and G , and makes the adoption of the proportional/proportional-allocation rule less likely.

Lined portion of the canal network. The larger the share of the canal network lined with cement or concrete, the lower the overall amount of cooperative effort required to maintain the system's infrastructure. The model in Section 2.1.1 makes no prediction regarding this variable's effect. Nevertheless, reductions in the overall amount of necessary maintenance labor might reduce the monitoring costs of the proportional/proportional-allocation rules, thereby increasing their likelihood. (The lined share is effectively exogenous in all but one of the surveyed systems. Only in that system did the water users play a role in the lining of canals, and even there they could only afford to add a few meters of homemade rock and cement mixture every year. In all other systems, lining was carried out at the time of system construction or rehabilitation, by some agent other than the water users.) The lined-share variable is defined as the percentage of the canal network that is lined times an indicator variable equal to zero if the government undertook any canal-lining at the system subsequent to the original construction of the system, and one otherwise. This correction is meant to ensure that the measured lined share is indeed exogenous to the choice of distributive rule.

Water depth. Water depth is a measure of irrigation supply. Here I use *potential* water depth, the reservoir capacity relative to the irrigated area. The discussion in Section 2.1 suggests that lower irrigation supply makes the proportional-allocation rule more likely, meaning that one expects a negative association between water depth and the proportional/proportional-allocation rules. (This reasoning rests on the assumption that systems with higher reservoir capacity consistently have higher irrigation supply.)

Smallest parcel size. If the smallest parcel is sufficiently large, then the model asserts that output losses under the proportional-allocation rule will more closely approximate those of the proportional rule. The larger the smallest parcel size, thus, the more likely that the proportional/proportional-allocation rules will be observed, rather than the equal-division rule.

Local wage. I take the unit cost of maintenance effort to be measured by the local wage, given that agricultural labor markets exist, frequently at a very local level, everywhere in the surveyed areas of Guanajuato.¹³ The model predicts that that the higher the unit cost

¹² I cannot improve upon the explanation of *ejidos* given by Stephen: "*Ejido* refers to agrarian reform communities granted land taken from large landowners as a result of the agrarian struggles during the Mexican Revolution (1910–1917) . . . Such land is held corporately by the persons who make up the *ejido*. Originally, the *ejido* bestowed use rights on a list of recipients, while the state retained ultimate property rights. *Ejido* land could not be sold or rented, but holders could pass their use rights on to relatives. As a result, many families have worked the same parcels of land for several generations. In 1992, changes amending Article 27 of the Mexican Constitution made it possible to privatize *ejido* land following a complex process of land measurement, certification, and individual titling" (Stephen, 1997, fn. 1).

¹³ In the absence of functioning labor markets there are interesting asymmetries in households' opportunity cost of providing cooperative effort. Households with large land-holding would have a higher marginal product of labor; if this burden of maintenance effort were viewed by others in the users' group as larger for larger land-holders, that might serve as a justification for the puzzling proportional-allocation rule. Under that rule, large land-holders bear a larger cost although the number of hours contributed is numerically identical for all households. Accordingly, such households might receive a larger share of system benefits. I stress that this explanation is not appropriate in the Guanajuato *unidades*, but this mechanism could lead to the adoption of proportional-allocation rules in common-pool resource systems where there is no labor market.

of maintenance effort, the smaller the costs of the proportional-allocation rule. Thus, a higher wage increases the likelihood of observing a proportional/proportional-allocation rule. At the same time, if the wage is an important component of transaction costs G and H (through more intensive monitoring, for example), systems in high-wage areas are more likely to choose the low-transaction-cost equal-division rule.

In the statistical models that follow, I include the ratio of the smallest parcel size to the local wage; this is suggested by the contribution threshold in Corollary 1 (condition (7)). For the poorest household, this condition is met if

$$\frac{\ell_{\min}/L}{c/pWn} \geq 1$$

The expression on the left-hand side is made up of three components:

$$n \times \frac{W}{L} \times \frac{\ell_{\min}}{c}$$

Each of these components is an independent variable in the statistical analysis: the number of households, n ; the water depth, W/L ; and the ratio of the smallest parcel size to the local wage, ℓ_{\min}/c .

Age of the water users' association. In Section 2.1.2, I argued that transaction costs G and H decrease with the age of the water users' association, as farmers learn to coordinate more efficiently. Thus, I expect that adopters of the proportional/proportional-allocation rule are more likely to have older associations.

The agrarian reform of the 1920s and 30s in Mexico essentially froze the distribution of land-holding (and the number of households) in each irrigation system. Thus to a first approximation, the Gini coefficient, the number of *ejidos*, and the number of households are exogenous parameters. This attractive feature of the Mexican setting (from the standpoint of experimental design) facilitates the interpretation of the statistical results.

2.2.2. Predicting the presence of a distributive rule

Now I collect the explanatory variables considered in Section 2.2.1 to construct a statistical model of the selection of distributive rules. I estimate a logit model of the probability that a given system has adopted the proportional/proportional-allocation rule rather than the equal-division rule.

As a preliminary exercise, Table 4 presents the results of a multinomial-logit model in which the three categories are the proportional, proportional-allocation, and equal-division distributive rules. The comparison group is the equal-division rule. The estimated coefficients on the explanatory variables are broadly similar for both the proportional and proportional-allocation rule, underscoring the difficulty of distinguishing between the two groups on the basis of a sample this size.

Table 5 gives the results of the logit model of the probability of choosing a proportional or proportional-allocation rule, rather than an equal-division rule. The most statistically significant findings are the following: (1) *Higher economic inequality is strongly associated with the presence of a proportional/proportional-allocation rule.* The coefficient on the Gini term is significant at the 99% level. This result is consistent with an interpretation of the model in Section 2.1 in which wealthier landowners press for a proportional/proportional-allocation

Table 4

A multinomial-logit model of the probability of an irrigation system choosing the proportional or proportional-allocation distributive rules, versus the equal-division rule (the comparison group)^a

Variable	Coefficient	S.E.	t-ratio
<i>Proportional rule</i>			
Gini	0.1866	0.0620	3.008
Households	0.0095	0.0188	0.504
<i>Ejidos</i>	-0.0489	0.8677	-0.056
WUA age	0.1334	0.0532	2.508
Lined %	0.0334	0.0324	1.032
ℓ_{\min}/wage	-2.1089	10.3754	-0.203
Water depth	0.0003	0.0013	0.234
Constant	-13.2194	4.6459	-2.845
<i>Proportional-allocation rule</i>			
Gini	0.1123	0.0449	2.502
Households	0.0158	0.0182	0.868
<i>Ejidos</i>	-0.1270	0.8273	-0.154
WUA age	0.0712	0.0419	1.698
Lined %	0.0367	0.0245	1.494
ℓ_{\min}/wage	1.8791	9.3006	0.202
Water depth	-0.0017	0.0011	-1.588
Constant	-5.6599	3.0836	-1.835

^a $N = 48$; $\chi^2(14) = 48.02$; Probability $> \chi^2 = 0.0000$; Log likelihood = -24.9; Pseudo- $R^2 = 0.4910$.

Table 5

Results of a logit model predicting the choice of a proportional/proportional-allocation rule^a

Variable	Coefficient	S.E.	t-ratio
Gini	0.1173	0.0443	2.65
Households	0.0154	0.0184	0.84
<i>Ejidos</i>	-0.1176	0.8296	-0.14
WUA age	0.0732	0.0412	1.79
Water depth	-0.0013	0.0011	-1.23
ℓ_{\min}/wage	1.2346	9.2215	0.13
Lined %	0.0336	0.0241	1.39
Constant	-5.7606	3.0051	-1.92

^a $N = 48$; $\chi^2(7) = 38.73$; Probability $> \chi^2 = 0.0000$; Log likelihood = -11.83; Pseudo- $R^2 = 0.62$.

rule, rather than an equal-division rule, because the former rule gives them higher returns. This could be because of the widened difference between the wealthy household's share of benefits and its share of costs, or because of higher marginal productivity of water on larger parcels. (2) *Older irrigation groups are more likely to have chosen a proportional/proportional-allocation rule.* The coefficient on the age of the water users' association is significant at the 93% level. This finding is consistent with the interpretation that older groups will have learned less costly ways to implement rules with higher transaction costs of record-keeping, negotiation, and monitoring and enforcement. (3) *Systems with more lined canals are more likely to have chosen a proportional/proportional-allocation rule.* The coefficient on the lined share of the canal network is significant at the 84% level.

Table 6
Goodness of fit of the logit model presented in Table 5^a

	Predicted choice		Observed count
	Equal-division rule	Proportional/proportional-allocation rule	
Observed choice			
Equal-division rule	13	4	17
Proportional/proportional-allocation rule	3	28	31
Predicted count	16	32	48

^aThe possible choices are (i) a proportional or proportional-allocation distributive rule or (ii) an equal-division distributive rule. The prediction-success index σ for the model is 67% of its possible maximum value.

This finding suggests that canals with more lined sections lead to less-costly monitoring of rule compliance and less-costly delivery of unequal water shares.

Table 6 illustrates the goodness of fit of the model by showing the distribution of observed and predicted distributive rules. The overall prediction-success index σ suggested by McFadden, Puig, and Kirschner (see Maddala, 1983, p. 76), is, in my case,

$$\sigma = \sum_{r=1}^2 \left[\frac{N_{rr}}{48} - \left(\frac{N_{.r}}{48} \right)^2 \right] = 0.30$$

where N_{rr} is the number of correct predictions for distributive rule r , and $N_{.r}$ is the predicted count for distributive rule r . The maximum value of this index is

$$1 - \sum_{r=1}^2 \left(\frac{N_{.r}}{48} \right)^2 = 0.44$$

Thus, the predictive success of the model is $67\frac{2}{3}\%$ ($= 0.30/0.44$) of its potential value.

To facilitate an assessment of the economic significance of these results, I normalize the independent variables in Table 3 so that the mean of each is zero and the standard deviation is one. I then re-estimate the logit model, the results of which are presented in Table 7. On the

Table 7
Results of a re-estimation of the logit model in Table 5, with normalized independent variables^a

Variable	Coefficient	S.E.	t-ratio
Gini	2.8839	1.0879	2.65
Households	2.1657	2.5888	0.84
<i>Ejidos</i>	-0.1890	1.3329	-0.14
WUA age	1.6156	0.9087	1.79
Water depth	-1.0819	0.8765	-1.23
ℓ_{\min}/wage	0.2344	1.7506	0.13
Lined %	0.8775	0.6294	1.39
Constant	1.7708	1.1951	1.48

^aEach of the normalized explanatory variables has mean zero and standard deviation equal to one. $N = 48$; $\chi^2(7) = 38.73$; Probability $> \chi^2 = 0.0000$; Log likelihood = -11.83; Pseudo- $R^2 = 0.62$.

Table 8

The marginal effect of a one-unit change in each independent variable on the estimated probability $\hat{\delta}^a$

Variable	Marginal effect of one-unit change (%)
Gini	35.85
Households	26.92
<i>Ejidors</i>	-2.35
WUA age	20.08
Water depth	-13.45
ℓ_{\min}/wage	2.91
Lined %	10.91

^a $\hat{\delta}$ is the estimated probability of choosing a proportional/proportional-allocation rule, versus an equal-division rule. The marginal effect of independent variable x_k is defined as $\partial\delta/\partial x_k = f(x'\hat{\beta})\hat{\beta}_k$ where $f(\cdot)$ is the density function of the logistic distribution, $\hat{\beta}_k$ is the estimated coefficient in the normalized-variable logit model presented in Table 6, evaluated at the vector of mean values of x' .

basis of these results I present in Table 8 the marginal effect of a one-unit increase in each variable on the estimated probability of observing a proportional/proportional-allocation rule, evaluated at the vector of mean values of the independent variables.¹⁴ A one-unit change in any independent variable is equivalent to a change of one standard deviation in the non-normalized variable. (Standard deviations of the non-normalized variables are listed in Table 3.)

A one-standard-deviation increase in the Gini coefficient has the largest marginal effect on the probability of choosing a proportional/proportional-allocation rule (36%). Increases in the number of households and the age of the water users' association also have large positive marginal impacts (27 and 20%, respectively). Increases in the number of *ejidos* represented and the potential water depth have large negative impacts on the estimated probability (-2 and -14%, respectively). The negative impact of the number of *ejidos* is consistent with a central result of Wade's (Wade, 1987) celebrated field study of irrigation management in 41 villages in Andhra Pradesh (South India). (The low level of significance of the number of *ejidos* is not consistent with Wade.) Wade found that irrigation organization was more successful where the management organization overlapped with other structures of authority. Thus, if there is a significant overlap between the *ejido* and the *unidad* (and consequently fewer *ejidos* per *unidad*), then the *unidad* can draw on the institutional legitimacy and authority of the *ejido*.

3. Concluding remarks

3.1. Summary of results

In this paper, I presented a model of individual incentives to provide collective maintenance labor under four distributive rules observed in a field study of Mexican farmer-managed

¹⁴ As the mean value of each variable is now zero, the density function of the logistic distribution is here a function only of the estimated intercept term.

irrigation systems. I showed that rules with congruent cost-sharing and water-allocation arrangements elicit higher levels of compliance (and thereby generate higher levels of output). Transaction costs differ among the rules, however: proportional water-allocation and cost-sharing imply higher costs of record-keeping, monitoring, and negotiation. I gave conditions under which an incongruent rule occasions lower systemwide costs than the congruent rule that divides maintenance costs and irrigation water proportionally to land-holding size. Nevertheless, any system could elicit full compliance with low transaction costs by dividing maintenance costs and irrigation equally among all households. Why then do the surveyed systems exhibit so much heterogeneity of distributive-rule choice? Wealthier households may press for proportional water allocation, either because this increases the difference between their benefits and costs, or because, starting from equal division, water productivity is higher on larger parcels.

In the empirical portion of the paper, I estimate a logit model of the likelihood that a system has chosen the proportional/proportional-allocation rule, versus the equal-division rule. I find that economic inequality strongly increases that likelihood. This evidence is consistent with the interpretation that wealthier land-holders successfully press for larger shares of the irrigation supply. I also find that older water users' associations are more likely to have chosen a proportional or proportional-allocation distributive rule. If longer-lived irrigation groups learn to implement more-complex rules more efficiently over time, they will be more likely to exhibit the proportional/proportional-allocation rule. (Note that I do not seek to uncover the factors that lead to the appearance of local institutions to manage the commons. Instead, I seek to establish empirical regularities among the currently-existing population of resource-using groups.)

3.2. *Relation to other work*

Analytical work on the institution of common property emphasizes the conditions under which it is more efficient than private property rights. Anderson and Hill (1983) show that the process of establishing property rights in a common pool resource will dissipate rents and efficiency gains unless the process is entrusted to residual claimants — like peasant irrigators in a water users' association. Lueck (1994) models common property as an endogenous institution that can generate higher welfare than private property in agricultural production. Quiggin (1995) illustrates that common-property ownership of certain agricultural inputs — such as grazing land or irrigation water — characterized by scale economies is efficient in combination with 'family farms' that minimize labor-supervision costs. In a different vein, Sethi and Somanathan (1996) model the evolution of social norms among the users of a common-pool resource.

This paper seeks to answer a different, though related, question. Given that common property exists over a certain common-pool resource, under what circumstances will it be exploited in a welfare-maximizing way? A particularly salient condition is the level of wealth inequality. Dayton-Johnson and Bardhan (1996) and Baland and Platteau (1998) explore the theoretical relationship between inequality and resource conservation, drawing examples from the case-study literature. The analysis in the present paper is (practically) unique in this context in that it is closely based on field research among a class of resource-using systems.

3.3. Extensions of the analysis

A central prediction of this paper is that over time, more of today's resource-using groups will choose the proportional/proportional-allocation rule. Some factors could speed up this process: market-oriented reforms in the rural sector; and rural-development strategies to promote efficiency in the use of resources.

Recent reforms in Mexican agriculture (alluded to in Footnote 14) will likely increase the volume of transactions in the land market, as *ejido*-holders gain title to their land. For decades, the land-holding distribution has been effectively frozen; these new changes are expected to lead to greater land-holding inequality in the rural sector. Nevertheless, common property remains the form of ownership of irrigation infrastructure for the Mexican *unidades*. The model and evidence in this paper suggest that such a change will increase the number of irrigation groups that choose proportional water-allocation arrangements. Since my paper does not model group formation, it is silent on the issue of whether groups will tend to break apart with greater inequality. The relationship between inequality and group stability might be quite complex: Quiggin (1993) suggests that successful common-property regimes rely on a minimal level of asset-holding inequality, and may restrain forces toward greater inequality present in fully private property regimes.

Rural-development strategies that engage farmers in the construction or rehabilitation of canals and reservoirs might also have an effect on the institutional form of irrigation groups. WECS/IIMI (1990), for example, describes an infrastructure-improvement project among small farmer-managed irrigation systems in Nepal that also sought to enhance the management capabilities of the groups. To the extent that such intervention reduces transaction costs G and H , by introducing accelerated learning-by-doing, such policies will also promote the adoption of the proportional/proportional-allocation rule.

Acknowledgements

Thanks are due to Pranab Bardhan, Charles Clarke, Alain de Janvry, Juan Pablo Flores Pérez, Sam H. Johnson III, Matthew Rabin, Clifford Zinnes, participants at the 1999 Northeast Universities Development Consortium conference at HIID, and two anonymous referees. The field research received generous financial support from the MacArthur Foundation's Research Network on Inequality and Economic Performance.

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