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Nancy McCarthy, Alain de Janvry and Elisabeth Sadoulet

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS

BERKELEY

California Agricultural Experiment Station

University of California

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS AND POLICY
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA AT BERKELEY

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Land Allocation Under Dual Individual-Collective Use in Mexico[1]

by

Nancy McCarthy

International Livestock Research Institute, Nairobi

International Food Policy Research Institute, Washington D.C.

and

Alain de Janvry and Elisabeth Sadoulet

University of California at Berkeley

Abstract

Households typically have to decide on allocating the resources which they control between individualized activities and activities where there is common access. In this case, the ability to cooperate in the management of common access resources determines the relative profitability of the two resource bundles and hence affects the allocation of resources held by households to one or the other. The Mexican social sector is of this type, with land under individual jurisdiction allocated to either crops or pastures: the product of land in crops is privately appropriated while land in pastures is collectively grazed. We develop a model that shows that, when cooperation fails in the management of collectively grazed pastures, more land is allocated to extensive crops than under successful cooperation and less to pastures, while the stocking rate on pastures is increased. This results in too much land in extensive crops and too many animals per hectare of pasture, a well known observation for Mexico. This prediction is confirmed by analysis of data from a sample of Mexican social sector households.

JEL classification: Q15: Land Ownership and Tenure.

Key words: Dual property rights, land allocation, overgrazing, Mexico.

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I. Introduction

There exists a generic set of situations where an individual has to decide on allocating a given resource bundle--typically land, labor time, or capital--between two alternatives: individual use and collective use. How much of the resource goes to each alternative depends, at the margin, on the utility which the resource yields in each. The marginal utility of the resource in collective use, for the individual who makes this decision, is affected by the behavior of others in contributing to and using the total amount of resources allocated to collective use, if there are externalities or economies of scale in collective use. Examples include land tenure regimes that give rural households the option of allocating land under their jurisdiction to either private use or to collective use shared with members of a community. How much they will each allocate to collective use will depend on efficiency in the management of the common access resource, which in turn depends on ability of community members to cooperate to reduce the negative externalities created by individual incentives to overuse the resource: if cooperative behavior prevails, efficiency in using the common access resource is high, and individuals will allocate more land to common use; if the community is unable to cooperate in managing the common access resource, efficiency in common access land use is low, and individuals will retain more land for private activities while simultaneously over-exploiting the common access resource. Other easily recognizable examples include time allocation to either individual enterprises or to maintenance of a common property resource like irrigation canals, pastures, and community infrastructure. If there are economies of scale or economies of coordination in these collective tasks, greater cooperation will induce greater individual time allocation toward them. Similar resource allocation dilemmas are encountered by individuals within households in deciding to contribute to the acquisition of private or collective goods, by citizens in deciding to participate to private or collective action activities, and by taxpayers in their willingness to abide to heavier tax burdens for the delivery of public goods and services.

This duality of forms of land use prevails in the Mexican "social sector" which is comprised of *ejido* and indigenous communities. These communities are groups of individuals who have been formally granted land by the government under the land reform program introduced in the 1917 Constitution, as an outcome of the peasant-led revolution of 1910 (DeWalt and Rees, 1994). The owner of the land is legally the community as a whole, but there are two forms of property rights regarding access to productive land within a community: usufructed individual plots and common property lands, principally in pastures and forests (see Figure 1). In their plots, individuals can either cultivate crops or leave land in natural pastures.[2] Crops are cultivated individually. Land allocated to natural pastures can either be grazed individually, excluding access by others, or opened for collective grazing. The boundaries between land in individual crops and land in common access pastures are thus internal to the members' individual plots, principally because much of the land in these plots must remain in fallow in rotation with crops. In addition to common property pastures, how much land goes to common access grazing thus depends on individual decisions. The widespread choice of collective over individual grazing is due to lower fixed costs associated with fencing, transportation infrastructure, and access to water holes. The 1992 reform of the 1917 Agrarian Law, which will give private titles to households over land plots currently in individual usufruct, will alter neither the existence of common property pastures nor the logic for this dual pattern of land use.

This system of dual patterns of land use is very important for Mexican agriculture and for management of the environment since 53% of the country's agricultural land and half of its irrigated area are in the social sector (de Janvry, Gordillo, and Sadoulet, 1997). In this sector, 67% of the land is in common property, with 80% of this area in pastures and forests. By far the most important crop for social sector households is maize which, together with beans and other low productivity grains, covered in 1994 71% of the cultivated area. Livestock is also an important activity, with 46% of the ejidatarios owning cattle, 21% horses, and 10% and 7% goats and sheep, respectively.

In this paper, we develop a behavioral model that integrates crop-livestock interactions into a farmer's decision problem, where the farmers in a community have either fully individualized land use or where dual patterns of land use prevail. If dual land use prevails, a farmer cultivates crops (which will be referred to here generically as "maize" since this is by far the dominant crop) individually, but any land allocated to pastures is grazed collectively. Maize stalks are used to feed livestock, but these are appropriated individually since they fall within the area fenced for crops. The basic issue that the model addresses is how do the patterns of accessing pastures (individual or common access) and the community's ability to cooperate over the management of common access pastures when they exist affect (1) the share of land under a farmer's jurisdiction allocated to maize and to pastures and (2) the farmer's decision regarding the number of animals to graze. We

[2] The boundaries between individual plots and common property (CP) land is fuzzy for two reasons. One is that land individually contributed to pastures is often de facto counted as part of CP land and not of individual plots. The other is that there always exists the possibility of some encroachment of individual plots on CP land, making effective individual jurisdiction over land extend beyond the current individual plot. In the model that follows, the boundary between individual plots and CP land need not be observed. All that matters is the boundary between crops and common access pastures.

contrast three patterns of decision making: (1) fully individualized land with no collective grazing, (2) individual decisions about allocation of land in plots to collective pastures, with cooperation on the optimum number of animals to be grazed on these pastures, and (3) individual decisions about both the allocation of land in plots to collective pastures and the optimum number of animals. The model helps explain why the uneven but usually low ability of social sector communities to cooperate contributes to reinforce a well-known double feature of the social sector of Mexican agriculture: dedication of extensive areas to the cultivation of low productivity maize and overgrazing in common access pastures.

II. Modeling individual incentives

Consider a community with M members and a total amount of cultivable land H. Each member i has usufruct over an individual plot of area h_i, and these areas are in general not equal across members (Figure 1). The community in addition has an area CP in common property pastures. Hence, total area is $H = \sum_{i=1}^{M} h_i + CP$. Members choose to produce one crop, maize, and to raise cattle. Member i thus decides how to allocate his land h_i between maize h_{mi} and pastures h_{ci} which are used to graze animals. He must also decide on n_i, the number of animals to graze. Total area in common access pastures is thus $H_c = \sum_{i=1}^{M} h_{ci} + CP$. Different communities have different access rules to pastures. We consider three institutional setups: (1) The case of complete exclusion, where each farmer uses individually pastures within his own plot to graze his own animals. (2) Lands allocated to pastures by individuals are in common access, with all members given equal grazing rights to the total area in common access pastures. Members jointly determine the total number of animals to graze N. In this case, each farmer chooses how to allocate his own land to maize and to pastures, given the number of animals $n_i = N/M$ which he is allowed to graze.[3] (3) Pastures are in common access, but non-cooperation prevails in deciding how many animals to graze.

With individual choice on land allocation to common access pastures, h_{ci} creates a positive externality for others since the contributor only captures $1/M$-th of the benefit of his contribution to collective pastures. Hence, there is under-provision of h_{ci} and too much land is in maize. At the same time, if there is no cooperation on the number of animals to be grazed, n_i creates a negative externality on others since the cattle owner only pays $1/M$-th of the cost of grazing. There is excess-provision of n_i, and the stocking rate $n_i/\bar{h}_c$ (where $\bar{h}_c = H_c / M$ is the average land in pasture per member) is too high, resulting in overgrazing of the pastures in common access. With

[3] In the communities with common access pastures and rules on the number of animals, the individual limits were equal for all members. This is typical of the constitution of social sector communities.

cooperation on the number of animals, the negative externality inducing overgrazing is eliminated. However, under-provision of land to pasture and excessive allocation of land to maize compared to exclusion still persist.

2.1. *Exclusive access to pasture land*

Under complete exclusion, the fixed cost structure is such that the land area h_i has been fenced and farmer i allocates this area between maize h_{mi} and pastures h_{ci} for grazing a number of animals which he controls. This farmer has fixed productive assets z_i in crop production and a constant marginal cost c_i in livestock production. The constrained optimization problem is written:

$$\underset{h_{mi}h_{ci}n_i}{\text{Max}}\ \Pi_i^E = p_m f(h_{mi}; z_i) + p_c\left[n_i\left(a - \frac{bn_i}{h_{ci}}\right) + k\phi f(h_{mi}; z_i)\right] - c_i n_i + \lambda(h_i - h_{mi} - h_{ci}) - FC_i^E$$

where:

Π_i^E is profit achieved under complete exclusion,
p_m and p_c are the prices of maize and livestock, respectively,
f is the production function for maize grain with decreasing returns in land due to the presence of fixed factors,
h_{mi}, h_{ci}, and h_i are land dedicated to maize and livestock, and total land, respectively,
z_i is the set of fixed factors in maize production,
n_i is the number of heads of livestock,
a and b are technical coefficients in the animal weight gain function with
a = pasture productivity,
b = pasture sensitivity to stocking,
k is a constant that captures the transformation of maize residue into animal weight gain,
ϕ is a parameter that gives the quantity of maize residue produced per unit of maize grain,
c_i is the constant marginal cost associated with each animal,
FC_i^E are fixed costs associated with herding under a completely individualized regime, and
λ is the Lagrange multiplier associated with the land constraint.

Maize in the communities studied is produced with highly traditional technology, with labor and (minimal) fertilizer inputs largely in fixed proportions to land. For this reason, use of variable inputs else than land can, without much loss of accuracy, be accounted for by h_{mi}. Fixed factors in maize production include human capital, the stock of machinery, and environmental characteristics.

The terms contained within the square brackets define the weight gain function for cattle. The first part of this function corresponds to gain from natural pastures. This particular functional form has been empirically tested by a number of investigators (Heady and Dillon, 1961) and gives a good fit for lands which are optimally or over-exploited, that is to say, it performs well except when grazing intensity is less than that coinciding with the maximum sustainable forage yield (Hart et. al., 1989). In the types of communities we are studying, there basically never is under-grazing. The second part of the weight gain function is the additional gain arising from the feeding of unharvested maize stovers, where $f(h_{mi};z_i)$ is the production function for maize, ϕf is the production of maize residues, and k is a constant that transforms maize residue into animal weight gain. This second part of the cattle weight gain equation is a simplification since it states that maize residues becomes kilograms of cattle weight, regardless of the number of cattle held. This approximation has validity only because the role of maize residues in the total feeding of animals is small. The specification of constant marginal costs in rangeland beef production has been used both in specialized studies (Torrell, Lyon, and Godfrey, 1991; Seligman, Noy-Meir, and Gutman, 1989) and is typical of the general literature on grazing in common property resources (Dasgupta and Heal, 1979; Conrad and Clark, 1987; Stevenson, 1991).[4]

Fixed costs FC_i^E for the individual include: a) the cost of installing a fence and, subsequently, yearly lump-sum costs of maintenance, b) the loss of cultivable land due to expansion of the road network, and c) costs associated with bringing animals to water.

The first order conditions for individual i with fixed assets z_i and cost c_i are:

$$\frac{\partial \Pi^E}{\partial n_i} = ap_c - \frac{2bp_c n_i}{h_{ci}} - c_i = 0, \quad (1)$$

$$\frac{\partial \Pi^E}{\partial h_{mi}} = p_m f_i' + k\phi p_c f_i' - \lambda = 0, \quad (2)$$

[4] Neglect of the role of animal manure on maize output is based on personal communications with experts in nutrient cycling at the International Livestock Research Institute based in Nairobi who claim that, under the type of climate and pasture management observed in the communities, the nitrogen contribution of livestock would be between 7.5 and 0.4 kg per hectare for the range of stocking rates observed. These are negligible amounts in terms of impacting maize yields.

and $$\frac{\partial \Pi^E}{\partial h_{ci}} = \frac{bp_c n_i^2}{h_{ci}^2} - \lambda = 0,$$ (3)

where f_i' is the marginal productivity of land in maize production. From (1), we derive the optimal stocking rate :

$$\left(\frac{n_i}{h_{ci}}\right)^* = \frac{a - c_i / p_c}{2b},$$ (4)

which is function of variables and parameters concerning livestock production only.[5] The optimal allocation of land to maize is then given by equations (2) and (3):

$$f_i'^* = \frac{bp_c}{(p_m + k\phi p_c)}\left(\frac{n_i}{h_{ci}}\right)^{*2} = \frac{p_c}{(p_m + k\phi p_c)4b}(a - c_i/p_c)^2.$$ (5)

2.2. Common access pastures with cooperation over the number of animals

We now consider the case where pastures in individual plots are pooled with common property pastures and open to common grazing, and where the community has the ability to cooperate in setting optimally the number of animals to graze on these pastures. The fixed costs FC^C associated with common grazing are lower than under privatized grazing as this allows to save on fencing, infrastructure costs, and costs of watering the animals. The M community members (or a social planner) decide cooperatively on the optimum number of animals N^* to be grazed given the area in common property pastures and the sum of the individual land contributions that members make to the area in pastures. With all individuals having equal constitutional grazing rights in common access pastures, the optimum number of animals which each can have is $n^* = N^* / M$.[6] The members, anticipating this behavior of the social planner in setting the number

[5] A non-negativity constraint would need to be added to the cattle weight gain function if the price of cattle would fall so much as to imply a negative stocking rate.

[6] The result from this optimization differs from an unconstrained social optimizer's solution since, in that case, all rights would be allocated to the lowest cost producer, given that marginal costs are constant. However, this does not correspond to the constitutional rights of ejido members according to which grazing rights are equally allocated among users. Secondary markets may then arise to offset, or at least decrease, the inefficiency arising from the group-level optimization via a re-allocation of stocking rights toward the low cost producers. Note that if the number of animals which each member is allowed to graze was proportional to his/her contribution to common access pasture, i.e., $n^*_i = \frac{h_{ci}}{H_c} N^*$, the positive externality on the allocation of land to pastures would disappear and the solution for both number of animals and land allocated to maize would be identical to the solution under exclusion.

of animals which each of them cave have, decide on the allocation of land in individual plots to exclusive crops and to common access pastures. This can be conceptualized as a principal-agent problem where the social planner is the agent setting N given H_c, and the community members are the principals who choose h_{mi} given n_i as follows:

Step 1: The agent is the social planner who chooses N given the land contributions made by members to the common access pasture area, i.e., given $H_c = \sum_{i=1}^{M} h_{ci} + CP$. His problem is:

$$\underset{N}{\text{Max}}\, \Pi^C = \sum_i p_m f(h_{mi}; z_i) + p_c\left[N\left(a - b\frac{N}{H_c}\right) + \sum_i k\phi f(h_{mi}; z_i)\right] - N\bar{c} - FC^C,$$

for given $H_c = \sum_i (h_i - h_{mi}) + CP$,

where $\bar{c}$ is the average marginal cost of an animal in the community.

The first order condition is: $\frac{\partial \Pi}{\partial N} = p_c\left(a - 2b\frac{N}{H_c}\right) - \bar{c} = 0$, which is independent of i.

This gives the optimum number of animals: $N^* = H_c\left(\frac{a - \bar{c}/p_c}{2b}\right)$ and hence also the optimum collective and individual stocking rates:

$$\left(\frac{N}{H_c}\right)^* = \left(\frac{n_i}{\bar{h}_c}\right)^* = \frac{a - \bar{c}/p_c}{2b}, \qquad (6)$$

where $\bar{h}_c = \frac{H_c}{M}$ is pasture land per member.

The optimum number of animals for each member is thus set at:

$$n^* = \frac{N^*}{M} = \frac{1}{M}\left(\sum_i (h_i - h_{mi}) + CP\right)\left(\frac{a - \bar{c}/p_c}{2b}\right).$$

Using the land constraint on each member, n^* varies with h_{mi} according to

$$\frac{\partial n^*}{\partial h_{mi}} = -\frac{1}{M}\left(\frac{a - \bar{c}/p_c}{2b}\right).$$

Step 2: The principals are the members who choose h_{mi} given n and fixed N/H_c. For each of them, the problem is:

$$\underset{h_{mi}}{\text{Max}}\, \Pi_i^C = p_m f(h_{mi}; z_i) + p_c\left[n\left(a - b\frac{N}{H_c}\right) + k\phi f(h_{mi}; z_i)\right] - nc_i + \lambda(h_i - h_{mi} - h_{ci}),$$

for given $n = \frac{1}{M} N$.

The first order condition is:

$$\frac{\partial \Pi_i}{\partial h_{mi}} = \left.\frac{\partial \Pi_i}{\partial h_{mi}}\right|_n + \frac{\partial \Pi_i}{\partial n}\frac{\partial n}{\partial h_{mi}}$$

$$= p_m f_i' + p_c k\phi f_i' + \left[p_c\left(a - b\frac{N}{H_c}\right) - c_i \right]\left[-\frac{1}{M}\left(\frac{a - \bar{c}/p_c}{2b}\right)\right] = 0.$$

Solving for f_i' gives:

$$f_i'\left(h_{mi};z_i\right)^* = \frac{bp_c}{p_m + k\phi p_c}\frac{1}{M}\left(\frac{N}{H_c}\right)^*\left[\left(\frac{N}{H_c}\right)^* + \frac{\bar{c} - c_i}{bp_c}\right]. \tag{7}$$

Hence, there is a negative externality in the allocation of pastures to the common pool: the optimum area in corn increases with M as each individual members only captures $1/M$-th of the benefit from the marginal hectare he allocates to pastures. Cooperation on the number of animals thus leads to an optimum stocking rate but to an excessive allocation of land to maize.

2.3. *Common access pastures with individual choices on the number of animals*

In this case, each individual has his own land endowment h_i and decides on the number of hectares to contribute to common property pastures h_{ci} and on the number of animals n_i to graze on the common access pastures, taking as given the other members' allocation of land to pastures. Using the subscripts i to denote the individual household and $\sim i$ to denote all other households, the optimization problem is written:

$$\underset{h_{mi}h_{ci}n_i}{\text{Max}}\ \Pi^{NC} = p_m f\left(h_{mi};z_i\right) + p_c\left[n_i\left(a - \frac{b\left(n_i + \sum n_{\sim i}\right)}{\left(h_{ci} + \sum h_{c\sim i} + CP\right)}\right) + k\phi f\left(h_{mi};z_i\right)\right] - c_i n_i + \lambda\left(h_i - h_{mi} - h_{ci}\right) - FC^{NC}.$$

The summation $\sum n_{\sim i}$ is the total number of animals pastured by all other members and $\sum h_{c\sim i}$ is the total land dedicated to pasture by all other individuals. Fixed costs are again different in this case: costs of fencing and maintenance are the same as under cooperation on the number of animals, but there are no costs of cooperation. By contrast to the privatized and cooperative solutions, there are negative externalities arising from over-exploitation of the common access pastures, resulting in overgrazing.

The first-order conditions are:

$$\frac{\partial \Pi^{NC}}{\partial n_i} = ap_c - \frac{2bp_c n_i}{H_c} - \frac{bp_c \sum n_{\sim i}}{H_c} - c_i = 0, \tag{8}$$

$$\frac{\partial \Pi^{NC}}{\partial h_{mi}} = p_m f_i' + p_c k\phi f_i' - \lambda = 0, \tag{9}$$

and $$\frac{\partial \Pi^{NC}}{\partial h_{ci}} = \frac{bp_c\left(n_i^2 + n_i \sum n_{\sim i}\right)}{H_c^2} - \lambda = 0, \tag{10}$$

where $H_c = h_{ci} + \sum h_{c\sim i} + CP$.

Equation (8) gives the individual optimal number of cattle:

$$n_i = \frac{(a - c_i/p_c)(h_{ci} + \sum h_{c\sim i})}{2b} - \frac{\sum n_{\sim i}}{2}.$$

Substracting $n_i/2$ to both sides of this relation gives:

$$n_i = 2\left[\frac{(a - c_i/p_c)H_c}{2b} - \frac{N}{2}\right].$$

The aggregate stocking rate is found by summation of these expressions over the M members:

$$\left(\frac{N}{H_c}\right)^* = \frac{2M}{M+1}\frac{(a - \bar{c}/p_c)}{2b}, \tag{11}$$

and the stocking rate for individual i is:

$$\frac{n_i}{h_c} = \frac{2M}{M+1}\frac{\left(a - \bar{c}/p_c + (M+1)(\bar{c} - c_i)/p_c\right)}{2b}. \tag{12}$$

By contrast to the cooperative case, there is a negative externality in grazing: the optimum stocking rate for each individual increases with the number of community members as the larger the number of members the smaller is the fraction of the cost of a marginal animal borne by one individual member.

Combining (9) and (10) gives the individual allocation of land to maize:

$$f_i'^{*} = \frac{b p_c}{(p_m + k\phi p_c)} \frac{1}{M} \left(\frac{N}{H_c}\right)^{*} \left(\frac{n_i}{\bar{\bar{h}}_c}\right)^{*}. \tag{13}$$

Here also, there is an externality created by collectivization of the land in pasture. Since an individual member only captures a fraction of the benefits of land in pasture, as M increases more land is retained in individually used crop land.

2.4. Comparison of solutions

We can now compare the individual stocking rates under the different regimes of access to pastures as given by equations (4) for exclusion, (6) for common access with cooperation, and (12) for common access with no cooperation. These equations can all be written in the same generic form:

$$\left(\frac{n_i}{h_{ci}}\right)^{*} = \frac{(a - \bar{c}/p_c)}{2b} + I_{NC}\left[\frac{M-1}{M+1}\frac{(a-\bar{c}/p_c)}{2b} + 2M\frac{(\bar{c} - c_i)/p_c}{2b}\right], \tag{14}$$

where I_{NC} is equal to one under common access with no cooperation and to zero under either exclusion or common access with cooperation. In this equation, $\bar{c}$ is defined as c_i under exclusion, and h_{ci} is land rights in pasture, equal to individual pasture land in the exclusion case and to the individual share of common access pastures $\bar{h}_c$ in the other two cases.

The first element of the right hand side of equation (14) indicates that, under all regimes, the number of cattle per hectare in pastures is an increasing function of pasture productivity a and the price of cattle p_c, and a decreasing function of pasture sensitivity b and of the average cost per animal $\bar{c}$. If cooperation prevails, the number of members in the community does not affect the optimal solution. The term in square brackets shows that, under non-cooperation, herd size increases by an additional term which is function of the number of members in the community, pasture productivity, cattle price, average cost, and the difference between the individual cost and the average community cost. This term is positive, with the possible exception of the least efficient individuals with highest cost c_i:

$$\frac{\partial (n_i/h_{ci})}{\partial I_{NC}} > 0 \text{ for } (c_i - \bar{c})/p_c < \frac{1}{2M}\frac{M-1}{M+1}(a - \bar{c}/p_c).$$

Hence, all individuals except the very inefficient cattle producers will have larger herds under non-cooperation than they would under cooperation.

The derivatives of this additional term with respect to its elements make explicit the consequences of non-cooperation on herd size. The derivatives with respect to pasture productivity and sensitivity:

$$\frac{\partial^2 (n_i/h_{ci})}{\partial I_{NC} \partial a} = \frac{M-1}{M+1} \frac{1}{2b} > 0 \text{, and}$$

$$\frac{\partial^2 (n_i/h_{ci})}{\partial I_{NC} \partial b} = -\frac{1}{b}\left[\frac{M-1}{M+1}\frac{(a-\bar{c}/p_c)}{2b} + 2M\frac{(\bar{c}-c_i)/p_c}{2b}\right] < 0 \text{ for } (c_i-\bar{c})/p_c < \frac{1}{2M}\frac{M-1}{M+1}(a-\bar{c}/p_c),$$

indicate that overstocking due to non-cooperation increases with pasture productivity and decreases with pasture sensitivity, the latter except for the least efficient producers.

In the estimated equations, we will include the effect of average cost in the community, controlling for the difference between individual and average cost:

$$\left.\frac{\partial^2 (n_i/h_{ci})}{\partial I_{NC} \partial \bar{c}}\right|_{c_i-\bar{c}} = -\frac{M-1}{M+1}\frac{1}{2bp_c} < 0 \text{ and } \left.\frac{\partial^2 (n_i/h_{ci})}{\partial I_{NC} \partial (c_i-\bar{c})}\right|_{\bar{c}} = -\frac{M}{bp_c} < 0.$$

This shows that overstocking will be less severe in less efficient communities, and also less severe for producers who are less efficient compared to the community average.

Overgrazing also increases with the price of livestock:

$$\frac{\partial^2 (n_i/h_{ci})}{\partial I_{NC} \partial p_c} = \frac{1}{2bp_c^2}\frac{(2M^2+M+1)\bar{c}+2M(M+1)c_i}{M+1} > 0,$$

and in larger communities, again with the possible exception of the most inefficient producers:

$$\frac{\partial^2 (n_i/h_{ci})}{\partial I_{NC} \partial M} = \frac{1}{b(M+1)^2}\left[(a-\bar{c}/p_c)+(M+1)^2(\bar{c}-c_i)/p_c\right]$$

$$> 0 \text{ for } (c_i - \bar{c})/p_c < \frac{1}{(M+1)^2}(a - \bar{c}/p_c).$$

The concept of aggregate stocking rate is not relevant under exclusion, since decisions and stocking rates vary among individuals. The overall average stocking rate could, however, be written:

$$\left(\frac{\overline{N}}{H_c}\right)^* = \frac{a - (\sum h_{ci} c_i / H_c)/p_c}{2b}. \tag{15}$$

Under common access regimes, aggregate stocking rates are given by (6) under cooperation and (11) under non-cooperation. Comparison of these expressions shows that the aggregate stocking rate under exclusion would be equal to the stocking rate under cooperation if all individuals were identical. With heterogeneity of efficiency, both the allocation of land and the stocking rates would differ across individuals, and the average may be either larger or smaller than under cooperation.[7] Under non-cooperation, the stocking rate is unambiguously higher than under cooperation by a multiplicative factor that is a function of the community size only.

Land allocated to maize production under the three regimes is given by equations (5), (7), and (13), which can all be written as the general expression:

$$f_i'^*(h_m; z_i) = \frac{bp_c}{p_m + k\phi p_c} \frac{1}{M}\left(\frac{N}{H_c}\right)^* \left[\left(\frac{n_i}{\overline{h}_c}\right)^* + I_C \frac{\bar{c} - c_i}{bp_c}\right], \tag{16}$$

where $I_C = 1 - I_{NC}$ is a cooperation index, and I_{NC} is defined as before. Under exclusion, $c_i = \bar{c}$ and $M = 1$, and the aggregate stocking rate (N/H_c) is equal to the individual stocking rate.

Since the marginal productivity of land decreases with plot size, the optimal maize area h_{mi} will increase as the individual or aggregate optimal stocking rates decrease, as the price of maize rises, and as fixed factors in maize production increase. It is undetermined with respect to the price of cattle, unless residues are negligible in which case land in maize will fall when p_c rises. When the size of the community increases, the land in maize expands if there are common access pastures ($M > 1$), whether cooperation prevails or not in livestock management. Finally, if cooperation

[7] This assumes no trading under exclusion.

prevails ($\ell_{NC} = 0$), the land in maize is smaller for the most efficient cattle producers ($\bar{\bar{c}} - c_i > 0$) since they want to contribute more land to common access pastures to be able to increase the number of animals they will graze on these pastures.

III. The Data

Two surveys were undertaken jointly by the Centro de Investigaciones y Docencia Económica (CIDE) in Mexico City and the University of California at Berkeley in nine social sector communities. The first survey collected information at the household level on land use patterns, production of crops and animals, and participation in village level meetings and collective tasks. Complete surveys were obtained for 175 households of which 150 own cattle. The second survey was directed at the nine community leaders and obtained information on community-wide land use patterns, community level use rates of common property pastures, the functioning of the community's governing body, the types of rules for participation in collective tasks, and the percentage of members who obey these rules.

The communities were not drawn from a random sample but selected to be representative of communities that have both crops and livestock under a variety of access rules to pastures. All but one are ejidos or indigenous communities with individual usufruct rights; the other is an indigenous village composed of small farmers with private lands which is not part of the social sector. Of those with usufruct rights, one community has explicit limitations on the number of cattle that members are allowed to graze, one has informal limits, one has moved to completely individualized use of pastures, and five have no explicit stocking limits. Of these latter five, two have a number of required collective duties and responsibilities including maintenance of fences and other installations, participation in weeding, pasture rotation schedules, etc.; whereas the remaining three have very few collective responsibilities.

Table 1 gives descriptive characteristics of the communities. The carrying capacity is a technical norm that indicates the potential stocking rate of pastures in a community measured as the number of hectares needed to support one animal unit during the course of a year. These norms have been established by COTECOCA for the whole country.[8] In Table 1, communities are ranked in decreasing order of actual stocking rates relative to carrying capacity, which gives a measure of actual grazing intensity relative to potential. Communities are thus ranked in decreasing

[8] COTECOCA is the Comisión Técnica Consultativa de Coeficientes de Agostadero. This commission is charged with determining the carrying capacity of pastures across the country. The data used here were obtained on request from this commission by giving the longitude and latitude coordinates of the communities surveyed.

order of overgrazing. From inspection of these descriptive statistics, there does appear to exist a relationship between cooperation to limit the number of animals or individualized decision making and a lower grazing intensity. The difference between San Juan de Michis and Nueva Aleman, two communities which border each other, is quite revealing. San Juan de Michis has explicit use rules, whereas Nueva Aleman does not; actual stocking relative to carrying capacity is double in the community without rules.

The area in extensive crops which compete with natural pastures for land allocation includes maize, beans, and other extensive cereals. Whatever little area devoted to horticulture, coffee, sugar cane, and tree crops which is not rotated with fallows is not counted in the area in crops that competes with pastures. The empirical analysis thus explains land allocation between pastures and low productivity crops, overwhelmingly maize, which are rotated with pastures.

Because we only have observations on nine communities, we are unable to endogenize the decisions (1) to use pastures individually or in common access and (2) to cooperate or not in using the latter. A much larger number of observations would be needed for this purpose. Hence, we are for the moment constrained to use the observed forms of access and observed cooperative behavior as exogenous determinants of stocking rates and land in maize. There is, however, a good justification to treat these as exogenous variables since both respond to long term determinants of behavior that are prior to individual decisions on land allocation and stocking rates. Exclusion responds to property rights (privatization) and a fixed cost structure that derives from geographical and historical factors. Ability to cooperate or not in community affairs is a broad concept that extends far beyond decisions on stocking rates. We can then invoke recursiveness between exclusion/cooperation and the stocking rate and land in maize variables.

IV. Empirical Model and Estimation

We now proceed to specify the equations to be estimated econometrically to explain the determinants of individual stocking rates and the land allocation decisions and to test the roles of exclusion and cooperation in these decisions, as derived from the theoretical model in equations (14) and (16). In the econometric estimations that follow, we use an indicator of pasture productivity (P, the carrying capacity in animals units per hectare) to capture the role of parameter a, and different indicators of efficiency in cattle production (Eff_i, which includes household education, age of the household head, and truck ownership) to capture the role of cattle production costs c_i.

Linearization of equation (14) leads to the following econometric specification for the stocking rate equation:

$$\frac{n_i}{h_{ci}} = \alpha_0 + \beta_0 P + \gamma_0 \overline{Eff} + \delta_0 p_c + I_{NC}\frac{M-1}{M+1}\left[\alpha_1 + \beta_1 P + \gamma_1 \overline{Eff} + \delta_1 p_c\right] + I_{NC}\frac{2M}{p_c}\gamma_2\left(Eff_i - \overline{Eff}\right), \quad (17)$$

with all parameters α, β, γ, and δ expected to be positive. Variables not indexed by i--namely the pasture productivity index P, average efficiency $\overline{Eff}$, cattle price p_c, and community size M--are community level variables. Their parameters will be identified by variations across communities. For prices, variations across communities are due to differential costs in getting products to markets. The only individual level factor affecting herd size is individual efficiency in the exclusion regime (the term $\overline{Eff}$ which is then equal to Eff_i) and relative efficiency in the common pasture regimes (the term $Eff_i - \overline{Eff}$).

Linearization of equation (16) leads to the following econometric specification for land allocated to maize production:

$$h_{mi} = \alpha + \beta p_m \pm \delta p_c + \varepsilon' z_i - \mu\left(\frac{N}{H_c}\right) - \upsilon\left(\frac{n_i}{h_{ci}}\right) + \varphi M + \psi I_C + \gamma I_C\left(Eff_i - \overline{Eff}\right), \quad (18)$$

where N/H_c is defined as equal to n_i/h_{ci} under exclusion, and all parameters are expected to be positive except for the price of cattle which is indeterminate and the relative efficiency effect, where producers who are relatively more efficient in cattle production allocate less land to maize production.

The stocking rate and the land in maize are function of the index of non-cooperation I_{NC} (or its complement, the index of cooperation $I_C = 1 - I_{NC}$). In the following estimations, we use two different specifications for I_{NC}. In the first, corresponding to the theoretical model, a dummy variable is used, where the two communities with exclusion and the community with explicit limits on the number of animals are assigned a zero value, and the remaining communities are assigned a value of one. The second specification uses an index of cooperation constructed from a principal component analysis of variables that characterize cooperative behavior to quantify the level of cooperation achieved in each community. While cooperating or not is a binary event, the impact of cooperation on the reduction in overgrazing relative to the non-cooperative optimum depends on the effectiveness of cooperation. This in turn depends on the number of issues that affect productivity on which rules have been established, the degree of abidance to rules, and the intensity of cooperation.

In the survey, we collected information on four variables which characterize cooperative behavior:

1. "Fence reparation rules". We use two variables: the binary existence of a rule, and the percentage of those who obey the rule. Where this rule does not exist, both variables take the value of zero.

2. "Other rules". Besides fencing, there are a number of duties that can be required of members such as maintenance of installations and weeding of pastures. Unlike fencing, the same rules rarely apply in more than two communities. We use two variables reflecting the existence and implementation of these rules. One is the number of other rules, and the other the average of the percentages of members who obey each rule. Each of these other rules were given the same weight and added together. Again, those with no other rules received a value of zero.

3. "Number of meetings" is how many meetings were held per year.

4. "Meeting attendance" is the percentage of members who attended meetings.

Because of high levels of correlation among these indicators of cooperation, we run a principal components analysis of these variables, and use the first factor as an indicator of non-cooperation. The first factor accounts for 85% of the cumulative correlation. The loadings of the variables on this component are as follows:

	Factor 1
Fence reparation rules (dummy variable)	0.398
Fence reparation rules* percent who obey the rules	0.406
Number of other rules	0.413
Average percent who obey other rules	0.413
Number of meetings	0.399
Meeting attendance	0.420

This factor is associated with high positive scores, of almost equal value, on all variables expected to be positively related to cooperation. Because we would like the index I_{NC} to reflect the degree of non-cooperation, this factor is normalized to lie in the unit interval, where zero corresponds to the individualized use regime. We will refer to this index as an indicator of "lack of cooperation".

V. Results

5.1. Stocking rate equation

Variables that serve as efficiency indicators Eff_i in the stocking rate equation (17) are years of schooling, a dummy variable for whether or not the family owns a truck, and the age of the household head, where age may enter non-linearly. For $\overline{Eff}$, the average values of these variables in the community are used. Both the price of cattle, p_c, and a herd size dummy variable times the price of cattle are used for the price effect. The dummy variable takes the value of zero if the household has three or fewer animals, and one if it has more than three. This is done to capture the fact that households with very small herds are likely to own these animals for purposes other than the commercial production of meat, e.g., oxen for cultivation, or a cow or two for household milk needs, and are thus expected to be less price responsive than households with larger herds.

There are three issues we must address before proceeding to the econometric estimations, namely 1) sample selectivity bias, 2) heteroskedasticity, and 3) the number of degrees of freedom when using community-level variables. As noted in Section III, the sample size for the econometric analysis is 175 households, of which only 150 are cattle-owners. Though the primary emphasis of the study is to model the behavior of farmers who both cultivate and own cattle, we do have information on 25 non-livestock owning households. Thus, in the first stage, we model the decision of whether to own cattle or not as a Heckman two-stage sample selection process. The Inverse Mill's Ratio derived from the first-stage probit is then used in the stocking rate and corn land equations. Secondly, because the data come from a cross-section sample, we tested each equation for heteroskedasticity. We used the Breusch-Pagan statistic to test for heteroskedasticity at the 5% significance level, and used the heteroskedasticity-consistent covariance matrix to correct for heteroskedasticity where necessary.

Finally, we must address the problem of degrees of freedom. Many of the variables differ only at the community level while we only have but nine communities, and hence nine degrees of freedom for variables at this level. And there are high correlations between many of these variables. As a result, it is difficult to estimate separately all the terms that include community-level variables. Thus, in models 1a and 2a, we include only the non-cooperation index and assume that all cross-effects are zero. In models 1b and 2b, we include the community cross effects with the index of non-cooperation. For the variables that characterize the individual differentials in efficiency, we only include those that improve the adjusted R^2.

Table 2 presents results for models 1 and 2 corresponding to the two indices of non-cooperation. With a few exceptions, results are as predicted by the model. In model 1a, the pasture productivity index and the price of beef*herd size dummy terms are positive and significant. Of the community efficiency variables, the average age of the household head is significant, with a maximum at 40 years old, and all efficiency variables are jointly positive and significant. Hence, communities with higher average levels of efficiency in cattle raising have higher stocking rates. The coefficient on the index of non-cooperation is positive and strongly significant, indicating that cooperation failure does induce over-grazing. In model 1b, community efficiency variables are not significant. The coefficients on the price of beef and the price of beef times the herd size dummy are positive and significant, indicating that the direct price response is 55% higher for large herd owners compared to those with three or fewer heads of cattle. The overall effect of I_{NC} measured at the average value of the multiplicative variables is positive and significant. When there is cooperation failure, the price of cattle reduces the stocking rate, a regularity that the current model is unable to predict, but the community efficiency level variables jointly increase the stocking rate, as expected. Hence, when cooperation fails, the relatively more efficient communities overstock more. Of the individual differential in efficiency in cattle production, the truckholding cross term is positive, indicating that, when there is cooperation failure, the relatively more efficient producers in the community overstock pastures more.

In models 2a-b, we use the index constructed from the principal components analysis to characterize the degree of non-cooperation in each community. In equation 2a, among community efficiency variables, average incidence of truckholding is positive and efficiency variables are jointly positive and significant. The price response coefficients are significant, again highlighting the greater price responsiveness of larger herd owners. The coefficient on the index of non-cooperation is strongly positive. This model gives a better fit than its counterpart, model 1a. In model 2b, as in model 1b, none of the community efficiency variables are significant. Coefficients on pasture productivity and the two beef price variables are positive and significant. In these two models, commercial producers are 50% more responsive to price incentives than owners of small herds. The overall effect of I_{NC} measured at the average value of the multiplicative variables is again positive and significant. Individual efficiency effects under non-cooperation show that more efficient producers overgraze more.

In conclusion, the different specifications for the effect of cooperation on stocking rates accord with both the theoretical model and intuition: under common access, the higher the degree of non-cooperation, the greater the stocking rate. The estimations also support the conclusion that, when cooperation fails or is weak, more efficient communities and more efficient members within a community will over-stock at higher rates. Accounting for differential levels of cooperation also seems relevant to predict stocking rates: using a goodness-of-fit criterion, model 2a, which uses a quantitative index of non-cooperation, performs better than model 1a where the qualitative dummy for non-cooperation vs. cooperation is used. Similarly, model 2b performs better than model 1b.

5.2. Land in maize equation

Models 3 and 4 for the land in maize equations presented in Table 3 were estimated using the predicted individual and community stocking rates from models 1b and 2b, respectively, and the corresponding cooperation indices. In model 3, all the fixed factors in maize production are significant. Of the price variables, the maize price is positive and significant for large herd size owners, with an elasticity of 0.35. The price of cattle affects positively the land in maize, indicating that the value of residues matters in cattle feeding for these large owners. The predicted individual stocking rate is negative and significant as predicted by the model. The community membership variable is not significant, indicating that the externality created by common access pastures on land allocation is not important per se. This largely comes from the fact that community membership is already accounted for in the predicted individual stocking rate. However, the role of cooperation is in all cases very important in reducing land allocation to maize, the main implication of the model. This is seen through both the direct role of the cooperation index and through the overall effect of I_C including the interaction effects with individual differences in efficiency. Among those interactions, households with a number of adults higher than the community average are more efficient in cattle raising and consequently have a lower area allocated to maize. Finally, the negative inverse Mills Ratio shows that households with livestock have a lower area in maize compared to households without livestock that were left out of the sample, due to explanatory variables other than those included in Table 4.

The results from model 4 are similar, confirming the most important result, namely the role of cooperation in reducing the area planted in maize. Differences with model 3 include significance of the price of maize for all cattle producers, small and large. The goodness-of-fit with a cooperation index is about identical to that obtained with the cooperation dummy.

We thus conclude that there is strong evidence in support of the observation that smaller amounts of land are allocated to maize cultivation in communities where pastures are used in common access when there is successful cooperation. We have weaker evidence that higher individual stocking rates reduce the area devoted to maize and that differentially more efficient livestock producers in the community contribute more pasture land to common access grazing.

VI. Conclusion

In this paper, we have modeled the impact of the forms of access to pastures in the social sector on both the stocking rate and the allocation of land between maize and pastures. We took for given the alternative forms of access to pastures: exclusion, common access with cooperation on stocking rate, and common access without cooperation. We also explored the fact that cooperation, while in theory a binary choice, in practice concerns a wide range of activities that can be more or less effectively performed across communities, providing a quantitative indicator of cooperation.

Results show that the stocking rate increases with cooperation failure. In addition, if cooperation fails, overgrazing is higher in communities that are relatively more efficient in cattle production and, within communities, by producers who are relatively more efficient. Finally, the index measuring the degree of cooperation gives a better fit than a cooperation dummy, indicating that there are indeed different qualities in the effectiveness of cooperation to reduce overgrazing.

With the few degrees of freedom available on community level variables, we cannot provide evidence on the role of a negative externality through community size on land area contributed to common access pastures. This could mean that there is cooperation in the allocation of land to crops and pastures. However, from extensive observation of decision-making in the communities, we know that this is not the case. It is more likely due to lack of degrees of freedom in and high correlations among community level variables. Results, nevertheless, give strong evidence that cooperation in determining the number of animals allowed to graze in common access pastures reduces the area allocated to maize.

Together, these results support the observation that, given common access pastures in the social sector and widespread weakness in cooperating (see de Janvry, Gordillo, and Sadoulet, 1997), there is an excessive amount of land going to individually cropped low productivity maize and overgrazing of pastures, with obvious consequences for poverty and environmental stress.

The Mexican government is well advanced in a land reform to give households in the social sector private property rights over individual plots formerly in usufruct, with the hope that this will lead to a more efficient agricultural sector and a less degraded environment. Though we do not have empirical estimates on the fixed costs of cattle production under cooperation, non-cooperation, and exclusion, the theoretical model and direct field observations suggest that, where cooperation can be achieved, common access pastures will generally be preferred to exclusion because of the fixed costs of fence installation and maintenance, as well as scarcity of water sources for the animals. Thus, even with changes in property rights, communities will in general choose to leave pastures open for common access, and this is likely to lead to lower gains in agricultural productivity and environmental conservation than those hoped for by government given community weakness in achieving cooperation. Success of the reforms thus importantly hinges on helping communities improve their cooperation performance. The magnitude of the gains that could be achieved via improved cooperation can be assessed by simulating the effect of improved cooperation using the estimated equations. To choose a meaningful level for the change in cooperation to be simulated, we can use again the contrast between Nueva Aleman where the non-cooperation index is equal to 0.42 (see Table 1) and San Juan de Michis where it is equal to 0.22. Using the best fit models (model 2b for the stocking rate and model 3 for land in maize), if the level of non-cooperation in an average community were reduced from 0.42 to 0.22, the stocking rate would decrease by 40% and the area planted in maize would decline by 22.1%. For both efficiency and sustainability purposes, promoting cooperation among community members should thus be a fundamental initiative complementary to the reform in property rights.

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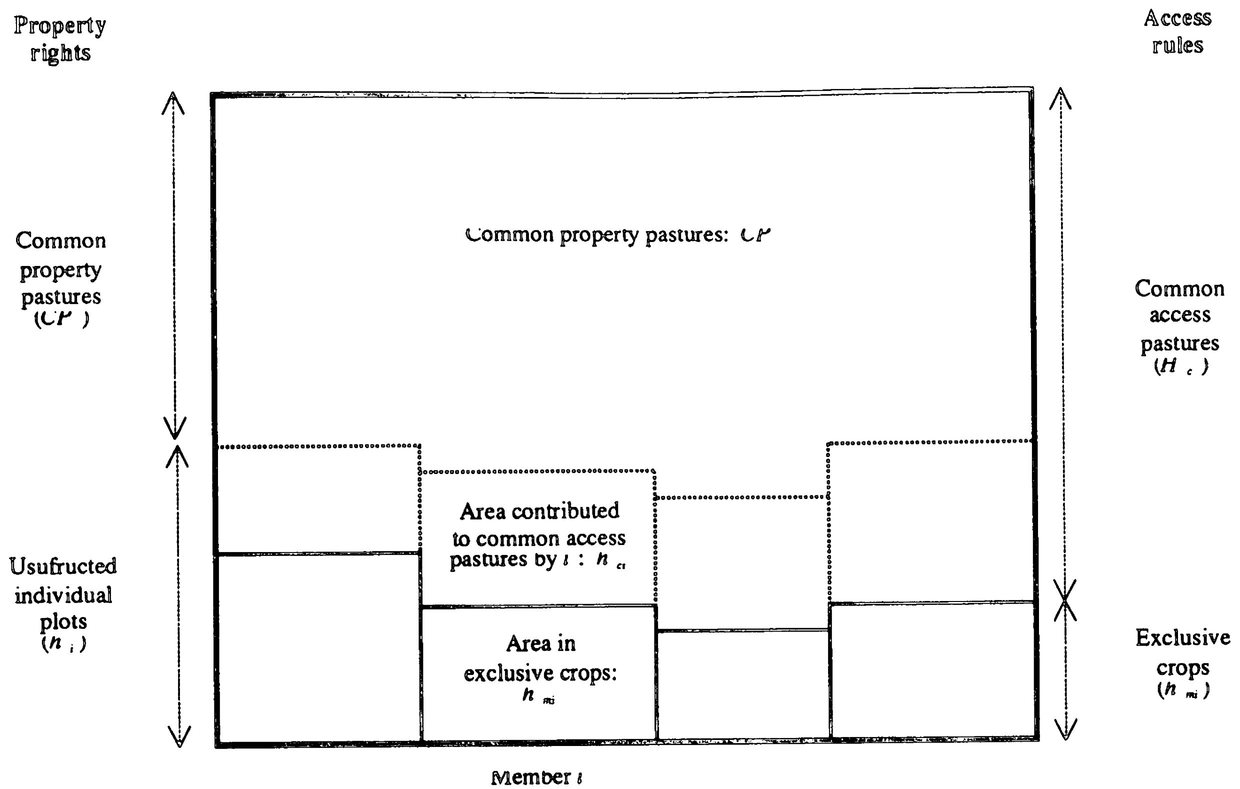
Figure 1
Land allocation in the social sector



Social sector community: Total area H , common property pastures CP

Area in usufructed individual plot by member i : $h_i = h_{mi} + h_{ci}$

Total area in common access pastures: $H_c = \sum h_{ci} + CP$

Total area: $H = \sum h_i + CP = \sum h_{mi} + H_c$

Table 1. Community characteristics

Communities	State	Property rights	Rules of access to pastures	Limits on number of animals	I_{NC} dummy[1]	I_{NC} indicator[2]	Number of members	Hectares in crops	Hectares in common access pastures	Hectares in pastures per farmer	Carrying capacity (animal units/ha)	Actual stocking (animal units/ha)	Actual stocking/ carrying capacity (%)
Quinceo	Michoacan	Usufruct	Common access	No limits	1	0.93	470	6.6	2183	4.6	0.13	1.52	1185.6
Nueva Aleman	Durango	Usufruct	Common access	No limits	1	0.42	22	6	2716	123.5	0.10	0.23	227.3
Alvaro Obregon	Chihuahua	Usufruct	Common access	No limits	1	0.68	92	19.2	20875	226.9	0.04	0.07	165.6
Coyula	Oaxaca	Usufruct	Common access	No limits	1	0.62	209	3.5	2410	11.5	0.33	0.50	150.0
Cheran Atzicurin	Michoacan	Usufruct	Common access	No limits	1	1	520	4.4	2092	4.0	0.13	0.18	144.0
Paso del Muerto	Michoacan	Usufruct	Common access	Informal limits	1	0.4	56	8.1	412	7.4	0.33	0.45	136.4
Hierbabuena	Oaxaca	Private	Exclusion	Not applicable	0	0	Not applicable	3.7	Not applicable	9.3	0.50	0.67	133.3
San Juan de Michis	Durango	Usufruct	Common access	Explicit limits	0	0.22	55	6.5	16400	298.2	0.10	0.11	107.5
Guivicia	Oaxaca	Usufruct	Exclusion	Not applicable	0	0	148	6.3	0	36.6	0.83	0.28	33.3

[1] Dummy index of non-cooperation.
[2] Principal component index of non-cooperation

Table 2. Stocking rate equations

Dependent variable: logarithm of stocking rate

All variables in logarithms except dummies and differences in efficiency variables

Explanatory variables	Model variables	Non-cooperation dummy: Model 1a Coefficient	Model 1a P-value	Model 1b Coefficient	Model 1b P-value	Non-cooperation index: Model 2a Coefficient	Model 2a P-value	Model 2b Coefficient	Model 2b P-value
Intercept		36.71	0.039	19.58	0.288	-4.27	0.019	-5.63	0.001
Pasture productivity index	P	0.94	0.000	1.04	0.000	1.50	0.000	1.44	0.002
Community-level efficiency variables	$\overline{Eff}$								
Average level of education		-0.50	0.041	-0.33	0.255	-0.21	0.418	-0.29	0.290
Incidence of truckholding		-0.36	0.431	-0.42	0.464	0.80	0.028	-0.58	0.658
Average age of household heads		-21.24	0.025	-12.78	0.193	0.25	0.571	0.61	0.152
Average age of household heads squared		2.90	0.022	1.77	0.175				
Joint test of efficiency variables (P-value)			0.030		0.326		0.043		0.369
Price of cattle	p_c								
Price of cattle		0.33	0.172	0.64	0.004	0.74	0.002	0.76	0.002
Price of cattle * Herd size dummy[1]		0.35	0.000	0.35	0.000	0.32	0.000	0.30	0.000
Community level effects of non-cooperation									
Index of non-cooperation	I_{NC}	1.42	0.000			2.88	0.000		
Community characteristics									
Pasture productivity index	$I_{NC}(M-1/M+1)P$			-0.09	0.775			-0.20	0.859
Price of cattle	$I_{NC}(M-1/M+1)p_c$			-1.46	0.004			-0.06	0.949
Community-level efficiency variables	$I_{NC}(M-1/M+1)\overline{Eff}$								
Average level of education				-0.75	0.096			0.19	0.702
Incidence of truckholding								3.72	0.043
Average age of household heads				1.89	0.000			0.38	0.732
Joint test of efficiency variables (P-value)					0.000				0.088
Individual level effects of non-cooperation[2]	$I_{NC}M\left(Eff_i - \overline{Eff}\right)$								
Diff. from comm. incidence of truckholding				0.002	0.076			0.002	0.091
Inverse Mills Ratio		0.94	0.147	1.04	0.125	0.07	0.898	0.86	0.108
Effect of I_{NC} at average value of the exogenous variables				1.18	0.000			2.56	0.000
Goodness-of-fit: adjusted R^2		0.615		0.680		0.673		0.720	
Simulations: % change in land in stocking rate due to cooperation[3]		-75.9		-69.3		-43.8		-40.0	

In models 1a and 1b, the index of non-cooperation is a dummy variable equal to one for non-cooperating communities.

In models 2a and 2b, the index of non-cooperation is the first principal component (see text).

[1] Herd size dummy is equal to one for herds larger than three heads of cattle, denoting commercial operations.

[2] Diff. is the difference between individual level and community average for the corresponding variable.

[3] Non-cooperation dummy falling from 1 to 0; non-cooperation index falling from 0.4 to 0.2.

Table 3. Land in maize equations
Dependent variable: logarithm of land in maize
All variables in logarithms except dummies and differences in efficiency variables

Explanatory variables	Model variables	Cooperation dummy Model 3a Coefficient	Cooperation dummy Model 3a P-value	Cooperation index Model 4a Coefficient	Cooperation index Model 4a P-value
Intercept		-1.220	0.175	-1.11	0.276
Prices of cattle and maize					
Price of cattle	p_c	0.19	0.497	-0.12	0.647
Price of maize	p_m	0.28	0.378	0.89	0.005
Price of maize * Herd size dummy[1]		0.35	0.008	0.23	0.095
Fixed factors in maize production	z_i				
Truck ownership		0.35	0.064	0.51	0.066
Tractor ownership		2.04	0.000	2.24	0.000
Age of household head		0.35	0.114	0.64	0.006
Number of adults in the household		0.25	0.043	0.12	0.376
Average maize yield in the community		0.35	0.006	0.29	0.034
Joint test of fixed factor variables (P-value)			0.000		0.000
Predicted stocking rate effects[2]					
Community stocking rate	N / H_c	0.03	0.838	0.08	0.608
Individual stocking rate	n_i / h_{ci}	-0.42	0.028	-0.31	0.144
Size of community	M	0.01	0.799	-0.01	0.896
Effects of cooperation					
Cooperation index[3]	I_C	-0.73	0.001	-1.25	0.009
Individual level effects of cooperation	$I_C\left(Eff_i - \overline{Eff}\right)$				
Diff. from comm. average level of education		-0.03	0.427	0.00	0.929
Diff. from comm. incidence of truckholding		0.27	0.223	-0.46	0.424
Diff. from comm. average age of household heads		0.00	0.491	-0.21	0.080
Diff. from comm. average number of adults in the household		-0.09	0.086	0.09	0.331
Joint test of efficiency difference variables (P-value)			0.411		0.464
Inverse Mills Ratio		-2.59	0.000	-3.16	0.000
Effect of I_C at average value of the exogenous variables		-0.74	0.001	-1.24	0.010
Goodness-of-fit: adjusted R^2		0.603		0.590	
Simulations: % change in land in maize due to cooperation		-22.1		-8.3	

[1] Herd size dummy is equal to one for herds larger then three heads of cattle, denoting commercial operations.
[2] Predicted from model 1b in Table 2 when using I_C dummy, and model 2b when using I_C principal component.
[3] $I_C = 1 - I_{NC}$