Does Inequality Lead to Greater Efficiency in the Use of Local Commons? The Role of Strategic Investments in Capacity

by

Rimjhim Aggarwal and Tulika A. Narayan

Working Paper No. 00-03

Date of Submission: March 2000

Department of Agricultural and Resource Economics
2200 Symons Hall • University of Maryland • College Park, MD 20742-5535 • USA • Tel. (301) 405-0057

February, 2000

Does Inequality Lead to Greater Efficiency in the Use of Local Commons? The Role of Strategic Investments in Capacity

Rimjhim Aggarwal and Tulika A. Narayan*

Abstract: This paper examines the impact of inequality in access to credit on efficiency in extraction from a common resource. A dynamic model is developed, where agents strategically choose the level of sunk capacity and the consequent extraction path. Sunk capacity is a function of cost of credit and serves as a commitment device to deter entry or force exit. Contrary to previous studies based on static settings, our results show that greater inequality does not necessarily lead to greater efficiency in extraction. In particular, we show that under moderate inequality, the resource stock is *lower* than that under perfect equality.

* Dept. of Agricultural and Resource Economics, University of Maryland, College Park, MD 20742.
Email: aggarwal@arec.umd.edu, tulika@arec.umd.edu

I. Introduction

A large part of the theoretical literature on common pool resources (CPRs) assumes agents to be homogenous (Gordon, 1954; Clark, 1976; Dasgupta and Heal, 1979; Levhari and Mirman, 1980; Sandler, 1992; Ostrom, 1994). Over the past few years, however, there has been a growing debate on the effect of heterogeneity on the use of CPRs in both cooperative and non-cooperative settings. This line of work can be traced back to Olson (1965) who hypothesized that the greater is the wealth inequality amongst members of a group, the larger is the probability of collective action. Although Olson's work has been very influential in the CPR literature, it is backed by limited empirical support. Field studies on CPR management present a very varied picture with a few supporting Olson's argument but a majority finding either an opposite or an ambiguous result.[1]

In a recent synthesis of this literature, Baland and Platteau (1995) suggest that to make sense of these diverse findings it is helpful to distinguish between the different types of heterogeneity, such as those arising from differences in endowments, objectives or cultural background of the agents. They argue that while homogeneity in objectives and cultural background are absolute prerequisites for collective action, this does not necessarily hold true for heterogeneity in private wealth of agents. In a set of papers that appeared in this journal, Baland and Platteau (BP) (1997, 1998) explore this effect of heterogeneity in private wealth of agents on efficiency in use of commons under several different cases of regulated and unregulated commons.

One of the striking results from their papers arises in a context where agents appropriate a common resource in the absence of any external regulation. It is well known that in such a setting, agents are likely to extract in excess of social optimum. Now, consider a situation where agents have differential access to an important input used in the extraction of this common resource. To fix ideas, think of this input as credit. Due to information problems, particularly in low-income countries, the

[1] Thus for instance, Johnson and Libecap (1982) in their study of the Texas shrimp fishery found that when fishermen differ in their inherent skills in fishing, cooperative agreements such as catch restrictions are unlikely to succeed. See also Bardhan (1993) and Aggarwal (2000) for examples from Asian irrigation systems. Kanbur

amount of credit available is often closely linked to ownership of assets (such as private land), which can be offered as collateral. Therefore, inequities in asset ownership often translate into inequities in access to credit. The following question thus becomes important: How, if at all, would the efficiency in use of CPRs be affected if the distribution of credit were changed, keeping the total amount of available credit constant?

To examine this question, BP consider a simple static setting, where extraction is a concave function of effort and one unit of credit is required to exert one unit of effort. Starting from a situation where all agents have equal access to credit they consider a dis-equalizing change in access to credit keeping the total amount available constant. Agents who now become credit constrained are likely to reduce their extraction levels, and as a response, the unconstrained agents are likely to increase their level of extraction. However, because of the assumption of concavity of the effort function, it follows that the increase less than compensates for the decrease. Thus total extraction is likely to fall, leading to a more efficient outcome. They thus conclude that the more unequal is the distribution of credit constraints, the more efficient is the appropriation from CPRs.[2]

This unambiguous result on the effect of inequality on efficiency has important policy implications. Given the widespread degradation of natural resources under conditions of poorly defined property rights, governments are struggling to find alternative ways to halt this process. BP claim that their central argument is applicable in a wide array of contexts in which constraints or factor market imperfections limit the access of some users to important inputs used in extraction of CPRs. Thus, for instance, if credit is an important input that is administratively distributed, then their analysis suggests that an unequal distribution of available credit amongst users of a CPR would create a

---

(1992) and Baland and Platteau (1998) provide a survey drawing upon studies from various different CPR contexts.

[2] Clark (1980) also establishes a positive relationship between inequality and efficiency in the context of common access fisheries. However, he defines inequality in terms of the skill differentials of the agents.

situation where the large holders self-limit their extraction, thus leading to situation where extraction is lower than in the case where the available credit were distributed in an equal way

The present paper is motivated by the observation that BP's result, derived within a static setting, may not hold in the more realistic dynamic settings in which most CPR extraction (including the case of fisheries examined by BP) takes place.[3] In a dynamic resource setting, the following considerations become important. First, it is well known that in a dynamic setting the inter temporal tradeoffs between conservation and depletion are important, and this opens up the possibility of a far richer set of outcomes (including the possibility of self-enforcing cooperative equilibria), which could potentially alter the conclusions reached in a static setting. Second, note that access to credit which is the basis of heterogeneity in the BP paper, becomes especially significant in situations where large investments, (either in the form of installing capacity or adoption of new technology) have to be made prior to extraction from the CPR. Since these investments influence extraction choices in the future, a a one-stage game (as used by BP) is inadequate to capture the complexity of the strategic environment that arises due to the timing of the different moves.

Prior investments in capacity influence future extraction choices in a number of dynamic CPR settings. A prime example is that of groundwater for which property rights are generally poorly defined in most countries. In the specific case of India, landowners have the right to drill wells on their own land and pump out as much water as they desire. However, the fixed costs of drilling a well and buying the pumping equipment are very high, particularly in semi-arid areas where wells need to be very deep in order to intercept water-bearing fractures in the sub-strata. The deeper is the well, the lower is the probability that it would become dry at any given time. Due to limited access to credit, a majority of small and marginal landowners in these areas have not invested in wells, while large farmers have invested in multiple wells with very high pumping capacities (Shah, 1993; Aggarwal 2000). Interestingly, given the huge subsidies on electricity supply, the marginal costs of pumping are very low and this has led to a rapid decline in the water table in this region. In the competitive pumping race that has ensued, those who have deeper wells have survived while those with shallower wells (generally the smaller landowners) have been driven out over time (Bhatia, 1992). An important policy question being posed in this context is regarding the effect that government's policies on distribution of credit can have on groundwater use, given the fact that direct regulation of groundwater is not administratively feasible in the short run.

Similarly in the context of many fisheries, the choice of capacity (as measured by vessel size and type of equipment used) is critical in determining the type and size of catch. Kurien (1992) in his case study of coastal fisheries in south India describes how with the expansion of export markets in prawns in the mid 1960s, merchants from urban areas started to heavily invest in vessels capable of deep sea fishing. Traditional fishermen with relatively poor access to credit were not able to take advantage of these opportunities and were slowly displaced as stocks depleted and their traditional technologies became redundant.

To model the strategic interplay between agents in such scenarios, where decisions regarding investment in sunk capacity are critical and have to be made prior to extraction, a two-stage formulation of the dynamic game is needed. In this paper we develop such a game in which agents first choose the level of sunk investment in capacity and then the extraction path over the infinite horizon. We assume agents to be homogenous in all respects except in terms of their access to credit. To model heterogeneity in access to credit we draw upon the widely observed fact that the extent of credit available through the formal credit market is generally rationed in most low income countries and is very closely determined by the amount of collateral (e.g. land or livestock) that can be offered. The residual demand is met through the informal market where interest rates are much higher. Thus agents face different costs of credit depending on their exogenously given asset endowments, and this difference in costs of credit constitutes the basis of heterogeneity amongst agents in the model.

[3] In this paper we only analyze the case of extraction from a CPR in a non-cooperative framework. Baland and Platteau (1997, 1998) also discuss the case of voluntary contributions towards the creation and maintenance of a

Given this dynamic setting, we derive a relationship between inequality (measured in terms of difference in cost of credit) and steady state resource stock. Contrary to the BP result, we show that greater inequality does not necessarily lead to greater efficiency in use of CPRs. In particular, we show that for moderate levels of inequality, the resource stock is lower than that under perfect equality. It is only for fairly high levels of inequality that the resource stock approaches the socially optimal level.

A recent working paper by Dayton-Johnson and Bardhan (1996) also suggests that the relation between heterogeneity in asset endowments and efficiency in resource use may be non-monotonic. However, the structure of their model is very different from ours. In particular, they have a two period setting in which the capacity level of agents is uniquely determined by their exogenously given asset endowments and the strategy set of agents is defined by the single effort level that they simultaneously choose in the first period (in the second period, it is always true that agents would apply maximum effort). As opposed to this, in our model, agents strategically choose the level of sunk investment in capacity as well as the consequent extraction path over the infinite horizon. Thus our focus lies more on the choice of sunk capacity in the first stage of the game and its role as a commitment device to deter entry or force exit of other agents from the extraction game in the second stage.

A number of papers in the industrial organization literature have explored the role of strategic investments (see for instance, Dixit, 1980; Fudenberg and Tirole, 1983; Spence, 1977). However, there have been very few applications in CPR contexts. Copeland (1990) explored the strategic effects of investments that enhance or destroy a common resource in the context of international externalities. However, the purpose of his paper was to establish the conditions that lead to under and over-investment. He did not specifically analyze the effect of heterogeneity amongst agents on the choice of these investments and on the efficiency in resource use. In our analysis, on the other hand, heterogeneity amongst agents (in terms of their cost of credit) becomes an important factor in determining both steady state stock levels and the total investment in capacity. To the best of our

---

CPR and find the results to be somewhat different from the extraction case.

knowledge, the effects of strategic investment in a dynamic CPR extraction game with heterogeneous agents have not been examined before.

The rest of the paper is organized as follows. To fix ideas we develop our model in the context of groundwater extraction, although as discussed above, the central ideas behind it have much wider applicability. In Section II, we present the benchmark case of a single well owner within an aquifer, who faces a competitive market for water. This case also defines the social optimum in our setting. Then, in Section III, we extend this analysis to the case of two homogenous agents who extract from the same groundwater aquifer. In Section IV, we introduce heterogeneity amongst these agents in terms of the cost of credit that they face. In Section V, we use the results from Section IV to map a relation between inequality on the one hand and steady state stock level and investment on the other hand. Finally, in Section VI, we conclude.

II. Sole Ownership

For completeness, we begin with the case of a single agent who has sole extraction rights to a groundwater aquifer. Consider the following two-stage model. In the first stage, the agent makes a decision regarding how deep to drill the well. Depth of the well is an important determinant of its capacity because water cannot be extracted from the well whenever the water level in the aquifer falls below the base of the well. In other words, the depth of the well defines a lower bound $\underline{X}$, such that whenever the water stock in the aquifer falls below $\underline{X}$, the well becomes dry. For tractability, we assume that there is one to one relationship between the investment, *I*, made in the depth of the well and $\underline{X}$ which is given as

[1] $$\underline{X} = \underline{X}(I)$$

where $\underline{X}'(I) < 0$ and $\underline{X}''(I) \geq 0$. The above investment is regarded as a sunk investment which has to be made once and for all, prior to extraction.[4] The marginal cost of investment is assumed to be a constant, denoted by f, which depends upon the rate of interest faced by the agent in the credit market.

In the second stage, the agent chooses an extraction path $w(t)$ that maximizes the present value of net returns from extraction. Following Gisser (1983), we assume that the cost of extracting water is an increasing function of the extent of lift,[5] shown in figure1 as AB. The extent of lift at any time *t*, in turn, depends on the water stock *X(t)* in the aquifer and thus the cost function for extraction can be written as

[2] $$C(t) = \frac{cw(t)}{X(t)}$$

where *c* is a constant and *w(t)* is the amount of water extracted at time *t*. The well owner is assumed to be a price taker in the market for water, with the price of water given by the constant *p*.

The agent's optimization problem can be solved through backward induction by first solving the second-stage problem conditional on the investment decision in the first-stage. The second-stage optimization problem is given as

[3] $$\underset{w(t)}{Max} \int_0^\infty \left(pw(t) - \frac{cw(t)}{X(t)} \right) e^{-d\,t} dt$$

s.t. [A] $\dot{X} = r - w(t)$

[B] $0 \leq w(t) \leq \overline{w}$

[C] $w(t) = 0$ for $X(t) < \underline{X}(I)$

where d is the discount rate and r is the natural recharge rate of water. Equation [A] governs the stock transition over time. Constraint [B] implies that at each instantaneous point in time there is an

[4] The horsepower of the pumping equipment may also be an important determinant of capacity. In most semi-arid regions, submersible pumps are used. Investments in such pumps, for all practical purposes, may also be regarded as sunk investments.

upper bound, $\overline{w}$, on the amount of water that can be extracted. To allow for the possibility of complete exhaustion, we assume that $\overline{w} > r$. Constraint [C] ensures that there cannot be any extraction whenever the stock of water falls below $\underline{X}(I)$.

Since the maximand in the above problem is linear in the control variable, *w(t)*, the equilibrium is a bang-bang solution. The optimal extraction path is given by the following most rapid approach path (MRAP)

[4]
$$w^S(t) = \begin{cases} \overline{w} & \text{if } X(t) > Max\{X^S, \underline{X}(I)\} \\ r & \text{if } X(t) = Max\{X^S, \underline{X}(I)\} \\ 0 & \text{if } X(t) < Max\{X^S, \underline{X}(I)\} \end{cases}$$

where X^S is the steady state stock level given as

[5]
$$X^S = \frac{d\ c + \sqrt{d^2 c^2 + 4d\ cpr}}{2d\ p}$$

Given this solution to the second-stage problem, in the first-stage the sole owner chooses the level of sunk investment in the depth of the well such that the marginal costs of investment equal the discounted marginal benefits from extraction. Let us assume that the initial stock level is greater than X^S. Let I^S be the level of investment that corresponds to X^S in [1]. From (4) it is clear that along the optimal path, the agent does not extract any water whenever the stock level falls below X^S. Thus the marginal benefits from investing beyond I^S are zero. However, for any level of investment $I < I^S$, the total benefit from investing is given by

[6]
$$B(I) = \int_0^{s(\underline{X}(I))} \left(p\overline{w} - \frac{c\overline{w}}{X(t)} \right) e^{-\ddot{a}t}\, dt + \int_{s(\underline{X}(I))}^{\infty} \left(pr - \frac{cr}{\underline{X}(I)} \right) e^{-\ddot{a}t}\, dt$$

where $s(\underline{X}(I))$ denotes the time at which the stock attains the lower bound $\underline{X}$. To ease notation, let $S(I) = s(\underline{X}(I))$. Differentiating [7] with respect to *I*, gives the marginal benefit from investing at any level $I < I^S$ as

[5] The difference between the water level in the well and the level to which it has to be lifted

$$[7] \qquad B'(I) \;=\; S'(I)\left[(\overline{w}-r)\left(p-\frac{c}{\underline{X}(I)}\right) e^{-d\,S(I)}\right]+\frac{cr}{\ddot{a}\,\underline{X}^{2}(I)}\cdot \underline{X}'(I)\,e^{-d\,S(I)}$$

In the appendix, we show that *B'(I)* is strictly positive and downward sloping for $I < I^S$.

Figure 2 shows the marginal benefit and cost curves of investment. The agent chooses the level of investment that equates the marginal cost of investment (f) with the marginal benefit of investment. If $f \le f^S$, then the agent invests I^S and drives the stock to the steady state level, X^S. On the other hand, if $f > f^S$, then the optimal choice of investment is less than I^S and given by the intersection of the marginal benefit and cost curves in figure 2. In this case, the steady state stock level is less than X^S. Given that the well owner is a price taker in the market for water, this solution also defines the social optimum in this setting.

III. Homogenous Agents

In this section we consider the case of two agents (*i* =1, 2) who extract from a common groundwater aquifer and are homogenous in all respects. As opposed to the case of sole-ownership, in a two-person case, the two-stage model is much more complex because of strategic behavior. For ease in exposition, we have divided this section in two parts. In the first part, we present the Nash equilibrium solution for the case usually modeled in the groundwater literature where only the extraction decision (and not the capacity choice decision) is taken into account (see for instance, Provencher and Burt, 1993; Gisser, 1983). Such a setting is useful in situations where either capacity can be quickly adjusted to any changes in extraction needs and/or costs of setting up capacity are negligible and so capacity does not represent a rigid constraint. In second part of this section we relax this assumption and present the two-stage model with capacity and extraction choice.

III.1 Extraction choice with no capacity constraints

The optimization problem for agent 1 here is given as (the case of agent 2 is symmetric)

[8] $$\underset{w_1(t)}{Max}\int_0^{\infty}(pw_1(t)-\frac{cw_1(t)}{X(t)})\,e^{-dt}\,dt$$

s.t [A] $\dot{X} = r - w_1(t) - w_2(t)$

[B] $0 \le w_1(t) \le \overline{w}$

Solving the two best response functions for a Nash symmetric solution we get a result analogous to the sole-ownership case. The groundwater stock is driven to X^N by the most rapid approach path (MRAP) given as

[9] $$w^N = \begin{cases} \overline{w} & \text{if } X(t) > X^N \\ r/2 & \text{if } X(t) = X^N \\ 0 & \text{if } X(t) < X^N \end{cases}$$

where

[10] $$X^N = \frac{d\ c + \sqrt{d^2 c^2 + 2d\ pcr}}{2d\ p}$$

On comparing equations [5] and [10] it is clear that $X^N < X^S$. This is the standard result of over-exploitation when agents do not fully internalize the externalities generated in the use of the commons. The gross payoffs from extraction in this case are given as

[11] $$p^N = \int_{\mathbf{0}}^{s(X^N)}\left(p\overline{w}-\frac{c\overline{w}}{X(t)}\right)e^{-d\,t} + \int_{s(X^N)}^{\infty}\left(\frac{pr}{\mathbf{2}}-\frac{cr}{\mathbf{2}X^N}\right)e^{-d\,t}$$

where $s(X^N)$ is the time at which the stock reaches the steady state level given as X^N in (10).

III.2 Two stage game with capacity and extraction choice

Now let us consider the case where agents have to choose the level of investment in capacity prior to extraction. As we show below, agents may now choose investment levels strategically in order to force exit or deter entry of the other agent.[6] In order to keep the analysis fairly general here, we assume that agents choose investment levels sequentially, with the choice of moves being endogenous to the game. In a game with symmetric agents this implies that agents move simultaneously.[7] It would be helpful to categorize the set J of options available to each agent as: $J = \{D, A, E\}$ where D stands for drive out, A for accommodate and E for exit. For agent 1 to be able drive out agent 2, two conditions must be satisfied. First, in stage 1 of the game, agent 1 must invest more than he expects agent 2 to invest, i.e. $I_1 > I_2$. Second, in stage 2, agent 1 must drive down the stock to a level beyond $\underline{X}(I_2)$ in finite time. By definition, adoption of the drive out option by any agent implies forced exit for the other agent and together these imply that there exists a time period t_d, such that for all $t > t_d$, there is only one agent in the game. As opposed to this, the strategy to accommodate implies that there are two agents in the game for all t. For accommodation to work, both players must invest at the same level. Finally, note that each agent always has the option of exiting out of the game in finite time, irrespective of what the other agent does.

Given this setting, we solve for the Cournot-Nash equilibrium defined as

DEFINITION 1*: A strategy set (I_1, I_2, w_1, w_2) is a Cournot-Nash (CN) equilibrium if the net discounted payoff to agent i ($i = 1,2$), from choosing (I_i, w_i) is maximized given the equilibrium strategy of the other agent.*

To solve for the *CN* equilibrium recall that X^N was found to be the Nash steady stock level in the absence of capacity constraints. Let I^N denote the level of investment in capacity that corresponds to X^N from [1]. Note that (I^N, I^N) cannot be the equilibrium investment strategy in the presence of capacity constraints. This is because each agent by investing a small amount, e , above I^N can drive out the other agent and get larger profits. To examine when such a drive-out strategy would be

[6] A number of papers in the industrial organization literature have examined the choice of capacity as an entry deterrent strategy (Tirole, 1988 provides a survey). The results in these papers have been found to be quite sensitive to the assumptions made regarding the timing of the moves, i.e. whether there is simultaneity in choice of capacities or an exogenously given sequentiality with one player (incumbent) having a first mover advantage, possibly due to technological lead.

chosen, we lay out the extraction paths and the associated gross payoffs when agent 1 pursues the drive out option under the expectation that agent 2 would invest I_2.

Note that if agent 1 expects I_2 to be less than I^S (the optimal steady state investment level under sole-ownership) then he would choose to invest I^S and drive down the stock to X^S. This case is similar to the sole ownership case. The more interesting case arises when agent 1 expects I_2 to be greater than I^S. This is the case we consider in the rest of this section.

Under the drive out strategy, agent 1's extraction path in the second stage is given as

$$[12] \qquad w_1^D = \begin{cases} \overline{w} & \text{if} \quad X(t) > \underline{X}(I_2 + e) \\ r & \text{if} \quad X(t) = \underline{X}(I_2 + e) \\ 0 & \text{if} \quad X(t) < \underline{X}(I_2 + e) \end{cases}$$

The gross payoff to agent 1 from extracting along this path can be written as

$$[13] \qquad p_1^D = \int_0^{S(I_2+e)} (p\overline{w} - \frac{c\overline{w}}{X(t)})e^{-dt}dt + \int_{S(I_2+e)}^{\infty} (pr - \frac{cr}{\underline{X}(I_2+e)})e^{-d\,t}dt$$

As one would expect, this drive out payoff received by agent 1 is a decreasing function of I_2 (proof in the appendix).

By definition, under the above drive out strategy, agent 2 is forced to exit and his extraction path is given as

$$[14] \qquad w_2^E = \begin{cases} \overline{w} & \text{if } X(t) \geq \underline{X}(I_2) \\ 0 & \text{if } X(t) < \underline{X}(I_2) \end{cases}$$

The gross payoff to agent 2 from extracting along this path can be written as

$$[15] \qquad p_2^E(I_2) = \int_0^{S(I_2)} \left(p\overline{w} - \frac{c\overline{w}}{X(t)} \right) e^{-d\,t}dt$$

[7] This is because when agents are symmetric they would have the same preferences over the choice of moves.

Note that the above payoff is a function of I_2. Under complete information, agent 2 knows that he would be driven out in the second stage. Therefore, given f, he chooses investment optimally in the first stage. For $f > 0$, the optimal *net* exit payoff is given as

[16] $$\Pi^E(f) = \int_0^{S(I^E)} \left(p\overline{w} - \frac{c\overline{w}}{X(t)} \right) e^{-d\,t} dt - f\, I^E \quad \text{where}$$

$$I^E = \arg\max \left\{ \int_0^{S(I)} \left(p\overline{w} - \frac{c\overline{w}}{X(t)} \right) e^{-d\,t}\, dt - f\, I \right\}$$

The above net exit payoff has a special significance in this setting. Each agent can always guarantee for himself this minimum payoff by exiting out of the extraction game in finite time, irrespective of the actions of the other agent. Thus $\Pi^E(f)$ represents the reservation payoff in this setting.

***Definition 2**: A strategy (I_i, w_i) for agent i (i=1, 2) is individually rational if the net payoff to agent i from this strategy is at least as large as his net exit payoff.*

As opposed to driving out agent 2, agent 1 can also accommodate him. If both agents invest I^N and accommodate each other then the gross payoffs are given by p^N in [11]. As argued earlier, this is an unstable equilibrium since $p^N < p_1^D(I_2 = I^N)$ and so agent 1 prefers to drive out agent 2 if the latter is expected to invest I^N. However, note that since $p_1^D(I_2)$ is a decreasing function of I_2 there exists an $I^{NC} > I^N$, such that for $I_2 = I^{NC}$

[17] $$p_1^D(I_2 = I^{NC}) = p^N$$

***Proposition 1**: In the homogenous case with capacity constraints, if it is individually rational for both players to accommodate each other and invest I^{NC} then*

a) (I^{NC}, I^{NC}) are the Cournot-Nash equilibrium investment levels.

b) X^N is the steady state stock level.

Proof: To check if (I^{NC}, I^{NC}) are the equilibrium investment levels consider what happens if there is a one step unilateral deviation by agent 1 to I^{NC} +ε (where ε > 0), in order to drive out agent 2. Given the shape of $p^{D}(I)$, it follows that $p^{D}(I^{NC}+e) < p^{D}(I^{NC}) = p^{N}$. Hence this deviation is not profitable. Now consider a unilateral deviation by agent 1 to I^{NC} *-e*. Since I^{NC} *-e.* < I^{NC}, agent 1 cannot drive out agent 2. Agent 2, however, would now find it optimal to drive out agent 1. Since the net exit payoff is lower than the payoffs from accommodation at I^{NC}, this deviation is also not profitable for agent 1.

When both agents accommodate each other, the steady state stock level is given by X^N in (17). Recall that X^N was shown to be the steady state stock level in the case without capacity constraints also. However, the difference in the case with capacity constraints is that strategic behavior leads both agents to invest more, since $I^{NC} > I^N$.

***Corollary1**: In the homogenous case with capacity constraints, both agents invest in excess capacity.*

IV Heterogeneous Agents

In this section we assume that agents are homogenous in all respects except in terms of the cost of credit they face. Let the cost of credit be denoted by f_1 and f_2, respectively, for the two agents. To begin with, let us examine how the net payoffs (under the different strategies defined in the previous section), vary with f_i (*i* = 1, 2). Under the strategy of accommodating by investing I^{NC}, the net payoffs are given as

[18] $$\Pi_i^A(f_i) = p_i^N - I^{NC} f_i$$

Note that $\frac{\partial \Pi_i^A(f_i)}{\partial f_i} = -I^{NC}$. On the other hand, the net exit payoffs are given as $\Pi_i^E(f_i)$ in [16], and it follows from the envelope theorem that $\frac{\partial \Pi_i^E(f_i)}{\partial f_i} = -I_i^E$.

Note that I^{NC} is not a function of f_i (see [17]), but I_i^E is a decreasing function of f (from [16]). This implies that starting from low levels of f_I (where $\Pi_i^A(f_i) > \Pi_i^E(f_i)$) as f_i increases $\Pi_i^A(f_i)$ falls at a constant rate while $\Pi_i^E(f_i)$ falls at a decreasing rate (see figure 3). This leads to the following lemma

***Lemma 1**: There exists a $f^0 > 0$, such that when $f_i > f^0$, the net exit payoffs for agent i exceed his net payoffs from accommodation.*

Now let us examine how the steady state stock and investment levels vary, as inequality amongst agents increases. We define inequality as the difference between f_1 and f_2, and model increases in inequality by a mean preserving spread given by decreasing f^1 and increasing f^2 such that $(f^1 + f^2)/2 = f$. Further we assume that $f < f^0$, so that when agents are homogenous, the net payoffs from accommodation are higher than the net exit payoffs. Lemma 1 then implies that for high enough levels of inequality, such that $f_2 > f^0$, agent 2 may find it optimal to exit out of the game. In the following two propositions we examine how changes in inequality affect investment and steady state stock levels.

***Proposition 2**: Starting from the level of equality, for small mean preserving deviations in marginal costs, such that $f_1 < f_2 < f^0$, the two agents continue to accommodate each other. The Cournot-Nash equilibrium investment levels are (I^{NC}, I^{NC}) and the steady state stock level is X^N.*

Proof: Since accommodation is individually rational for both players, the proof follows directly from proposition 1.

Proposition 3: *For large mean preserving deviations in marginal costs, such that $f_1 < f^0$* but $f_2 >$ f^0

a) *The Cournot-Nash equilibrium investment levels are given as* $[\max(I^S, I_2^E + e), I_2^E]$.

b) The steady state stock level is given by $\min[X^S, \underline{X}(I_2^E + e\}]$.

Proof: In this case where agents are very heterogeneous, the sequentiality of moves becomes important in the following way. First, consider what happens if agent 2 moves first. Since the option of accommodation by investing at I^{NC} is no longer individually rational for agent 2, he can either drive out agent 1 or exit out of the game himself. Since agent 1 faces a lower marginal cost of investment and invests after observing agent 2, drive out by agent 2 is not a feasible option here. Agent 2's only option is to exit and thus he chooses to invest I_2^E to maximize his net exit payoff. Given this, agent 1 chooses to invest [max (I^S, I_2^E +ε)]. Next consider what happens if agent 1 has to move first. If agent 1 invests I_2^E +ε, then agent 2 having observed agent 1's investment, will invest a little more than him and drive him out. To avoid being driven out, agent 1 will have to invest at a level where agent 2's net payoff from driving out agent 1 equals his net payoff from exit. Denote this level of investment by $\bar{I}_2$. Thus agent 1 will invest $\bar{I}_2$ +ε whereas agent 2 will invest I_2^E. Note that $\bar{I}_2 > I_2^E$ and so the payoffs for agent 1 when he moves first are (weakly) lower than his payoffs from the game where agent 2 moves first. However, agent 2's payoffs are the same under both specifications of the game. Thus, agent 1 weakly prefers to move second while agent 2 is indifferent. Therefore, it follows that if the sequentiality of moves is endogenous then agent 2 will move first. The equilibrium investment levels will be given as $[\max(I^S, I_2^E + e), I_2^E]$ and the steady state stock level will be given by $\min[X^S, \underline{X}(I_2^E + e)]$.

V. Inequality, Investment and Steady State Stock Levels

In this section we use the results from the previous section to map a relationship between inequality on the one hand, and investment and steady state stock levels on the other hand. In figures 4a and 4b, the marginal cost of investment of agent 2, denoted as f_2, is shown along the horizontal axis. The origin represents the point of *perfect equality* at which $f_2 = f$. As one moves to the right along this axis, f_2 increases while f_1 decreases, preserving the mean at f. Thus a movement to the right along this axis represents increasing levels of inequality. The aggregate investment levels and the steady state stock levels are shown along the vertical axis in figures 4a and 4b, respectively.

In a small neighborhood around the origin where $f_2 \leq f^0$, it is individually rational for each player to invest I^{NC} and accommodate the other player (proposition 2). So the aggregate investment levels and the steady state stock levels are the same as in the case of perfect equality. We label this as the range of *low inequality* in figure 4. As f_2 increases further such that $f_2 > f^0$, it is no longer individually rational for player 2 to invest I^{NC} and stay in the game indefinitely (lemma 1). It follows from proposition 3 that in a small neighborhood to the right of $f_2 = f^0$, agent 2 invests I_2^E and is driven out by agent 1 who invests $I_2^E + e$ and drives down the stock to $\underline{X}(I_2^E + e)$. Thus the steady state stock level as well as the investment levels are lower in this neighborhood than under perfect equality.

As inequality increases further, aggregate investment falls monotonically since I_2^E is a decreasing function of f_2. The relationship between steady state stock level and inequality is somewhat more complex. Note that the steady state stock level falls sharply at $f_2 = f^0$ and thereafter increases as inequality increases. For the case where $f_2 > f^0$, we can distinguish between the following ranges for increasing values of f_2 (see figure 4).

1) *Moderate inequality*: where aggregate investment level is ($2I_2^E + e$) < $2I^{NC}$ and the steady state stock level is $\underline{X}(I_2^E + e)$, with $\underline{X}(I_2^E + e) < X^N < X^S$.

2) *High Inequality*: where aggregate investment level is ($2I_2^E + e$) < $2I^{NC}$ and the steady state stock level is $\underline{X}(I_2^E + e)$, with $X^N < \underline{X}(I_2^E + e) < X^S$.

3) *Very High Inequality*: where aggregate investment level is ($I_2^E + I^S$) < $2I^{NC}$ and the steady state stock level is X^S.

Contrary to the conclusion reached by Baland and Platteau (1997), we find that the relationship between inequality and steady state stock level is non-monotonic. In particular, starting from perfect equality, as inequality increases, there is a range (which we refer to as the range of moderate inequality) where steady state stock level is *lower* than the level under perfect equality. On the other hand, in the low and high ranges of inequality, the steady stock level is at least as large as that under perfect equality. In the very high inequality range, steady state stock level is at the first best level.

V. Summary and Conclusions

Previous work on common pool resources has generally assumed agents to be homogenous. In this paper we have focused on one aspect of heterogeneity, namely that arising from differential access to an important input (credit) used in extraction from the CPR. Access to credit becomes particularly important in CPR contexts where considerable sunk investment is needed prior to extraction, and where this investment influences the nature and extent of extraction. Common examples are: groundwater pumping and deep-sea fishing. In modeling such cases, the following considerations become important. First, the choice of *both* investment levels and the extraction path are critical. Second, since agents impose externalities on each other in extraction, and prior investment levels influence the extent of these externalities, agents are likely to strategically choose investment levels. Third, the timing of moves is important and so a one-stage game is inadequate to capture the complexity of the strategic situation here.

Keeping these considerations in mind, we developed a two-stage model where agents choose the level of sunk investment in capacity and subsequently, the extraction path over the infinite horizon. Sunk investments served as a commitment device in this model to deter entry or force exit. Since the cost of credit influences these investment choices, heterogeneity amongst agents in terms of their access to credit affects both capacity and extraction choices. Using this model we find that contrary to results derived in previous studies based on a static setting, the relation between inequality and efficiency in resource extraction is non-monotonic. The steady state resource stock is closest to the socially optimal level when either inequality is very high or very low. For moderate levels of inequality, we show that the resource stock may in fact be lower than that under perfect equality. Further, we show that because of the strategic role of investments in this setting, agents invest in excess capacity in general, except when inequality is high.

In many CPR contexts, such as that of groundwater in semi-arid India, direct regulation of extraction rates is generally regarded as infeasible in the short run. An important indirect policy tool here is the administrative distribution of important inputs, such as credit used in groundwater extraction. Baland and Platteau have argued that in such cases unequal distribution of credit would lead to higher efficiency in use of commons. However, policies favoring a highly unequal distribution of credit may not be politically feasible. The contribution of our paper lies in showing that moderate levels of inequality in distribution may, in fact, lower resource stocks even below that under equal distribution.

Our basic model can be extended in several directions. An important extension would be to examine whether our result change qualitatively when there are more than two agents. Previous papers that have modeled only extraction choice and not capacity choice (such as Baland and Platteau, 1997; Dayton-Johnson and Bardhan, 1996) found the results to be qualitatively similar in a multiple agent setting. In the CPR literature there has also been a lot of interest in examining what happens when the product from extraction of the commons is sold in an imperfectly competitive market (Cornes *et al*,. 1986). In our model, since we assumed agents to be price takers, it followed that extraction is at its optimal level when there is a single agent extracting from the aquifer. However, when this agent also holds market power then there is likely to be over-conservation of the resource and optimality would require more than one agent. The strategic effects of investment are likely to be much more complex in such a setting.

Appendix

1) Proof: Under sole ownership, total benefits from investment are a strictly positive and concave function of investment for $I<I^S$.

For $I<I^S$, the total benefits are given by

$$TB(I) = \int_{\mathbf{0}}^{s(\underline{X}(I))} \left(p\overline{w} - \frac{c\overline{w}}{X(t)} \right) e^{-\ddot{a}t}\, dt + \int_{s(\underline{X}(I))}^{\infty} \left(pr - \frac{cr}{\underline{X}(I)} \right) e^{-\ddot{a}t}\, dt$$

$$\frac{\partial TB(I)}{\partial I} = MB(I) = \left(p\overline{w} - \frac{c\overline{w}}{\underline{X}(I)} \right) e^{-\ddot{a}s(\underline{X}(I))} \cdot \frac{\partial s(\underline{X}(I))}{\partial \underline{X}(I)} \cdot \frac{\partial \underline{X}(I)}{\partial I}$$

$$-\left(pr - \frac{cr}{\underline{X}(I)} \right) e^{-\ddot{a}s(\underline{X}(I))} \cdot \frac{\partial s(\underline{X}(I))}{\partial \underline{X}(I)} \cdot \frac{\partial \underline{X}(I)}{\partial I} + \frac{cr}{\ddot{a}\,\underline{X}^2(I)} \cdot \frac{\partial \underline{X}(I)}{\partial I}\, e^{-\ddot{a}s(\underline{X}(I))}$$

$$= (\overline{w} - r)\left(p - \frac{c}{\underline{X}(I)} \right) e^{-\ddot{a}s(\underline{X}(I))} \cdot \frac{\partial s(\underline{X}(I))}{\partial \underline{X}(I)} \cdot \frac{\partial \underline{X}(I)}{\partial I} + \frac{cr}{\ddot{a}\,\underline{X}^2(I)} \cdot \frac{\partial \underline{X}(I)}{\partial I}\, e^{-\ddot{a}s(\underline{X}(I))}$$

$$= \frac{\partial \underline{X}(I)}{\partial I} e^{-\ddot{a}s(\underline{X}(I))} \left[(\overline{w} - r)\left(p - \frac{c}{\underline{X}(I)} \right) \frac{\partial s(\underline{X}(I))}{\partial \underline{X}(I)} + \frac{cr}{\ddot{a}\,\underline{X}^2(I)} \right]$$

For $I<I^S$, $w(t) = \overline{w}$ for all t, therefore

$$\frac{\partial X(t)}{\partial t} = r - \overline{w} \qquad \Rightarrow \frac{\partial s(\underline{X}(I))}{\partial \underline{X}(I)} = -\frac{\mathbf{1}}{\overline{w} - r}$$

Thus, $$MB(I) = \frac{\partial \underline{X}(I)}{\partial I} e^{-ds(\underline{X}(I))} \left[\frac{cr}{d\,\underline{X}^2(I)} - \left(p - \frac{c}{\underline{X}(I)} \right) \right]$$

To check the sign of $MB(I)$ note that $\frac{\partial \underline{X}(I)}{\partial I} < \mathbf{0}$ (from [1]), therefore $MB(I) >0$ if

$$p - \frac{c}{\underline{X}(I)} > \frac{cr}{d\,\underline{X}^2(I)}$$

$$\Rightarrow \underline{X}(I) > \frac{d\,c + \sqrt{d^2c^2 + \mathbf{4}dpcr}}{\mathbf{2}pd} = X^S$$

For $I<I^S$, we know that $\underline{X}(I) > X^S$ and so the above condition is satisfied.

Now consider the sign of $\dfrac{\partial MB(I)}{\partial I}$

$$\frac{\partial MB(I)}{\partial I} = \left[\frac{\partial^2 \underline{X}(I)}{\partial I^2} e^{-ds(\underline{X}(I))} - d\,\frac{\partial \underline{X}(I)}{\partial I}\cdot e^{-ds(\underline{X}(I))}\,\frac{\partial s(\underline{X}(I))}{\partial \underline{X}(I)}\cdot\frac{\partial \underline{X}(I)}{\partial I}\right]\cdot\left[\frac{cr}{d\,\underline{X}^2(I)} - \left(p - \frac{c}{\underline{X}(I)}\right)\right]$$

$$+\frac{\partial \underline{X}(I)}{\partial I} e^{-ds(\underline{X}(I))}\left[-\frac{2cr}{d\,\underline{X}^3(I)}\frac{\partial \underline{X}(I)}{\partial I} - \frac{c}{\underline{X}^2(I)}\cdot\frac{\partial \underline{X}(I)}{\partial I}\right]$$

$$\Rightarrow\left[\frac{\partial^2 \underline{X}(I)}{\partial I^2} e^{-ds(\underline{X}(I))} - d\left(\frac{\partial \underline{X}(I)}{\partial I}\right)^2 e^{-ds(\underline{X}(I))}\cdot\frac{\partial s(\underline{X}(I))}{\partial \underline{X}}\right]\left[\frac{cr}{d\,\underline{X}^2(I)} - (p - \frac{c}{\underline{X}(I)})\right]$$

$$-\left[\frac{\partial \underline{X}(I)}{\partial I}\right]^2 e^{-ds(\underline{X}(I))}\left[\frac{2cr}{d\,\underline{X}^3(I)} + \frac{c}{\underline{X}^2(I)}\right]$$

Given the assumptions regarding $\underline{X}(I)$ in (1) it follows that $\dfrac{\partial MB(I)}{\partial I} < 0$ for $I<I_S$. QED.

2) Proof: p_1^D is a decreasing function of I_2 for $I_2>I^S$.

$$p_1^D = \int_0^{s(\underline{X}(I_2+e))}\left(p\overline{w} - \frac{c\overline{w}}{X(t)}\right)e^{-ät}\,dt + \int_{s(\underline{X}(I_2+e))}^{\infty}\left(pr - \frac{cr}{\underline{X}(I_2+e)}\right)e^{-ät}\,dt$$

$$\frac{\partial p_1^D}{\partial I_2} = \frac{\partial \underline{X}(I_2+e)}{\partial I_2} e^{-äs(\underline{X}(I_2+e))}\left[(\overline{w}-r)\left(p - \frac{c}{\underline{X}(I_2+e)}\right)\frac{\partial s(\underline{X}(I_2+e))}{\partial \underline{X}(I_2+e)} + \frac{cr}{ä\,\underline{X}^2(I_2+e)}\right]$$

In the two-person case,

$$\frac{\partial X(t)}{\partial t} = r - 2\overline{w}$$

$$\Rightarrow \frac{\partial s(\underline{X}(I))}{\partial \underline{X}(I)} = -\frac{1}{2\overline{w} - r}$$

Therefore,

$$\frac{\partial p_1^D}{\partial I_2} = \frac{\partial \underline{X}(I_2+e)}{\partial I_2} e^{-ds(\underline{X}(I_2+e))}\left[\frac{cr}{d\,\underline{X}^2(I_2+e)} - \left(\frac{\overline{w}-r}{2\overline{w}-r}\right)\left(p - \frac{c}{\underline{X}(I_2+e)}\right)\right]$$

Note that $\frac{\partial \underline{X}(I_2)}{\partial I_2} < 0$ from [1], therefore $\frac{\partial p_1^D}{\partial I_2}$ <0 if the following condition holds

$$\frac{cr}{d\,\underline{X}^2(I_2+e)} > \left(\frac{\overline{w}-r}{2\overline{w}-r}\right)\left(p-\frac{c}{\underline{X}(I_2+e)}\right)$$

Note that $\frac{\overline{w}-r}{\mathbf{2}\overline{w}-r}$ < 1, therefore the above condition would hold if

$$\frac{cr}{d\,\underline{X}^2(I_2+e)} > \left(p-\frac{c}{\underline{X}(I_2+e)}\right) \Rightarrow \underline{X}(I_2+e) < X^S \Rightarrow I_2+e > I^S$$

Note that for the case being considered, $I_2 > I^S$ and so the above condition is satisfied. QED

References

1. Aggarwal R. M., Possibilities and Limitations to Cooperation in Small Groups: The Case of Group Owned Wells in Southern India, *World Development*. Forthcoming, (2000).

3. Baland, J. M. and J. P. Platteau, Does Heterogeneity Hinder Collective Action? Working Paper, Department of Economics, University of Namur, (1995).

2. Baland, J. M. and J. P. Platteau, Wealth Inequality and Efficiency in the Commons Part I: The Unregulated Case, *Oxford Economic Papers*. **49**, 451-482(1997).

4. Baland, J.M. and J.P. Platteau, Wealth Inequality and Efficiency in the Commons Part II: The Regulated Case, *Oxford Economic Papers*. **50**, 1-22(1998).

5. Bardhan, P., Rational Fools and Cooperation in a Poor Hydraulic Economy, Working Paper No. C93-015, Center for International and Development Economics Research, University of California, Berkeley, CA (1993).

6. Bhatia, B., Lush Fields and Parched Throats- A Political Economy of Groundwater in Gujarat, *Economic and Political Weekly*. **19**, A-142- 170 (1992).

7. Clark, C. W., “Mathematical Bioeconomics,” Wiley, New York, (1976).

8. ——— Restricted Access to Common Property Fishery Resources: A Game-Theoretic Analysis, *in* “Dynamic Optimization and Mathematical Economics” (P. T. Liu, Ed.) Plenum, New York (1980).

9. Copeland, B. R., Strategic Enhancement and Destruction of Fisheries and the Environment in the Presence of International Externalities, *Journal of Environmental Economics and Management*. **19**, 212-226 (1990).

10. Cornes, R., C.F. Mason and T. Sandler, The Commons and the Optimal Number of Firms, *Quarterly Journal of Economics*. **101**, 641-646 (1986).

11. Dasgupta, P. and G. Heal, “Economic Theory of Exhaustible Resources,” Cambridge University Press, Cambridge, U.K. (1979).

12. Dayton-Johnson, J. and P. Bardhan, "Inequality and Conservation on the Local Commons: A Theoretical Exercise,” Working Paper No. C96-071, Center for International and Development Economics Research, University of California, Berkeley, CA (1996).

13. Dixit A., The Role of Investment in Entry Deterrence, *Economic Journal*. **90**, 95-106 (1980).

14. Fudenberg, D. and J. Tirole, Capital as a Commitment: Strategic Investment to Deter Mobility, *Journal of Economic Theory*. **31**, 227-256 (1983).

15. Gisser, M., Groundwater: Focusing on the Real Issue, *Journal of Political Economy*, **91,** 1001-1027 (1983).

16. Gordon, H. S., Economic Theory of a Common Property Resource: The Fishery, *Journal of Political Economy*, **62**, 124-42 (1954).

17. Johnson, R. N. and G. D. Libecap, Contracting Problems and Regulation: The Case of Fishery, *American Economic Review*, **72**, 1005-1022 (1982).

18. Kanbur, R., Heterogeniety, Distribution and Cooperation in Common Property Resource Management, Working Paper No. 844, World Bank, Washington, DC (1992).

19. Kurien, J., Ruining the Commons and Responses of the Commoners: Coastal Overfishing and Fishworkers' Actions in Kerala State, India, *in* "Grassroots Environmental Action: People's Participation in Sustainable Development" (D. Ghai and J.M. Vivian, eds.) Routeldge, London and New York (1992).

20. Levhari, D. and L.J. Mirman, The Great Fish War: an example using a Dynamic Cournot-Nash Solution, *Bell Journal of Economics.* **11**, 322-244 (1980).

21. Provencher, B. and O. Burt, The Externalities Associated with Common Property Exploitation of Groundwater, *Journal of Environmental Economics and Management.* **24**, 139-158 (1993).

22. Olson M., "The Logic of Collective Action," Harvard University Press, Cambridge, MA (1965).

23. Ostrom, E., R. Gardner and J. Walker, " Rules Games and Common Pool Resources," University of Michigan Press, Ann Arbor, MI (1994).

24. Sandler, T., " Collective Action: Theory and Applications," University of Michigan Press, Ann Arbor, MI (1992).

25. Shah, T., "Groundwater Markets and Irrigation Development," Oxford University Press, Bombay (1993).

26. Spence, M., Entry, Capacity, Investment and Oligopolistic Pricing, *Bell Journal of Economics*. **8**, 534-544 (1977).

27. Tirole, J., "The Theory of Industrial Organization," MIT Press, Cambridge, MA (1988).

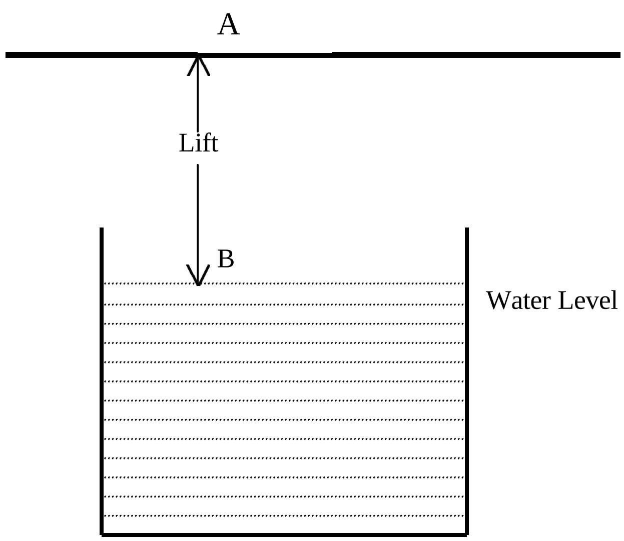

Figure 1: Schematic diagram of groundwater aquifer depicting the lift AB

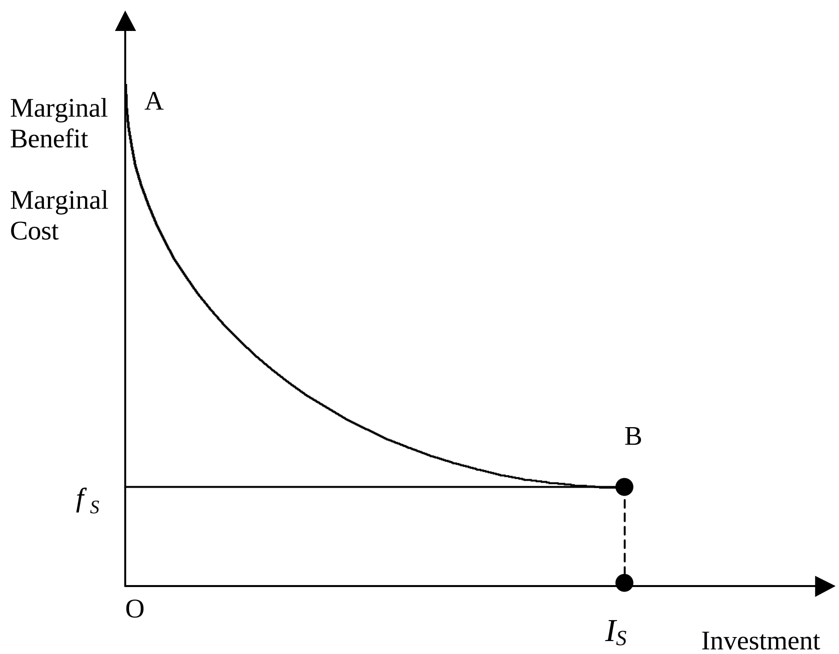

Figure 2: Marginal benefit and costs of investment under sole-ownership

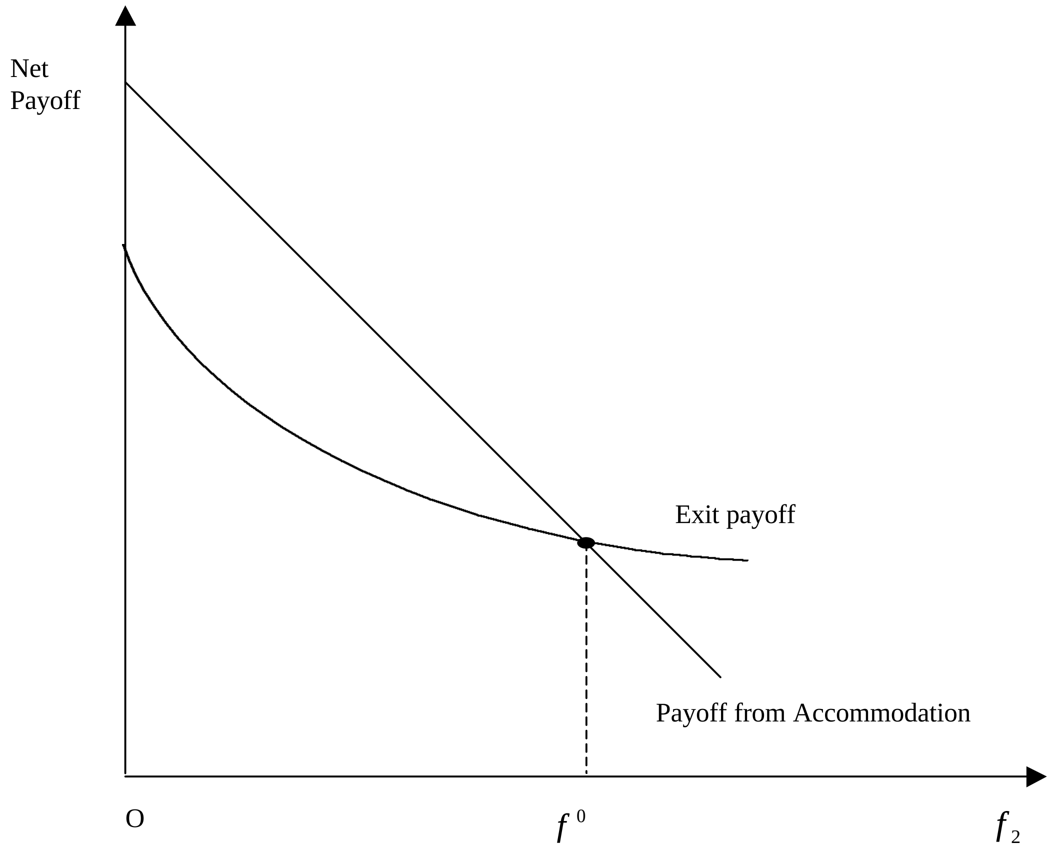

Figure3: Net payoff from exit and accommodation strategies.

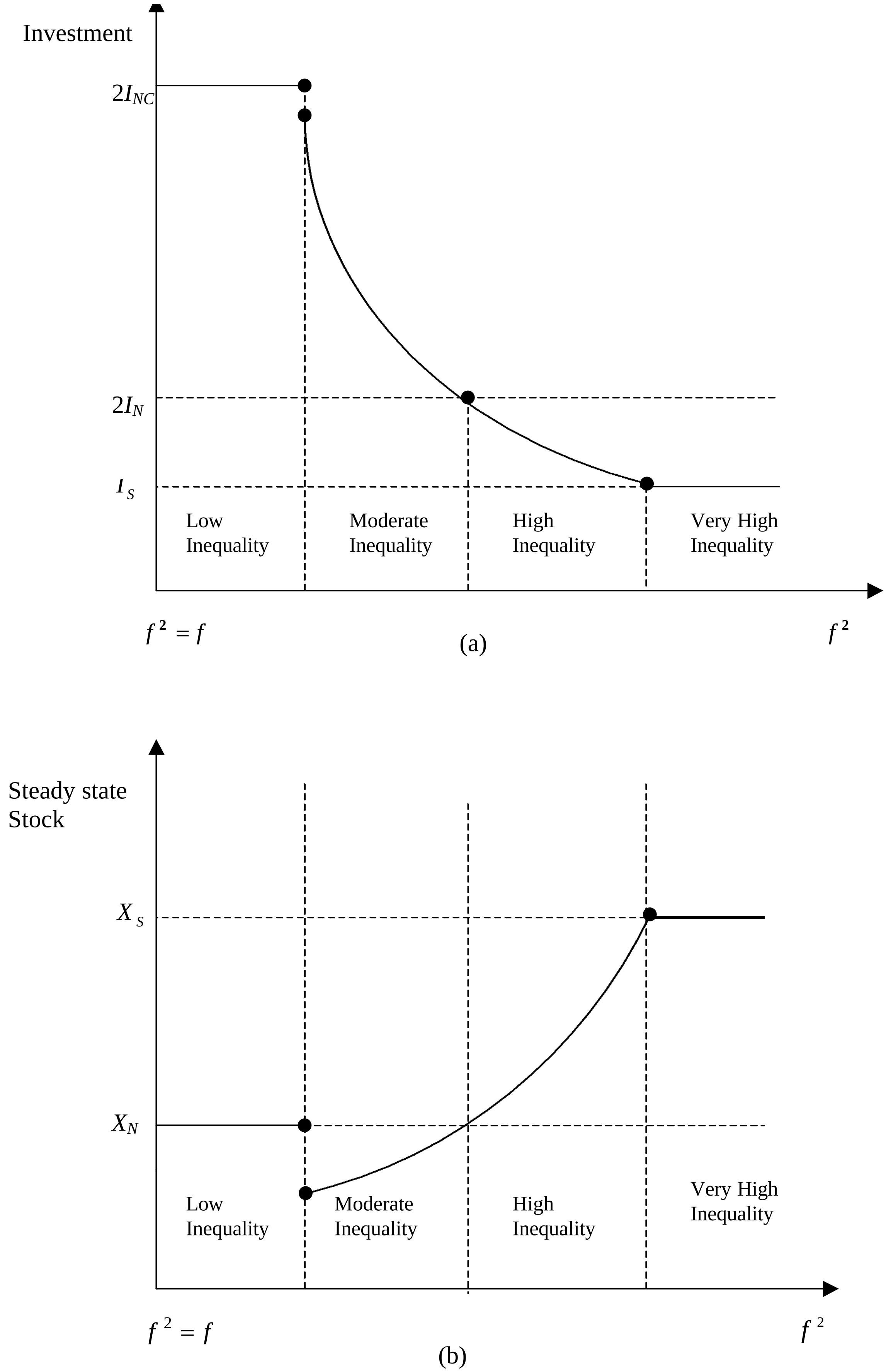

Figure 4: Effect of Inequality on Investment and Steady State Stock