Common-Property Resource Use and Outside Options: Cooperation across Generations in a Dynamic Game

May 2004

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Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, August 1-4, 2004

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abstract

With some common-property natural resources, cooperative behavior by resource users persists over multiple generations. This paper presents a noncooperative dynamic game with overlapping generations of players using a common-property resource. The evolution of the resource stock depends on how much is harvested by the agents in each generation. This study identifies conditions under which a subgame perfect equilibrium supports an efficient, cooperative resource use. It explores how heterogeneity among the agents and changes in outside economic opportunities affect cooperation in the commons. The study finds that, depending on the agents' harvest sharing rule, the condition under which homogeneous agents can cooperate in equilibrium may not be sufficient for cooperation when agents differ in harvesting productivity. It also suggests that integration of local commons to the outside market economy may have a negative effect on efficient local resource management. The paper concludes with an explanation of stylized facts about long-enduring self-governed commons, and policy implications regarding local resource management and rural finance when the commons face changes in the outside economic environment.

1 Introduction

Individuals often lack private property rights to resources such as fisheries, grazing lands and forests but share them in common with a group of people. Lacking sole ownership, each user has a temptation to deviate from what is optimal for the group and may overuse the resource. As implied by the words "tragedy of the commons," many communities with common-property resources (CPRs) face the problem of resource degradation.[1] However, some CPRs are collectively yet successfully managed by a large number of users without overuse.[2] With these CPRs, resource users set their own rules of resource use with reward for cooperation and punishment for non-cooperation. The resource users do not necessarily count on a legal system for solving disputes, or taxes or regulations set by an outside authority.[3] In addition, with most resources that have been successfully self-governed by the users, cooperation persisted over many generations of resource users. Cooperative rural land use in Switzerland and Japan was sustained for several hundred years until the twentieth century (Ostrom 1990, McKean 1986). Resource users with different life spans, possibly facing different economic conditions in different periods, have managed to cooperate across generations in these cases.

Why do we observe cooperation across generations of resource users in some cases and not in others? To answer this question, this paper uses a non-cooperative dynamic game of CPR use by overlapping generations of players and finds conditions under which generations of players cooperate to achieve efficient resource use as a subgame perfect equilibrium outcome of the game. Such conditions characterize the relationship between first-best sustainability and parameters that are considered to be relevant in the stylized facts about cooperation in the commons—carrying capacity of the resource, the number of resource users in each generation, their discount rate and

[1] For example, Turkish inshore fisheries and groundwater in California to name a few (Ostrom 1990).

[2] Examples include mountain meadows in rural villages in Switzerland and Japan, irrigation in coastal Spain and the lobster fishery in Maine (Ostrom 1990, McKean 1986, Acheson 1988). Extensive collections of case studies on CPRs include National Research Council (1986), Wade (1988), Tang (1992), Baland and Platteau (1996) and Agrawal (2002).

[3] The Maine lobster fishery is an example where both self-governance by fishermen and governmental restrictions on the fishery have worked to avoid resource degradation (Acheson 1988, Acheson and Brewer 2003).

harvesting technology.

This study addresses two additional issues of common-property resource use: the effects of heterogeneity among resource users and outside economic opportunities on cooperation in the commons. Empirical studies show that heterogeneity among resource users discourages efficient CPR management (Bardhan 1995). One type of heterogeneity among agents is their life span: agents of different generations may have different interests in resource conservation. In addition, many CPRs are used by people who differ in harvesting productivity, income or wealth levels. In CPR use such as irrigation, rural villages have a variety of resource output-sharing rules ranging from equal sharing to a sharing scheme where farmers with larger wealth or land receive a greater amount of outputs from commons (Bardhan 2000, Dayton-Johnson 2000). This study examines first-best sustainability in a dynamic context where agents from different generations with different productivity use a commons, and describes how heterogeneity affects cooperation under alternative harvest-sharing rules and different outside options.

In many countries, the functions of local non-market organizations, including those for CPR use, have changed as local communities gained access to outside markets for labor supply, exchange of harvests for other commodities, and inputs for harvesting and production of other goods. Some authors argue that improved accessibility and market integration of isolated, fragile areas into the mainstream economy have led to over-exploitation of CPRs (for example, Jodha 1992 cited in Baland and Platteau 1996, p.271). Baland and Platteau (1996) also report case studies where "younger generations tend to be less and less interested in village affairs in general, and in the regulation of local CPRs in particular, when they have alternative income sources in the village (e.g., by growing cash crops in individual fields) or, above all, when they have got an employment in a distant place" (p.276). Income changes of rural people in developing countries have ambiguous effects on the intensity of environmental resources use (Dasgupta and Mäler 1994). Changes in the market environment for local communities are sometimes delivered intentionally by outside agencies as a policy against rural poverty. An example is 'microfinance' or 'microcredit,' small loans by commercial banks or non-governmental organizations (e.g. the Grameen Bank in Bangladesh) to poor farmers in rural communities for income-generating activities (Anderson et al. 2003, p.265). In some cases, microfinance resulted in further resource degradation.[4] This study analyzes a version of the model where resource users in each period have an option to participate in outside markets or to receive microcredit, and examines formally whether improved access to each type of outside markets conflicts with efficient resource use.

The main findings of this paper are summarized as follows. The results of the model explain stylized facts about successful commons (proposition 1): a first-best, cooperative resource use is supported as a subgame perfect equilibrium outcome when the resource users' discount rate is low, the number of resource users is small, and the resource capacity is large (i.e. large carrying capacity and high intrinsic growth rate of the resource) relative to the resource users' harvesting capacity. Whether heterogeneity of resource users affects first-best sustainability depends on the way resource users share their harvest. Heterogeneity among resource users in harvesting productivity does not influence first-best sustainability when a resource user's harvest share is proportional to the user's effort exerted for harvesting (corollary 1). If the resource users' harvest shares are equal regardless of each one's effort exerted, then the first best becomes unsupportable in equilibrium when inequality in productivity of resource users increases (corollary 2). Access to an outside labor market does not influence first-best sustainability and may increase the resource users' maximum equilibrium welfare (proposition 3). However, cooperation may become unsupportable when agents have access to product markets and such access may be welfare-decreasing for the resource users (corollary 3). Microcredit, which allows agents to increase harvest productivity and production of other goods, can also discourage agents to cooperate in resource use when they could sustain cooperation without such credit (proposition 5). These results explain how local non-market institutions may deteriorate as resource users in local commons gain access to external markets or microcredit.

[4] Anderson et al. (2002) reports that "In Madagascar, access to member-based financial institutions encouraged agricultural intensification . . . [which,] while reducing pressure on forests and grasslands, . . . increased demands on irrigation and other water systems" (p.97). According to their survey on 147 microcredit organizations, 12% (42%) of the respondents answered that the rate of deforestation (water use) increased in villages where microcredit was introduced.

Some existing studies have analyzed the effects of heterogeneity on efficient use of commons using static games or finite-horizon games (Sandler 1992, Baland and Platteau 1997, 1999 and Dayton-Johnson and Bardhan 2002).[5] Unlike finite-horizon games, the infinite-horizon game in this paper characterizes cooperative resource use with a threat of future punishment on temporary defectors—a mechanism often observed in successfully self-governed CPRs (Ostrom 1990).[6] Theoretical studies find ambiguity regarding the effects of outside options on cooperative use of commons (Baland and Platteau 1997, Dayton-Johnson and Bardhan 2002). By examining different effects of different outside options—access to labor markets, product markets and credit, this paper delineates how first-best sustainability changes when agents have access to different types of markets.

In what follows, section 2 introduces a dynamic game of CPR use by overlapping generations of players. Section 3 identifies conditions under which a Pareto optimal allocation is supported as a subgame perfect equilibrium outcome when agents have no outside options, and examines the effects of heterogeneity among agents on first-best sustainability. Section 4 discusses how a change in different types of outside economic opportunities (access to labor or product markets and microcredit) affect cooperation in the commons. Section 5 concludes the paper with policy implications regarding local resource management.

2 The Model

2.1 Game environment

This section defines a game of CPR use by overlapping generations of players.

Players

In each period starting from period 0, N agents are born and live for 2 periods. In period 0 there

[5] Wiggins and Libecap (1987) argued that firms with smaller reserves or output shares have stronger incentive to deviate from quota limits imposed by an oil-production cartel. Mason and Polasky (2002) argue that countries with larger oil reserves tend to have a stronger incentive to join the OPEC and demonstrated that their prediction fits well with the actual membership of most oil-producing countries.

[6] Runge (1981) argued that, using a static-game framework, CPR use should be modelled as an 'assurance problem,' a game with multiple equilibria where a cooperative equilibrium is supported under some conditions on each agent's belief on other agents' actions.

exist agents born in period -1. Let (t,i) be the ith agent born in period t.

Assumption 1 *Each agent is endowed with 1 unit of labor when young and zero units of labor when old.*

This is a key assumption in the model that implies the dependence of old members on young members, which is observed in many isolated rural communities with CPRs.

State transition

The agents jointly use a renewable natural resource. The resource stock in period $t+1$ depends on the stock size and the amount of harvest in period t:

Assumption 2 *The resource transition function g is given by a logistic growth function: with stock s_t and total harvest h_t in period t, the stock in period $t+1$ is given by*

$$s_{t+1} \equiv s_t - h_t + g(s_t) \quad \textit{where} \quad g(s_t) = rs_t(1-\frac{s_t}{K}),\ r \in (0,1] \ \textit{and}\ K > 0. \tag{1}$$

Parameters r and K are the intrinsic growth rate and the carrying capacity of the resource. The total harvest in period t is determined by the stock available in period t and the actions by the young agents in period t, as explained below.

Actions and strategies

Labor input $l \in [0,1]$ by agent (t,i) yields an effort level $e = a_i l$ where $a_i > 0$ is the productivity coefficient that determines the effort level per unit of labor. Assume that the distribution of productivity $\bar{a} = \{a_1, a_2, \ldots, a_N\}$ is the same across generations: agents (t,i) and $(t+1,i)$ have the same productivity a_i for all $t = 1,2,\ldots$ and all $i = 1,\ldots,N$. Agents with productivity a_i are called agents of type i. In what follows, assume that each agent (t,i) chooses the effort level between 0 and a_i (instead of choosing labor input). Along with effort, each young agent chooses how much of harvest to transfer to the old agents in the same period. Let $\Delta^N \equiv \{\theta \in I\!R^N_+ | \sum_{j=1}^N \theta_j \leq 1\}$ be the set of vectors of shares that each agent can choose. Then the action set for each agent when young is given by $A_i \equiv [0,a_i] \times \Delta^N$. Suppose agent (t,i) chooses action $(e^{t,i}, \theta_1^{t,i}, \ldots, \theta_N^{t,i}) \in A_i$.

Then $e^{t,i}$ is the effort level by agent (t,i) and $\theta_j^{t,i} \times 100\%$ of (t,i)'s harvest is transferred to agent $(t-1,j)$. As explained later, the agents' effort profile and the stock level determine each agent's harvest share.

What motivates young agents to transfer consumption goods to the old agents from their previous generation? In this game, and in any game with overlapping generations of players in general, choosing positive transfers is a best response to all players if the threat of punishment upon deviation—the threat to a potential deviator by his descendants to choose zero transfer upon defection—is credible. In any community with a commons, this is not the only intergenerational transaction; people interact based on kinship. Parents invest in children's human capital while the children support their parents when they become old. Hence, it is more plausible to assume that agent's productivity depends on investment by their parents. While acknowledging that these kinship ties are important in intergenerational cooperation in resource use, this paper abstracts from them and characterize the conditions for first-best sustainability in the absence of kinship.

The relationship between the effort and harvest of each agent is as follows. As in equation (1), the stock available in period t is the stock at the beginning of period t, s_t, plus the increment given by natural growth $g(s_t)$. Let $e^t = (e^{t,1}, e^{t,2}, \ldots, e^{t,N})$ be the profile of efforts by the young agents in period t. If the total effort by N young agents in period t does not exceed the available stock $s_t + g(s_t)$, then the total harvest is equal to the sum of efforts $\sum_{i=1}^N e^{t,i}$. Otherwise, the total harvest equals the available stock $s_t + g(s_t)$.

Assume that the sharing rule of total harvest is exogenously given to the agent.[7] Consider two alternative harvest-sharing rules observed in case studies: proportional sharing and equal sharing. <u>Proportional sharing</u> is a harvest-sharing rule where the harvest share of agent (t,i) is proportional to agent (t,i)'s share in the total effort in period t:

$$h^{t,i}(e^t, s_t) = \frac{e^{t,i}}{\sum_{j=1}^N e^{t,j}} \cdot \min\left\{\sum_{j=1}^N e^{t,j}, s_t + g(s_t)\right\}.$$

<u>Equal sharing</u> is a harvest-sharing rule where the total harvest is shared equally by the agents who

[7] Dayton-Johnson (2000) discusses endogeneity of harvest sharing rules in commons.

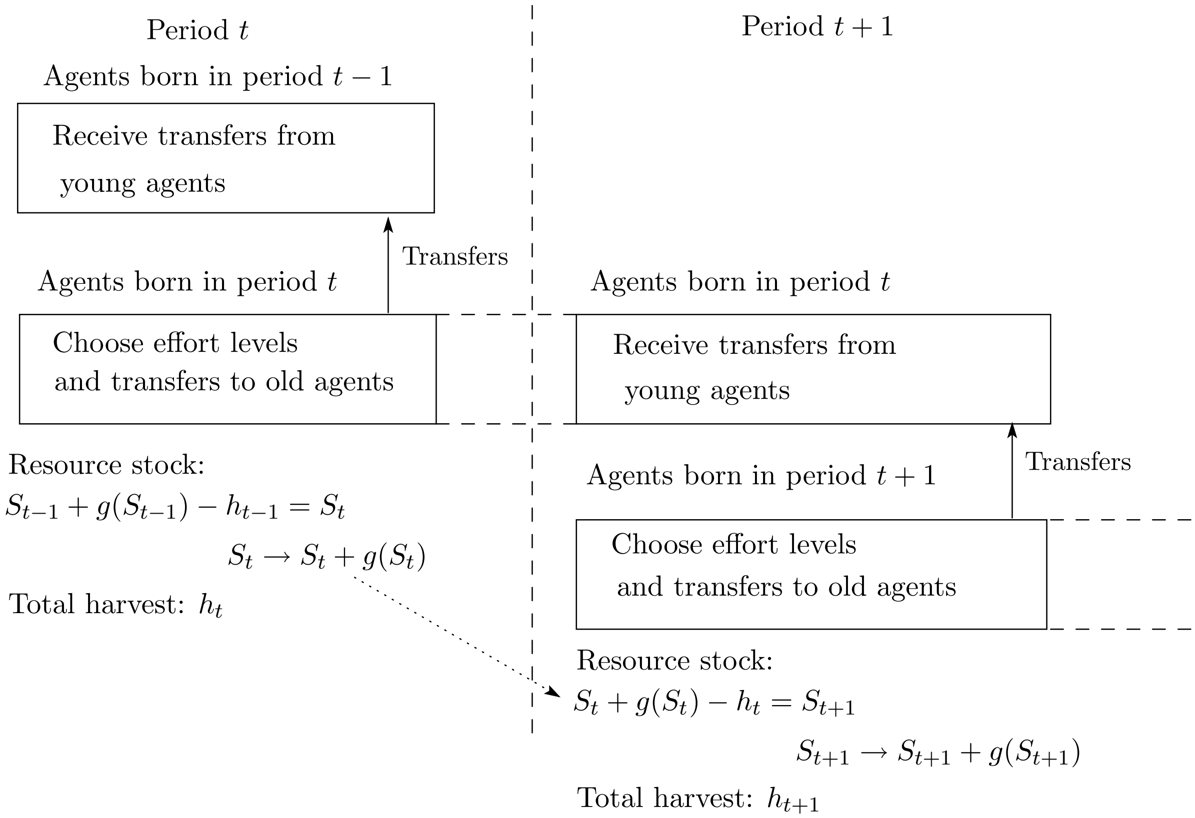


Figure 1: Interaction between generations in the game.

apply efforts. If each agent in generation t applies efforts, then agent (t, i)'s harvest share is

$$h^{t,i}(e^t, s_t) = \frac{1}{N} \cdot \min\left\{\textstyle\sum_{j=1}^{N} e^{t,j}, s_t + g(s_t)\right\}.$$

Depending on the type of the resource, institution, culture and norms, one harvest sharing rule mimics the actual harvest-sharing rule better than the other.[8] The next section examines how heterogeneity in agents' productivity influences first-best sustainability under the above harvest-sharing rules.

Players condition their strategies on the history of actions by the previous generations and the resource stock transition. In the initial period 0, the set of history is given by $H^0 \equiv \{s_0\}$

[8]Dayton-Johnson (2000) reports that both types of sharing rules are observed in rural irrigation use in Mexico. As seen in the next section, the effect of agents' heterogeneity on first-best sustainability is different under proportional sharing and equal sharing.

where s_0 is the initial resource stock. For any period t, $H^t \equiv \{s_0\} \times \left[\left(\prod_{i=1}^N A_i\right) \times [0,K]\right]^t$ is the set of histories of actions and the resource transition from period 0 up to period $t-1$. A history $H_t \in H^t$ is a path of actions and the resource stock from period 0 to period $t-1$. (A capitalized H stands for history, and a lowercase h for harvest.) A strategy of agent (t,i) is given by a function $\phi^{t,i} : H^t \to A_i$. A strategy profile is given by a sequence of strategies by all agents $\phi = \{\{\phi^{t,i}\}_{i=1}^N\}_{t=0}^\infty$.[9]

Payoffs

Each agent's utility is a function of the consumption of harvest in each period. Let $(c_t^{t,i}, c_{t+1}^{t,i})$ be the consumption by agent (t,i) when young and when old.

Assumption 3 *Agents cannot save or store the harvest in one period for consumption in another period.*

Under assumption 3, consumption when young $(c_t^{t,i})$ is given by the harvest minus the amount of transfers to agents $\{(t-1,1),\ldots,(t-1,N)\}$ (i.e. the old agents in period t). Consumption when old $(c_{t+1}^{t,i})$ is given by the sum of the transfers $\theta_i^{t+1,j} h^{t+1,j}(e_{t+1}, s_{t+1})$ from agent $(t+1,j)$, $j=1,\ldots,N$, the young agents in period $t+1$. If agents choose actions $\{(e_t^{\tau,j}, \theta_1^{\tau,j}, \ldots, \theta_N^{\tau,j})\}$ (where $j=1,\ldots,N$, $\tau=0,1,\ldots$), then the consumption path of agent (t,i) is given by

$$c_t^{t,i} = \left(1 - \sum_{j=1}^N \theta_j^{t,i}\right) h^{t,i}(e_t, s_t) \quad \text{and} \quad c_{t+1}^{t,i} = \sum_{j=1}^N \theta_i^{t+1,j} h^{t+1,j}(e_{t+1}, s_{t+1}).$$

Given a strategy profile ϕ and the actions and the resource transition induced by ϕ, the life-time utility (payoff) of player (t,i) is given by

$$U(\phi) \equiv u\left(\left(1 - \sum_{j=1}^N \theta_j^{t,i}\right) h^{t,i}(e_t, s_t)\right) + \beta u\left(\sum_{j=1}^N \theta_i^{t+1,j} h^{t+1,j}(e_{t+1}, s_{t+1})\right)$$

where $\beta \in (0,1]$ is a discount factor. The following assumption will be maintained in this study.

Assumption 4 *The periodwise utility function $u : \mathbb{R}_+ \to \mathbb{R}$ is continuously differentiable, strictly increasing and strictly concave with* $\lim_{c\to 0} u'(c) = \infty$.

[9] In fact, agents do not need to have information as much as H^t. The strategy to support a cooperative outcome can be defined with weaker information requirement.

Under this assumption, an agent with consumption path $(c, 0)$ (where $c > 0$) is better off with consumption path $(c - \varepsilon, \varepsilon)$ for some ε such that $0 < \varepsilon < c$. Assumptions 1 and 4 imply that agents are better off if a transfer scheme is available where young agents in each period give some of the consumption to the old agents born one period earlier. In summary, a dynamic game of CPR use by an overlapping generations of players is characterized by a 6-tuple of parameters $< N, u, \beta, \bar{a}, g, s_0 >$.

Nash equilibrium and subgame perfect equilibrium

Nash and subgame perfect equilibria are defined in a conventional way. For a given initial stock s_0, a strategy profile is a Nash equilibrium if no player profits from unilateral deviation. A subgame perfect equilibrium is a strategy profile such that after every history, the continuations of the strategy profile constitutes a Nash equilibrium.

2.2 Feasible and Pareto optimal allocations

Here I define feasible and Pareto optimal allocations in the game. In particular, I define a stationary Pareto optimal allocation where the agents' harvest is equal to the maximum sustainable yield (defined later) in each period. An allocation (C, S) consists of a consumption path for each agent in each generation $C = \left(\{c_0^{-1,i}\}_{i=1}^N, \ \{\{c_t^{t,i}, c_{t+1}^{t,i}\}_{i=1}^N\}_{t=0}^\infty\right)$ and a sequence of the resource stock $S = \{s_t\}_{t=0}^\infty$. Allocation (C, S) is resource-feasible given $s_0 \in [0, K]$ if (i) the consumption paths of all agents are nonnegative, (ii) the consumption paths satisfy the harvest-technology constraint: $\sum_{i=1}^N [c_t^{t-1,i} + c_t^{t,i}] \leq \min\{\sum_{i=1}^N a_i, s_t + g(s_t)\}$ for all $t = 0, 1, 2, \ldots$, and (iii) the consumption paths satisfy the resource transition constraint: $s_{t+1} = s_t + g(s_t) - \sum_{i=1}^N [c_t^{t-1,i} + c_t^{t,i}]$ for all $t = 0, 1, 2, \ldots$. Condition (ii) states that the total consumption by the agents alive in period t cannot exceed the total harvest in period t, which is bounded by technologically feasible harvest ($\sum_i a_i$) and the resource stock available at the end of period t ($s_t + g(s_t)$). Allocation (C, S) is Pareto optimal given the initial stock s_0 if (i) it is resource-feasible given s_0 and (ii) there is no other resource-feasible allocation (C', S') with $s'_0 = s_0$ such that $u({c'}_0^{-1,i}) \geq u(c_0^{-1,i})$, $\quad u({c'}_t^{t,i}) + \beta u({c'}_{t+1}^{t,i}) \geq u(c_t^{t,i}) +$

$\beta u(c_{t+1}^{t,i})$ for all $i = 1, 2, \ldots, N$ and all $t = 0, 1, 2, \ldots$ with at least one strict inequality for some agent (τ, j). Under a Pareto optimal allocation, harvest and the resource stock may not be stationary over time. With some initial stock levels, we can define a stationary Pareto optimal allocation where the agents of the same type have the same consumption path. In an overlapping generations model without assets other than a renewable resource, the stationary Pareto optimal stock levels depend on the social discount factor (the discount factor in the social welfare function). When the social discount factor is 1, the stationary Pareto optimal stock level is the one associated with the maximum harvest yield. The maximum sustainable yield (MSY) h^* and the associated stock s^* are given by a solution to

$$\max_{h\geq 0, s\geq 0} h \qquad \text{s.t. } s \geq s + g(s) - h \quad \text{and} \quad h \leq \textstyle\sum_{i=1}^{N} a_i.$$

The second constraint in the above maximization problem comes from the assumption that the technologically feasible harvest in one period is bounded by $\sum_i a_i$. It follows from the definition of g in equation (1) that the MSY is given by

$$h^* = \begin{cases} Na & \text{if } \sum_{i=1}^{N} a_i \leq \frac{rK}{4}, \\ \frac{rK}{4} & \text{if } \sum_{i=1}^{N} a_i > \frac{rK}{4} \end{cases}$$

and the associated stationary stock level s^* is given by

$$s^* = \begin{cases} \min\{s \in [0, K] : s = s - \sum_{i=1}^{N} a_i + rs\left(1 - \frac{s}{K}\right)\} & \text{if } \sum_{i=1}^{N} a_i \leq \frac{rK}{4}, \\ \frac{K}{2} & \text{if } \sum_{i=1}^{N} a_i > \frac{rK}{4}. \end{cases}$$

In words, s^* is the minimum stock level such that the stock does not fall below s^* when the total harvest is h^* in each period. We call $\frac{rK}{4}$ the unconstrained maximum sustainable yield; this is the MSY that is feasible if the productivity constraint ($h \leq \sum_i a_i$) is not binding.

A stationary Pareto optimal allocation with MSY is a stationary Pareto optimal allocation where the total harvest in each period is the maximum sustainable yield. Under some conditions on the initial stock s_0 and the distribution of productivity $\bar{a}$, a stationary Pareto optimal allocation with MSY in each period is well defined. Lemma 1 states such conditions.[10]

[10] Proof of the lemmas and the propositions in this paper is available from the author.

Lemma 1 *In game $< N, u, \beta, \bar{a}, g, s_0 >$ with the resource transition function g given by (1), a stationary Pareto optimal allocation with MSY exists (i) if the initial stock is at the MSY level ($s_0 = s^*$) and agents' total productivity is greater than or equal to the MSY ($\sum_{i=1}^{N} a_i \geq \frac{rK}{4}$) or (ii) if the initial stock is greater than or equal to the MSY level ($s_0 \geq s^*$) and the agents' total productivity is less than or equal to the MSY ($\sum_{i=1}^{N} a_i \leq \frac{rK}{4}$). Furthermore, if the periodwise utility function is given by $u(c) = c^{1/2}$, then a stationary Pareto optimal consumption allocation with MSY for type-i agents, (c_y^{i*}, c_o^{i*}), is given by $(\frac{\lambda_i^2}{\sum_j \lambda_j^2} \frac{1}{1+\beta^2} \frac{rK}{4}, \frac{\lambda_i^2}{\sum_j \lambda_j^2} \frac{\beta^2}{1+\beta^2} \frac{rK}{4})$ in case (i) and $(\frac{\lambda_i^2}{\sum_j \lambda_j^2} \frac{1}{1+\beta^2} \sum_i a_i, \frac{\lambda_i^2}{\sum_j \lambda_j^2} \frac{\beta^2}{1+\beta^2} \sum_i a_i)$ in case (ii) where $\lambda_i \geq 0$ is the welfare weight of type-i agents such that $\sum_{i=1}^{N} \lambda_i > 0$.*

Parameter λ_i measures the weight of the type-i agent in each generation. (It is assumed that the intra-generational distribution of types is the same across generations). With the above cases (i) and (ii) in lemma 1, section 3.1 will examine whether there is a strategy profile that supports a stationary Pareto optimal allocation with MSY as a subgame perfect equilibrium outcome. With different initial stock levels, a stationary Pareto optimal allocation with MSY may not be well defined. In such cases, we need to find a non-stationary allocation as a target allocation to be supported as an equilibrium outcome.

In what follows, assume that the periodwise return function u is given by

$$u(c) = c^{1/2}. \tag{2}$$

This functional form is chosen so that the utility is concave in consumption and $u(0)$ is well defined.[11] For the ease of notation, let G denote the game $< N, u, \beta, \bar{a}, g, s_0 >$ with resource transition g and periodwise utility u given by (1) and (2).

3 Commons without Outside Options

In order to identify the effect of heterogeneity on first-best sustainability, this section examines first-best sustainability when agents have no outside options.

[11] In the punishment phase in the proposed strategies to support cooperation, a retired agent has zero consumption if some agent has deviated from cooperation in a previous period.

3.1 Supporting a stationary Pareto optimal allocation

Consider the following strategy profile to support a stationary Pareto optimal allocation with MSY as an equilibrium outcome.

<**Strategy profile** ϕ^{1*} >

Phase I In period t ($t = 0, 1, \ldots$), each young agent (t, i) chooses action $(\bar{e}^{*i}, \bar{\theta}^{*i}) \in A_i$ where

$$\bar{e}^{*i} = \frac{a_i}{\sum_j a_j}\frac{rK}{4}, \quad \bar{\theta}^{*i}_j = \begin{cases} \frac{\beta^2}{1+\beta^2} & \text{for } j = i, \\ 0 & \text{for } j \neq i. \end{cases}$$

(That is, agent (t, i) chooses effort $\frac{a_i}{\sum_{j=1}^N a_j}\frac{rK}{4}$ and gives transfer of $\frac{\beta^2}{1+\beta^2}\bar{e}^{*i}$ to agent $(t-1, i)$.) Agents repeat this action profile as long as the action profile in the previous period $t-1$ was $\{(e^i, \theta^i)\}$ such that $e^i \leq \bar{e}^{*i}$ and $\theta^i \geq \bar{\theta}^{*i}$ for all i or if two or more agents deviated. If a single agent deviated in period τ, then move to phase II_τ.

Phase II$_\tau$ All young agents in periods after τ choose effort levels $\{a_i\}$ and zero transfer.

In phase I of strategy profile ϕ^{1*}, each agent chooses effort and transfer that induce the stationary Pareto optimal allocation with MSY. Once someone unilaterally deviates from the action in phase I, then all agents in the following generations choose the maximum effort levels $\{a_i\}$ and zero transfer (phase II). The strategy profile in the subgames starting from phase II is a Nash equilibrium because the action profile in phase II is a Nash equilibrium in a stage game given any stock level. The following proposition gives conditions under which phase I constitutes a Nash equilibrium, i.e. ϕ^{1*} is subgame perfect:

Proposition 1 *In game G with proportional sharing, strategy profile ϕ^{1*} is a subgame perfect equilibrium and it supports a stationary Pareto optimal allocation with MSY as the equilibrium outcome (a) if $s_0 \geq s^*$ and the agents' total harvest cannot exceed the MSY ($\sum_i a_i \leq \frac{rK}{4}$) or if (b) $s_0 = s^*$ and the agents' total productivity $\sum_i a_i$ satisfies $\sum_i a_i \leq (1+\beta^2)\frac{rK}{4}$.*

Proof. Under either condition (a) or (b), a stationary Pareto optimal allocation with MSY is well defined by lemma 1. We need to show that no player has an incentive to deviate from cooperation in both phase I and phase II given any stock level. As discussed above, continuation starting from Phase II constitutes a Nash equilibrium. It remains to show that phase I constitutes a Nash equilibrium. Under condition (a), the total harvest by N young agents does not exceed the maximum sustainable yield $\frac{rk}{4}$ in each period. Starting with $s_0 \geq s^*$, the resource stock does not fall below the MSY level s^*. Hence, the stock dynamics is irrelevant in characterizing the conditions for supporting the MSY-path as a subgame perfect equilibrium outcome. The only way the deviation can be profitable in phase I is by deviating from the specified amount transfer to the retired. If agent (τ, i) deviates from the actions in phase I, then the maximum consumption that the agent can have is a_i, by harvesting up to the maximum and making zero transfer to the retired. Then agent (τ, i) receives zero transfer upon retirement, so the maximum deviation payoff to agent (τ, i) is $a_i^{1/2}$. In phase I, an agent will consume $\frac{1}{1+\beta^2}a_i$ when young and $\frac{\beta^2}{1+\beta^2}a_i$ when old. So the continuation payoff to cooperation in phase I is $\left(\frac{1}{1+\beta^2}a_i\right)^{1/2} + \beta\left(\frac{\beta^2}{1+\beta^2}a_i\right)^{1/2}$. Squaring this term, we have $(1+\beta^2)a_i$. Because $(1+\beta^2)a_i \geq a_i$ for all i and $\beta \in (0,1]$, it follows that payoffs to deviation never exceed the payoffs to cooperation. Hence, cooperation is supported as a subgame perfect equilibrium outcome if $\sum_i a_i \leq \frac{rK}{4}$ and the initial stock satisfies $s_0 \geq s^*$.

Under condition (b), the maximum total harvest by N young agents exceed the maximum sustainable yield $\frac{rK}{4}$. The maximum payoff to agent (t, i) upon deviation is bounded by $a_i^{1/2}$. If agent (t, i) does not deviate from phase I, then the continuation payoff is

$$\left(\frac{1}{1+\beta^2}\frac{a_i}{\sum_{j=1}^N a_j}\frac{rK}{4}\right)^{1/2} + \beta\left(\frac{\beta^2}{1+\beta^2}\frac{a_i}{\sum_{j=1}^N a_j}\frac{rK}{4}\right)^{1/2}.$$

So agent (t, i) does not have an incentive to deviate from cooperation if

$$\left(\frac{1}{1+\beta^2}\frac{a_i}{\sum_{j=1}^N a_j}\frac{rK}{4}\right)^{1/2} + \beta\left(\frac{\beta^2}{1+\beta^2}\frac{a_i}{\sum_{j=1}^N a_j}\frac{rK}{4}\right)^{1/2} \geq a_i^{1/2}, \text{ i.e. } \quad (1+\beta^2)\frac{rK}{4} \geq \textstyle\sum_{j=1}^N a_j.$$

Hence, the strategy profile is a subgame perfect equilibrium if $s_0 = s^*$ and $(1+\beta^2)\frac{rK}{N} \geq \sum_i a_i$. ■

There are two alternative conditions for first-best sustainability, (a) and (b). Under condition (a), the total maximum effort $(\sum_i a_i)$ is less than the unconstrained MSY and the initial stock is greater than or equal to the MSY level s^*. Given $s_0 \geq s^*$, this implies that the game is effectively a repeated game played by overlapping generations of players. The only efficiency concern in this case is whether agents have an incentive to make a positive transfer to the old agents. Such repeated games have been analyzed by several studies. In particular, under the conditions in proposition 1, the game is an N-agent version of the 'pension game' by Hammond (1975). On the other hand, under condition (b), the stock can decline to a level below s^* if agents apply the maximum effort level. In this dynamic CPR game, the first best is sustainable in such nontrivial cases where the resource depletion is technologically feasible. Proposition 1 implies that cooperation is sustainable as long as the initial stock is large enough and $\sum_i a_i \leq (1+\beta^2)\frac{rK}{4}$. This inequality holds if the resource is relatively abundant (large r, K), if the number of resource users N is small, if the agents are patient (large β), or if the harvesting technology is not advanced (low a_i's). This inequality as the condition for sustaining cooperation is consistent with empirical findings on the traditional CPR use in rural areas with primitive harvesting technology under low population pressure.

Condition (a) in proposition 1 implies that, in a repeated game by overlapping generations of players (e.g. Hammond 1975), the first best is supportable without any further restriction on the parameters (other than condition (a) which guarantees that the game is a repeated game). Condition (b) is stronger than condition (a), implying that stronger conditions are needed for agents to support cooperation across generations in dynamic games than in repeated games.

The following corollary states that inequality does not affect first-best sustainability under proportional sharing.[12]

Corollary 1 *Suppose harvest is shared according to proportional sharing. Consider two games G and G' that are identical except for the distribution of productivity $\bar{a}$ and $\bar{a}'$ where $\bar{a}'$ is a mean-preserving spread of $\bar{a}$. If $(1+\beta^2)\frac{rK}{4} \geq \sum_i a_i$ and $s_0 \geq s^*$, then the following strategy profile ϕ^{1*} is a subgame perfect equilibrium and supports the same stationary Pareto-optimal allocation with MSY in both G and G'.*

[12]This invariance result is robust against the choice of the functional form of the utility function.

Under proportional sharing, the continuation payoff to defection is proportional to the agent's productivity. With transfers proportional to the agents' productivity, the continuation payoff to cooperation is also proportional to the agent's productivity. This is why redistribution of productivity among agents does not influence first-best sustainability. In previous studies such as Baland and Platteau (1997), inequality does affect the efficiency of the resource use (even though the effect is ambiguous). The above neutrality result on inequality is due to the nature of the model in this study.[13]

The following proposition characterizes first-best sustainability under equal sharing.

Proposition 2 *In game G with equal sharing, a stationary Pareto-optimal allocation with MSY is supportable as a subgame perfect equilibrium outcome if* $\max_i a_i \leq (1+\beta^2)\frac{rK}{4N}$.

Under equal sharing, the continuation payoff to cooperation is under-proportional to the agent's productivity whereas the continuation payoff to defection is proportional to the agent's productivity. Cooperation must be preferred to defection by all agents; hence, first-best sustainability depends on the productivity of the most productive agent. In other words, the agent with the highest productivity is the 'weakest link' in sustaining cooperation.

Comparing a distribution and its mean-preserving spread, the maximum among the agents' productivity may be larger with the former or the latter. Hence, under equal sharing, the effect of increasing inequality on first-best sustainability is ambiguous: inequality may or may not enhance first-best sustainability. However, an increase in inequality among homogeneous agents may make the first best unsupportable (e.g., if $a = (1+\beta^2)\frac{rK}{4N}$ prior to the increase in inequality).

Corollary 2 *Consider game G with equal sharing. Suppose* $\bar{a} = \{a_i\}_{i=1}^N$ *where* $a_i = a$ *for all* i*. For any* $\bar{a}$ *such that* $a \leq (1+\beta^2)\frac{rK}{4N}$*, there exists a mean-preserving spread of* $\bar{a}$ *(call it* $\bar{a}'$*) such that the first-best outcome is not supportable under a game with* $\bar{a}'$*.*

[13] In Dayton-Johnson (2000), heterogeneity does not influence the equilibrium under both of the above two harvest-sharing rules. In his model, the post-deviation payoff is independent of the productivity of the agent. In my model, the post-deviation payoffs are increasing in the productivity or wealth of a player. This is why an agent may not have an incentive to follow cooperation under equal sharing when the same agent has an incentive to cooperate under proportional sharing.

Another observation is that, with this model, we do not observe a U-shaped relationship between heterogeneity and cooperation as in Dayton-Johnson and Bardhan (2002). This is precisely because of the overlapping-generations structure of the game, or of heterogeneity among resource users in their life span. Under 'complete' inequality where productivity is zero for all agents except for one in each generation, externality across generations still remains. Sole ownership in each generation does not imply efficiency in an overlapping-generations model.

If $s_0 \neq s^*$ and $\sum_i a_i > \frac{rK}{4}$, then no Pareto optimal allocation is stationary. The above condition is sufficient for first-best sustainability as long as the initial stock s_0 exceeds s^*. If $s^0 < s^*$, then first-best sustainability requires additional assumptions.

4 Commons with Outside Options

Empirical studies have mixed findings about the effects of 'market integration' or outside economic opportunities on local CPR management. As seen in section 1, theoretical studies also find ambiguity regarding those effects. One reason behind these mixed findings is that market integration takes several different forms where each has a different effect on resource users' decisions to cooperate in the commons. There are three sorts of outside opportunities that are relevant to people with rural commons: a labor-market opportunity, a resource-product market opportunity and a (micro)credit opportunity. The first opportunity allows agents to provide labor and earn wage income outside the commons. With the second opportunity, agents can trade the resource harvested to outsiders for other commodities at some given price. Microcredit allows agents to make investment for increasing their harvesting productivity and to produce goods other than harvest. By classifying outside opportunities into the above three distinct categories, this section examines the effects of each type of market integration on cooperation in the commons. In what follows, assume the following:

Assumption 5 *All agents have the same harvesting productivity $a > 0$ such that $Na \geq \frac{rK}{4}$, so that agents can harvest the unconstrained maximum sustainable yield. The initial stock level s_0 is equal to the MSY level s^*.*

Assumption 5 allows us to focus on the effect of outside options on cooperation in the commons without complications arising from non-stationarity of equilibrium.

4.1 Access to a labor market

Suppose first that agents have an option to participate in an outside labor market.

Assumption 6 *Agents have access to a labor market by paying fixed cost $f_l \geq 0$. Upon access, an agents who provides l units of labor receives wage wl where $w \geq 0$ is a given wage rate in each period.*

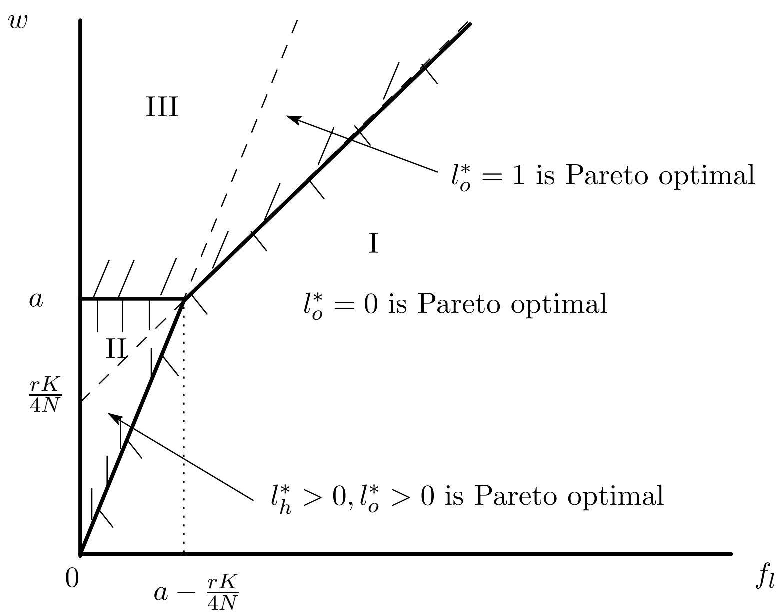
Agents are price takers. An increase in w may be a result of economic growth in urban areas outside the commons. Parameter f_l represents the transaction of market access or barriers to trade. Let $l_h \in [0,1]$ and $l_o \in [0,1]$ represent the units of labor an agent supplies for harvesting and to the outside labor market. If an agent chooses $l_h < 1$ and $l_0 \in (0, 1 - l_h]$, then the agent's income when young is given by $l_h a + l_o w - f_l$. If an agent does not supply labor to the market, then the income is $l_h a$. The agents may or may not use labor-market options under stationary Pareto optimal allocations. Figure 2 describes three types of optimal labor allocations under different combinations of f_l and w. Agents do not harvest the resource but work outside in the stationary Pareto optimal allocation if the wage rate is sufficiently high relative to the fixed market-entry cost.

How do changes in the wage rate and the market-entry cost influence first-best sustainability? The following proposition asserts that the effect is nonnegative.

Proposition 3 *Under assumptions 1-6, the following holds:*

(i) If the first best is supportable in equilibrium without a labor market opportunity, then the first best is supportable under any combination of wage rate w and market-entry cost f_l.

(ii) If the first best is not supportable in equilibrium without a labor market opportunity, then the first best becomes supportable under sufficiently high wage rates and low entry cost levels such that $w > \left\{f_l + \frac{rK}{4N}, a\right\}$. Under such (w, f_l), the equilibrium payoffs to the agents are higher than in a game without the labor market opportunity.



(l_h^*, l_o^*: allocation of labor for harvesting and outside labor market.)

(w: wage rate of the outside market, f_l: cost of entry to the labor market.)

Figure 2: Stationary Pareto optimal allocations under different conditions of the labor market.

Proposition 3 implies that access to outside labor markets alone does not have a negative effect on first-best sustainability and can be welfare-improving for the agents. Access to an outside labor market does not discourage cooperative resource use because high wage rates induce resource users to provide more labor in the labor market (and hence to use less labor for harvesting).

4.2 Access to product markets

This section considers first-best sustainability when agents have access to product markets where they can trade goods. Assume the following:

Assumption 7 *Agents receive utility from consuming harvest and another good (manufacturing good). Each agent's periodwise utility is given by* $u(c_h, c_m) = c_h^{1/2} + c_m^{1/2}$ *when the consumption of harvest and the manufacturing good is* (c_h, c_m).[14]

[14]The assumption on the functional form of utility makes the computation of payoffs straightforward.

Assumption 8 *Agents have access to product markets by paying fixed cost $f_m > 0$. Upon access, agents can purchase the manufacturing good at price p_m, in terms of harvest, in each period.*

With access to the product markets, agents can trade their harvest for the manufacturing good at a fixed price p_m. Like f_l, the fixed cost f_m measures the transaction cost of market access. With assumptions 7 and 8, each young agent chooses effort, 'participate' or 'not participate' in the product markets, consumption of harvest and the manufacturing good, and transfer of harvest and the manufacturing good to old agents.[15] Under these additional assumptions, the maximum sustainable yield is still consistent with Pareto optimality. Without access to the product markets, consumption of the manufacturing good is zero. With access to product markets, agents can trade harvest for the manufacturing good but pays a fixed cost f_m. So a stationary Pareto optimal consumption allocation upon access to the product markets is given by a solution to

$$\begin{aligned} U^{tr} \equiv \max_{c_{h,y}, c_{m,y}, c_{h,o}, c_{m,o}, \theta} \quad & c_{h,y}^{1/2} + c_{m,y}^{1/2} + \beta\left(c_{h,o}^{1/2} + c_{m,o}^{1/2}\right) \\ \text{s.t.} \quad & c_{h,y} + p_m c_{m,y} \leq (1-\theta)\left(\frac{rK}{4N} - f_m\right),\ c_{h,o} + p_m c_{m,o} \leq \theta\left(\frac{rK}{4N} - f_m\right), \\ & c_{h,y}, c_{m,y}, c_{h,o}, c_{m,o} \geq 0, 0 \leq \theta \leq 1. \end{aligned}$$

(Superscript *tr* stands for 'trade' in the product markets, and subscripts y and o for consumption when young and when old.) The following proposition gives the condition for first-best sustainability in the presence of product markets.

Proposition 4 *Under assumptions 1-5, 7 and 8, a stationary autarky Pareto optimal allocation is a subgame-perfect equilibrium outcome if* $(1+\beta^2)\frac{rK}{4N} \geq \max\left\{a, \left(1+\frac{1}{p_m}\right)(a - f_m)\right\}$. *A stationary Pareto optimal allocation, where product markets options are used, is a subgame-perfect equilibrium outcome if* $(1+\beta^2)\left(\frac{rK}{4N}\right) \geq a + \beta^2 f_m$.

The condition for first-best sustainability is stronger in the presence of product-market options.

How does a product-market option influence first-best sustainability? The following corollary follows from proposition 4.

[15] Assume that the agents cannot produce the manufacturing good. This assumption is relaxed in the next subsection.

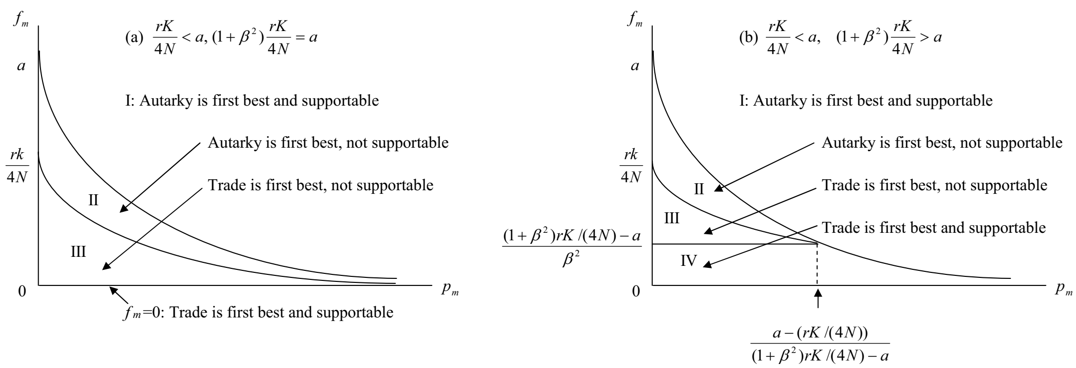


Figure 3: First best sustainability with product markets.

Corollary 3 *Suppose that assumptions 1-5, 7 and 8 hold and that the first best is supportable in equilibrium without product markets option (i.e. $(1+\beta^2)\frac{rK}{4N} \geq a$).*

(i) There exists two nonempty sets of combinations of product-market prices and market entry costs $A, B \subseteq \mathbb{R}^2_+$ such that (i) for any $(p_m, f_m) \in A$, an autarky Pareto optimal allocation cannot be supported as a subgame perfect equilibrium outcome and (ii) for any $(p_m, f_m) \in B$, a Pareto optimal allocation that involves the use of the product-market option cannot be supported as a subgame perfect equilibrium outcome.

(ii) If the market entry cost f_m is zero, then, for any manufacturing price $p_m \geq 0$, the first best is supportable and the agents' maximum equilibrium payoffs increase upon trade.

As opposed to labor-market options, product-market options may deteriorate cooperative resource use in the commons. The second point of corollary 3 is that access to product markets (given any manufacturing price level) does not influence first-best sustainability as long as the market-entry cost f_m is zero. Figure 3 describes how the condition for first-best sustainability changes under various values of market options (p_m, f_m) when the first best is sustainable without market options (i.e. $(1+\beta^2)\frac{rK}{4N} \geq a$). In both cases (a) and (b) in the figure, region II (III) represents the set

A (B) in corollary 3—the set of market options where the first best becomes unsupportable. For sufficiently high market entry cost levels (in region I), Pareto optimal allocations are supportable in equilibrium. Given a price of the manufacturing good, a decline in the market entry cost (from region I to region II or III) will cause the first best to become unsupportable.

4.3 Access to microcredit for production

Suppose that agents have access to microcredit, which they can use to increase their harvesting capacity or to purchase inputs for manufacturing.

Assumption 9 *The agents have access to a credit market where agents can purchase inputs for harvest-capacity expansion and manufacturing. The input price is $r_k > 0$. With k_h units of input, the harvest productivity increases by $b_h k_h^{1/2}$. With k_m units of input, an agent can produce $b_m k_m^{1/2}$ units of the manufacturing good.*

With inputs for harvest-capacity expansion, agents can increase their effort levels per unit of labor. With inputs for manufacturing, agents can produce manufacturing good on their own.[16] With assumptions 7-9, each young agent chooses effort, consumption of harvest and the manufacturing good, inputs for harvest-capacity expansion and manufacturing, and transfer of harvest and the manufacturing good to old agents.

In what follows, in order to isolate the effects of credit on first-best sustainability, assume that the product-markets entry cost f_m is zero. If the total harvest productivity Na exceeds the maximum sustainable yield $\frac{rK}{4}$ as in assumption 5, then the input for harvest-capacity expansion k_h is zero for all agents in a stationary Pareto optimal allocation. By deviating from a cooperative strategy supporting the stationary Pareto optimal allocation with MSY, an agent can now harvest more than a by increasing the harvesting productivity through microcredit. The following proposition describes the condition for first-best sustainability under access to microcredit.

[16] I assume away labor inputs for harvest-capacity expansion and manufacturing, and hence the problem of labor allocation between harvesting and manufacturing. With labor allocation between harvesting and other activities, sustaining the MSY may not be Pareto optimal. See section 5 for a further discussion.

Proposition 5 *Under assumptions 1-5 and 7-9, a stationary Pareto optimal allocation is supported as a subgame perfect equilibrium outcome if*

$$(1+\beta^2)\left[\frac{rK}{4N}+\frac{(p_m b_m)^2}{4r_k}\right]\geq a+\frac{b_h^2}{4r_k}+\frac{(p_m b_m)^2}{4r_k}. \tag{3}$$

Furthermore, a stationary Pareto optimal allocation is supportable (not supportable) as an equilibrium outcome if $\frac{\beta p_m b_m}{b_h}$ *is sufficiently large (small).*

In inequality (3), the left-hand side represents the payoff from cooperation and the right-hand side the maximum payoff upon deviation. The term $\frac{(p_m b_m)^2}{4r_k}$ is the maximum income from manufacturing, and $a+\frac{b_h^2}{4r_k}$ the maximum harvest upon the optimal deviation from cooperation. Proposition 5 implies that whether the first best is supportable in the presence of microcredit depends on the profitability of manufacturing relative to harvest-capacity expansion. Recall that, without access to credit for production, the condition for first-best sustainability is

$$(1+\beta^2)\frac{rK}{4N}\geq a. \tag{4}$$

When condition (4) does not hold, condition (3) holds if $\beta p_m b_m - b_h$ is sufficiently large. That is, access to credit improves agents' incentive to cooperate in resource use if the agents' discount factor is large and if the marginal return from manufacturing (measured by $p_m b_m$) is larger than the marginal return from harvest capacity expansion (measured by b_h). Alternatively, even if condition (4) holds, condition (3) may not hold if b_h is sufficiently larger than $p_m b_m$. Hence, access to credit for income-generating opportunities may discourage agents to cooperate in resource use.

5 Discussion

This paper introduced a dynamic game of common-property resource use with overlapping generations of players to investigate conditions under which a subgame perfect equilibrium supports cooperative resource use across generations of resource users. The main findings include (1) the conditions for first-best sustainability that are consistent with stylized facts of commons, (2) the effects of heterogeneity on collective action, and (3) the effects of access to outside markets on collective action.

The results of the model explain stylized facts about successful commons: a first-best, co-operative resource use is supported as a subgame perfect equilibrium outcome when the resource users' discount rate is low, the number of resource users is small, and the resource capacity is large (i.e. large carrying capacity and high intrinsic growth rate of the resource) relative to the resource users' harvesting capacity. Heterogeneity among resource users in harvesting productivity does not influence first-best sustainability when a resource user's harvest share is proportional to the user's effort exerted for harvesting. If the resource users' harvest shares are equal regardless of each one's effort exerted, then the first best becomes unsupportable in equilibrium when inequality in productivity of resource users increases. Different outside market options have different effects on the efficient use of a local commons. Access to an outside labor market does not influence first-best sustainability and may increase the resource users' equilibrium welfare. However, cooperation may become unsupportable when agents have access to a market for selling harvest or a credit market when they could sustain cooperation without such access. In particular, the first best becomes unsustainable as the cost of access to these markets declines. This result suggests that local non-market institutions may deteriorate as resource users in local commons gain access to external markets at a lower cost.

These findings explain tension between younger and older generations that are often found in rural villages in developing countries, where increasing outside opportunities in the course of national economic development resulted in malfunctioning of local CPR governance (Baland and Platteau 1996, pp.275-277). Findings regarding product markets are consistent with case studies where resource degradation occurred after opportunities to sell highly-valued cash crops became available to people in local commons.

The analytical results in this paper have the following policy implications. First, the analysis suggests that self-governance will not work if conditions for first-best sustainability are not satisfied.

In such cases, policy interventions by an outside authority may be necessary to enhance or enforce cooperation.[17] Even in cases where it may be possible to support first-best sustainability, a wrong set of policies or institutions may prevent this from occurring. Inefficiency may be a result of inappropriate rules of resource use that are not consistent with heterogeneity of resource users. In many countries, policies for conservation of CPRs included land reform or nationalization of forests, and many of them did not work to stop resource overuse.[18] The analysis suggests that one reason such policies do work is because they may not respect heterogeneity of the regulated resource users.

The result from section 4.2 implies that, in equilibrium, agents will not trade in product markets when the entry cost to the markets is prohibitively high. When the entry cost is zero, then market participation increases the resource users' maximum equilibrium payoffs without resource overuse. Access to product markets with some positive cost of market barriers, however, may cause the first best to become unsupportable. In the course of market integration of local commons, policies can mitigate resource overuse by reducing the barriers to trade.

Section 4.3 examined the effect of microcredit on first-best sustainability without labor market options. Without labor markets, restrictions on microcredit—so that credit cannot be used for harvest-capacity expansion—may be necessary in order to avoid resource overuse. However, if agents have access to a labor market (with a sufficiently high market wage rate) along with microcredit for production, then microcredit for harvest-capacity expansion can be effective in both reducing poverty and sustaining efficient resource use. This is because, with improved harvesting productivity, agents can maintain the same harvest with less labor inputs where the saved labor can receive wages in the labor market. Therefore, introduction of microcredit will be effective in reducing poverty and sustainable resource use in an environment where essential inputs for resource use, including labor, can be utilized elsewhere.

This research abstracts from several aspects of CPR use, including the cost of monitoring

[17]Such external intervention may have its own set of problems. See Ostrom (1990).

[18]Examples include an irrigation project in Sri Lanka and nationalization of forests in Nepal (Ostrom 1990, p.157 and p.178).

agents' actions, heterogeneity among agents in non-economic dimensions, non-market values of natural resources and uncertainty in resource transition. The model in this paper assumes that agents from different generations interact only once. As in the folk theorem for repeated games with overlapping generations of players (Kandori 1992), first-best sustainability is increasing in the frequency of interactions by agents from different generations. Therefore, the condition for first-best sustainability derived in this study can be interpreted as the condition for the least auspicious environment for intergenerational cooperation in the commons. Some authors suggest that group-based lending of microcredit (e.g. by the Grameen Bank in Bangladesh) helped improved non-market collective action in local villages (Anderson, et al. 2002, 2003). A close examination of the relation among the types of lending, market environments and resource use will suggest the design of microcredit schemes that works against rural poverty and promotes collective action. The effect of outside options to a commons was examined in a partial equilibrium model. Migration from local commons to the urban area and scarcity of resources will affect the resource price and the wage rate. The number of resource users is assumed to be fixed in the model, but a high resource-product price (e.g., the price of cash crops) will induce outsiders to enter the commons, and this may result in the breakdown of first-best sustainability. Exploration of these issues is left for future research.

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