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Why are some Communities able to Preserve their Natural Resources while some Others Fail to Achieve it?

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Why are some communities able to preserve their natural resources when others fail to achieve it?

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Abstract

This paper presents an analytical framework to understand why some communities successfully manage their renewable natural resources and some fail to do it. We develop a two players, two-period non-cooperative game where a community can impose some exogenous amount of sanctions. We show that rules preventing dynamic inefficiencies may exist even though static inefficiencies still remain. Inequalities reduce static inefficiencies but increase dynamic inefficiencies.

Keywords: Common-pooled resource ; Resource preservation ; Social sanction ; Institutions for collective action ; Noncooperative game theory

JEL codes: Q2, C72 , D02 , D23, P48,

1 Introduction

Traditional societies are often depicted as smart managers of their environment when modern institutions would tend to overuse or even deplete natural resources.

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Combined with a growing awareness of environmental issues, this vision frequently supports plans to hand over natural resources management to local communities.

Nonetheless, this romantic view should be taken up with caution. Each human being exerts pressure on and interacts with his environment. The social structure and the institutions, he belongs to may or may not organize these relationships. Although long-enduring societies have most probably found a way to match their lifestyle to the available resources, they are not *per se* efficient resource managers. It can be that resources are so abundant that efficient management is not an issue at all because, for given population size and disposable technologies, natural resources seem to be infinite. On the other side, Diamond (2005) points out eight processes by which some old societies have collapsed because they were unable to tackle efficiently environmental challenges. Diamond argues that full deforestation of the island has led to a collapse of this civilization (Diamond, 2005). Brander and Taylor (1998) construct a model which links population dynamics and endogenous natural resources degradation and could explain Eastern Island decline. They further describe some other civilizations that might have followed the same path. So, traditional societies are not always able to manage their resources in a way such that they can perpetuate themselves, which is clearly far away from sustainable development.

From a large survey of socio-anthropological literature, Baland and Platteau (1996) report that *'it can be concluded that, if members of traditional rural communities are relatively good at perceiving and solving distributive problems arising in connection with the use of natural resources (...) they are not inherently conservationists as they are often portrayed in popular accounts and even in socio-anthropological writings'*. They further point out the issue that if *'traditional rural societies were apparently able, at least in certain circumstances, to make effective collective arrangements to solve distributive problems, why should they then have been less efficient in organizing to prevent depletion/degradation of common-pooled resources?'* (Baland and Platteau, 1996, p. 232).

Basically, when population density is increasing, and natural resources are becoming scarcer relatively to the size of the population, common pool resources use has to be, in some way, restricted (Hardin, 1968). By its social structure, a community can overcome the tragedy of the commons. Nevertheless, this question has often been raised in a static framework, that is how members are able to share, to distribute a fixed pie within a given period. This paper aims at addressing the question of the dynamic inefficiency. What happens if the pie is growing over time? Are members of communities able to preserve the renewable resource base?

The answer given by Baland and Platteau is mostly based on a lack of scientific knowledge by the communities at stake. Members of traditional societies are assumed to *'share a magical pre-rationalist view of the world'*. Actually, they

consider the flow of resources as determined by some supranatural agencies when their own actions would be irrelevant to explain fluctuations of the flow (Baland and Platteau, 1996, p. 211). In this paper, we want to explore the issue assuming that agents are rational and possess perfect information on other agents reaction function and about natural resources dynamics. We build a two-period, two agents game based on Tullock contest success function (1980) to show that the tragedy of the common has both static and dynamic inefficiencies.

Then we discuss how the threat of exogenous sanctions can discipline players and allow to reach an Pareto superior equilibrium. Under strong assumptions of perfect information, certainty and benevolent planner, we first show that it is possible to partly overcome static inefficiencies but to fail to solve the dynamic problem. We then describe conditions in which players preserve the resource until the last period before fighting to appropriate it. The discussion of the model indicates that efficient conservation followed by a fight for appropriation will arise for a broad range of resource growth rate and initial value, especially if players can decide on the type of resource that they will extract before the game takes place.

The main determinants of successful collective action are the available institutional technology, the growth rate of the renewable resource and potential inequalities among players. When inequalities are large, larger sanctions are required to reach the first best. Actually, with inequalities, static inefficiencies progressively vanish but the dynamic failure becomes impossible to overcome. We also investigate what happens when the level of effort has also an impact on the harvested quantities and not only on their repartition. Clearcut conclusions are more difficult to draw out in this case.

More details about the two types of inefficiencies and associated rules are presented in the first part of the second section, which afterwards covers the relevant theoretical literature. Section three develops the core model in a specific framework. The role of social sanction is discussed in section four. Section five analyses heterogeneity across players. The sixth section concludes.

2 Empirical foundations and related literature

Since Hardin's tragedy of the commons (1968), it is well-known in the literature that rational users of common pool resources tend to over-exploit them. Nevertheless, in some communities, rules are set such that resources exploitation occurs more efficiently.

2.1 Stylized facts

A first layer of rules addresses *'appropriation problems'*. It means that members of communities are, under certain circumstances, able to design rules that allocate a fixed quantity of resource unit such as to avoid rent dissipation and reduce conflicts between appropriators (Ostrom, 1990). Rotation systems seem to be largely used to regulate access to scarce resources. For instance, it is reported that in Nepal, *'systems of spatial control have also been adopted in some traditional management situations. Within these systems, areas are delineated that can be harvested at a specified period. Sometimes, these systems cover the whole resource over the period of one season, and their main function is to ensure that all members have equal access to both the nearby and more distant areas'* (Arnold and Campbell, 1986, p 436).

A second level of rules can be implemented to answer what Ostrom (1990) calls *'provision problems'*. These rules focus on the fact that today harvested quantities affect what can be harvested tomorrow. Even in the context of renewable resources, the extracted quantity of one period affect negatively the resources stock, which will negatively influence next period yield. From case studies in Uttarakhnad, India, Agrawal (1994) describes systems in rural communities where *'villagers who designed rules have attempted to match regeneration levels and withdraws by assessing fodder growth during the year, fixing extraction levels below the annual regeneration, and metering fodder extraction using simple measures'*. An institution - called panchayat - delegates officials to assess that fodder extraction remain below the threshold determined ex-ante. Fines can eventually be levied on deviating extractors (Agrawal, 1994, p 272).

It should well be noticed that the existence of one rule type does not necessarily involves the existence of the other. To use Baland and Platteau (1996, p 210) formulation *'rules solving assignment problems do not, by themselves, help to conserve resources: as a matter of fact, management of a resource implies restraint in its use and there is nothing in sharing rules to ensure that resource users control the extent of pressure on the natural environment or the mode of exploiting it.'* An example is provided by Agrawal (1994). In his study, he found also villages *'where panchayats have not design rules to match withdrawn [with] regeneration'*. In two forest villages from the six analyzed, grass is sold through auctions. It means that the successful bidder has little incentives to hold extracted quantities down. For example, the winner of the auction can cut the grass so close to the ground that he damages the roots and harms next year harvest (Agrawal, 1994, p 272). In this case, even if appropriation rules are designed, little concern is set on provision rules.

The opposite case is also depicted in the literature even if it comes out less often. Baland and Platteau (1996) admit that if it is not possible to control

access to resources, it should even be harder to monitor their use. Nevertheless, they get across cases where conservation rules exist despite flexible access rules. Resources users' behaviour is then driven by a moral code whose internalization determines the propensity to follow it. So users can adopt a conservative behaviour even if violation of the rules remains undetected and, without considering the psychological cost of remorse, yields a higher individual pay-off in term of extracted quantities.

To sum up, the social structure of some communities allows them to overcome the tragedy of the commons as defined by Hardin (1968). Nevertheless, some institutions induce their members to manage their natural resource on a sustainable way, and some fail to do it. In extreme cases, it can even lead societies to collapse.

2.2 Theoretical background

This model is closely related to the work of Sethi and Somanathan (1996) and Dayton-Johnson and Bardhan (2002), which are themselves in line with the analysis of common pool resource static inefficiency found in Hardin (1968), Dasgupta and Heal (1979) and Chichilnisky (1994). All model use Tullock (1980)'s contest success function and somehow discuss the role of sanction mechanisms to determine if the efficient outcome is reached or not. Sethi and Somanathan (1996) tilt their analysis in the direction of evolutionary game theory. They investigate the share of cooperative behaviour versus self-interested behaviour remaining in the population over time. Their results assume that pure decentralized sanctions can be imposed by players who cooperate and that any player who decides to impose a sanction at the end of the game simultaneously bears the cost. They keep the same kind of assumptions in further research where they investigate a system of sanctions in which part of the agents have a preference for reciprocity (Sethi and Somanathan, 2006).

The literature on dynamic inefficiencies found in common pool resources is still under construction. We have already cited the work of Sethi and Somanathan (1996) where the focus also lies on resource stock dynamics. Relying on the work of Gordon (1954) on the economic theory of fisheries, Levhari and Mirman (1980) build a model to understand the dynamics of a fish population. The fish stock is affected by the aggregate fishing effort which results of strategic interactions between fishers. They separate the static from the dynamic inefficiency but do not allow fishers to endogenously design a mechanism to switch the equilibrium. Hence, the same Cournot-Nash equilibrium repeats over time and is only affected by the remaining fish stock.

3 Basic model

In this section we will first present a very crude model where effort are unproductive. This model allows a smoother presentation. It will then be extended to a more realistic case where efforts are also productive. Results are qualitatively similar. Since most of the literature is framed around fishing problems, we will stick to this leading example for the convenience of exposure.

3.1 Set-up of the model

We model our common pool resource problem in line with previous work done by Dasgupta and Heal (1979), Chichilnisky (1994), Sethi and Somanathan (1996) and Dayton-Johnson and Bardhan (2002). This model can be applied to any exhaustible and renewable resource. For the clarity of exposure and without loss of generality, we frame it as a wood collection problem. Two identical and perfectly informed woodcutters i and j , can log trees in a forest, $F_0 > 0$, pre-existing in strictly positive quantities at the beginning of the game. The game lasts two periods. After each period the remaining forest resources grow at a constant rate g and, for the simplicity of notation, we define $G = 1 + g$. So in the second period the value of the forest is a function of g and of the first period cuts $F_1 = G * (F_0 - X_1)$. Aggregate extraction X_t is a standard Cobb-Douglas function of aggregate logging effort, $E_t = (e_{it} + e_{jt})$, of the forest stock and of a productivity parameter $0 \leq \alpha < 1$.¹

$$X_t = f(e_{it} + e_{jt}, F_{t-1}) = f(E_t, F_{t-1}) = (E_t)^\alpha * F_{t-1} \quad (1)$$

The utility function of player i is given by the expression.

$$U_i(x_{it}((e_{it}, e_{jt}, X_{it}))) = \sum_{t=1}^2 (x_{it} - c * e_{it}) \quad (2)$$

The decision variable is i 's effort and wood is considered as the numeraire. In the remaining part of this section, let us first discuss a specific case where $\alpha = 0$. It means that effort is unproductive but has a role in the appropriation process. In a second instance we will relax this assumption to combine violent appropriation and productive effort.

3.2 Unproductive effort but violent appropriation, $\alpha = 0$

When α is equal to zero, the extraction function becomes a step function with $f(E = 0, X) = 0$ and $f(E > 0, X) = X$. If no effort is provided by any of the

¹We rule out the case of $\alpha \geq 1$ since concavity is required to depict situations of resource scarcity.

loggers, the wood stock remains untapped. For any strictly positive level of effort of at least one agent the resource is fully depleted. This is a strong assumption since even a infinitesimally small amount of effort could prove sufficient to observe full depletion. However it can approximate some real life situations², we consider this specification has a limit case. We solve the game by backward induction.

3.2.1 Second period Subgame Nash Perfect Equilibrium

There exist two second period subgames. The first one is trivial. Some effort was made in the first period clearing the forest. Whatever the second period strategies, $X_2 = 0$ and there is no reason to provide any strictly positive amount of costly effort. Both players choose $e_{i2} = e_{j2} = 0$.

Lemma 1. *If $e_{i1} = e_{j1} = 0$, the only second period Nash Subgame Equilibrium is characterized by $\hat{e}_{i2} = \hat{e}_{j2} = \frac{GF_0}{4c}$ and payoffs equal to $u_{i2} = u_{j2} = \frac{GF_0}{4}$.*

Proof. If no effort is provided in $t = 1$, the wood stock grows and $F_1 = GF_0$. Each woodcutter will maximize his second period utility. For player i we have:

$$\max_{e_{i2}} u_{i2} = \max_{e_{i2}} \frac{e_{j2}}{e_{i2} + e_{j2}} GF_0 - ce_{i2} \quad (3)$$

This yield a first order condition

$$\frac{\partial u_{i2}}{\partial e_{i2}} = 0 \Leftrightarrow \frac{e_{i2}}{(e_{i2} + e_{j2})^2} GF_0 - c = 0 \quad (4)$$

Since players are identical, the problem of logger j yields a symmetric first order condition and the equilibrium level of effort is

$$\frac{e_2}{(2e_2)^2} GF_0 - c = 0 \implies e_2 = \frac{GF_0}{4c} \quad (5)$$

Let's call this equilibrium effort level \hat{e} . When \hat{e} is chosen, each player's payoff is given by the expression

$$u_{i2} = \frac{\hat{e}_{i2}}{2\hat{e}_2} GF_0 - c\hat{e}_{i2} = \frac{GF_0}{2} - \frac{GF_0}{4} = \frac{GF_0}{4} \quad (6)$$

□

²In the case of a forest it can be seen as a tree in a nearby forest that may be chopped in a single stroke. It can also depict the harvest of some forest products such as mushrooms or medicinal plants. Once their location is known, their collection requires little specific effort because this activity is potentially embodied in others such as firewood collection or tending livestock.

Lemma 2. *If $g \geq 0$ and $F_0 > 0$ then $\frac{GF_0}{2} < GF_0 - 2c\varepsilon$, i.e. the aggregate payoff under competitive extraction is strictly smaller than the aggregate payoff that a benevolent planner would achieve.*

Proof. From lemma 1 it is easy to compute the aggregate payoff under competitive extraction and it is equal to $\frac{GF_0}{2}$. This situation is not a Pareto optimum since if both woodcutters decrease their effort by an arbitrary small quantity of effort ε , as much forest product as before will be harvested at a smaller cost. Actually the social optimum of this Subgame is characterized by a corner solution where the strategy choice is $e_{i2} + e_{j2} = 2\varepsilon$. In this case, the forest is fully depleted. Since woodcutters are symmetric, total harvest and effort can be equally divided and each player will get an individual payoff equal to

$$u_{i2} = u_{j2} = \frac{\varepsilon}{\varepsilon_{i2} + \varepsilon_{j2}} GF_0 - c\varepsilon_{i2} = \frac{GF_0}{2} - c\varepsilon_{i2}$$

The aggregate payoff is then given by the expression $GF_0 - 2c\varepsilon$. Under initial conditions, this is strictly larger than $\frac{GF_0}{2}$ \square

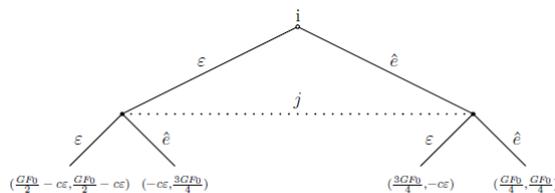


Figure 1: Second Period Extensive Subgame

The extensive game form of this subgame is depicted in figure 1. At the Subgame Perfect Nash Equilibrium, in aggregate, half of the harvested wood stock will compensate for the cost of effort. It is not a Pareto optimum. We define this inefficient allocation of effort as a *static inefficiency*. It is typically the issue that most of the literature about the commons is discussing.

3.2.2 Solving the basic model

By backward induction, the first period game shrinks to a choice between no effort in $t = 1$ and violent appropriation of the forest stock in $t = 2$ or violent appropriation in the first period.

Lemma 3. *If the growth rate of the resource is large enough, the resource will be conserved from period one to period two.*

Proof. Let's assume that logger j is willing to play $e_{j1} = 0$. Woodcutter i can then play $e_{i1} = \varepsilon$ and appropriate the whole initial forest stock at almost no cost. He will do so if and only if

$$u_i(\varepsilon_{i1}, 0, \hat{e}_{i2}, \hat{e}_{j2}) = F_0 - c\varepsilon > u_i(0, 0, \hat{e}_{i2}, \hat{e}_{j2}) = \frac{GF_0}{4}$$

For lumberjack j , the situation is such that

$$u_j(\varepsilon_{i1}, 0, \hat{e}_{i2}, \hat{e}_{j2}) = 0 < u_j(0, 0, \hat{e}_{i2}, \hat{e}_{j2}) = \frac{GF_0}{4}$$

It is obvious that $e_{i1} = 0$ is not a credible strategy for woodcutter i if $G < 4$. By symmetry, no fisher can credibly commit to play $e_1 = 0$ if $G < 4$. If $G \geq 4$ loggers will refrain from cutting trees in the first period. \square

Lemma 4. *If one woodcutter has incentives to extract in the first period, then both woodcutters have incentives to do so. They will jointly deplete the initial forest stock and get a payoff equal to $u_i = u_j = \frac{F_0}{4}$.*

Proof. The first part of the proof follows from the proof of lemma 1. If woodcutters have incentive to extract in the first period, each of them will maximize his first period utility:

$$\max_{e_{i1}} u_{i1} = \max_{e_{i1}} \frac{e_{i1}}{e_{i1} + e_{j1}} F_0 - ce_{i1} \quad (7)$$

This problem is similar to the problem addressed in lemma 4. The optimal level of effort is given by the expression $e_{i1} = e_{j1} = \frac{F_0}{4c}$. Let's define this level of effort as \tilde{e} . At this equilibrium, individual payoff are equal to $u_{i1} = u_{j1} = \frac{F_0}{4}$. \square

There also exists a *static inefficiency* in the first period. A benevolent - and myopic - planner could exhaust the resource in the first period at almost no cost. From the resource point of view, the result would be equivalent but the aggregate payoff would be almost double as large as under competitive extraction.

The extensive game form of the whole game is drawn in figure 2. There exists two potential equilibria.

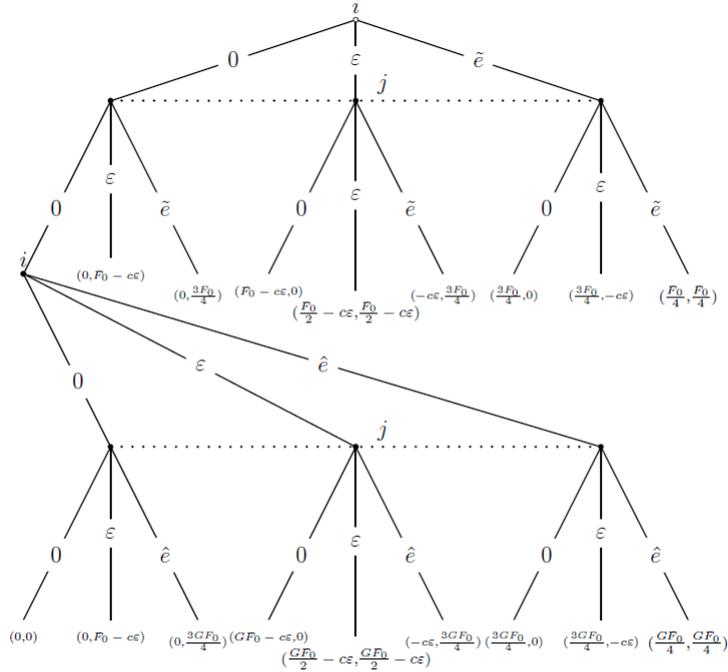


Figure 2: Extensive Game

Proposition 1. *If the growth rate of a renewable resource is large enough, this resource is going to be conserved from period one to period two. Despite the absence of dynamic inefficiencies, static inefficiencies remain. If the growth rate is not large enough, the Perfect Nash Game Equilibrium results in both static and dynamic inefficiencies.*

Proof. From lemma 3 and 1, we know that if $G > 4$, the equilibrium strategy will be $[(0, 0); (\hat{\epsilon}, \hat{\epsilon})]$. If $G < 4$, the equilibrium strategy is $[(\tilde{\epsilon}, \tilde{\epsilon}); (0, 0)]$, i.e. exhaustion of the resource at the beginning of the game. If $G = 4$, there exist two pure strategy equilibria $[(0, 0); (\hat{\epsilon}, \hat{\epsilon})]$, $[(\tilde{\epsilon}, \tilde{\epsilon}); (0, 0)]$ and a mixed strategies Nash equilibrium which gives equal probabilities to both pure strategy equilibria. It should be notice that as long as $G \geq 1$ woodcutters would be better off if they could commit to conserve the resource in the first period since $\frac{GF_0}{2} \geq \frac{F_0}{2}$. We define this loss as a *dynamic inefficiency*. \square

Dynamic inefficiencies are defined as the loss in aggregate payoff that arises when loggers are unable to reach the second period Nash Subgame Equilibrium. This loss is a piecewise function of the growth rate. For positive and small growth rate this loss is increasing. If the growth rate is large enough, *dynamic inefficiencies* vanish.

Corollary 1. *The socially efficient outcome of the game is never reached.*

Proof. As soon as $G \geq 1$, the highest achievable aggregate payoff is $GF_0 - 2c\varepsilon$. The socially optimal strategy is to conserve the resource in the first period before clearing the whole forest with an arbitrary small amount of effort ε in the second period. From lemma 4 and 1 and proposition 1 we know that this is never a Nash equilibrium of the game. \square

In the basic game, loggers are unable to peacefully share the wood stock. They are doomed to waste effort to appropriate part of the resource within a period. It is defined as a *static inefficiency*. Moreover, if the growth rate of the trees is too low, each woodcutter fears that, by refraining from felling trees in one period, the other logger will harvest the whole forest resource for oneself. It results into a *dynamic inefficiency*.

3.3 Productive effort and violent appropriation, $0 < \alpha < 1$

Subsection to be developed. Results depends crucially on the concavity of the extraction function. For α close to 0, results are qualitatively close to the one of the previous subsection. For α close to 1, the problem of the common is less acute.

4 Social sanctions

In a broad literature about the commons, the role of communities in natural resource management and conservation is emphasized. Two main stylized facts are often pinpointed. First, communities are able to design rules, monitor individual actions and impose sanctions to members who deviate from prescribed behaviour (see Baland and Platteau (1996) for more references). Second, as Ostrom (1990) argues, it would be easier for communities to implement *sharing rules* (called *appropriation rules in Ostrom (1990)*) than *conservation rules* (*provision rules in Ostrom (1990)*).

4.1 Sanctions: definition and achievable equilibria

Let us first define σ , an exogenous level of effective sanctions that a community is able to impose on its members and three specific thresholds:

- σ_{s1} : the minimal level of sanctions required to avoid period 1 static inefficiencies.
- σ_{s2} : the minimal level of sanctions required to avoid period 2 static inefficiencies.
- σ_c : the minimal level of sanctions required to avoid dynamic inefficiencies.

Lemma 5. $\sigma_{s1} = \frac{1}{2}F_0$

Proof. The proof of lemma 5 follows directly from lemma 4 and 2. □

Lemma 6. $\sigma_{s2} = \frac{1}{2}GF_0$

Proof. The proof of lemma 6 is similar to the one of lemma 5. □

Lemma 7. $\sigma_c = (1 - \frac{1}{4}G)F_0$

Proof. Lemma 1 proves that each woodcutter will get a payoff equal to $\frac{GF_0}{4}$ if the resource is conserved in the first period. The benefit of choosing $e = \varepsilon$ instead of $e = 0$ for one logger when the other plays $e = 0$ is equal to $F_0 - \varepsilon$. The minimal level of sanctions required to avoid a dynamic inefficiency is then equal to $F_0 - \frac{GF_0}{4}$ which can be rewritten as $(1 - \frac{G}{4})F_0$. □

Proposition 2. 1. *If $\sigma \geq \sigma_{s2}$, then the equilibrium strategy $[(0, 0); (\varepsilon, \varepsilon)]$ is implementable and the first best equilibrium can be reached.*

2. *If $1 \leq G < 2$, it is easier for a community to implement a sharing rule than to conserve the resource.*

3. *If $2 \leq G < 4$, it is easier for a community to implement a conservation rule than to share the resource in the first period.*

4. *If $4 \leq G$, σ will only reduce second period static inefficiencies.*

Proof. To prove the first item, let's assume that the rule set up by the community is $e_1 = 0$ and $e_2 = \varepsilon$. If any woodcutter deviates from the rule, he must bear a sanction equal to $\sigma \geq \sigma_2$. If one of them choose $e_1 \neq 0$ in the first period, he will extract F_0 at cost $c\varepsilon$ with an associated maximal net benefit equal to $F_0 - \frac{GF_0}{2} - \sigma < 0$. Cutting trees in the first period cannot be an equilibrium strategy. It is trivial to show that there is no equilibrium with $e_2 \neq \varepsilon$. This conclusion does not depend on G

The second and third items are direct consequences of lemma 5, 6 and 7.

The fourth item arises from proposition 1. □

4.2 Comparative statics

Considering a given level of effective sanctions σ in a group of players, we can compare the highest achievable equilibrium payoff for different initial values of the resource stock F and different growth rates with $1 + g = G$. From lemma 6 it is obvious that sharing in the second period will be the equilibrium if $1 \geq G < \frac{2\sigma}{F}$. This is the green area in figure 4.2. It is sufficient that 3 necessary conditions are

fulfilled to reach an equilibrium of conservation without sharing. First, by lemma 6, $G \geq \frac{2\sigma}{F}$. Second, by proposition 2, $G \leq 2$. Third, by lemma 7, $G \geq 4 - \frac{4\sigma}{F}$. This area is depicted in white in figure 4.2. Notice that if $G \geq 4$, σ does not play any role in resource conservation. By combining lemma 5 and 7, we can map all combinations of G and F for which players will extract non-cooperatively in the first period. The orange area is defined such that $F \geq 2\sigma$ and $G < 4 - \frac{4\sigma}{F}$. It means that the first period sharing occurs if and only if $\frac{2\sigma}{F} < G < 2$ and $F < 2\sigma$ or $G < 1$ and $F < 2\sigma$. This is the blue area in figure 4.2.

Once we know which equilibrium is achievable for each combinations of G and F , it is natural to derive welfare implications of the different equilibrium. This can be done by comparing players' utility between different combinations of G and F . Notice first that, from a benevolent planner point of view, it is always better to face a higher G and a larger F . This is also true in the absence of sanctions. In the presence of sanctions, small increases of G or F can lead to a switch to another, less desirable, equilibrium. For instance, take any point above $G = 1$ on the curve $G = \frac{2\sigma}{F}$ where the utility of both players $u_i = \sigma$. Then, for any strict increase of G or F , the utility of each player will strictly decrease. If G ends up above 2, second period sharing is no more an equilibrium and players will extract non-cooperatively in the second period, with a payoff close to 0.5σ . Actually, players' utility will remain lower than σ as long as $2 < G \leq \frac{4\sigma}{F}$. When $1 < G \leq 2$, any increase of G and all increase of F so that $F < 2\sigma$, will lead to switch from a second period sharing equilibrium to a first period sharing equilibrium. This first period sharing equilibrium is able to yield utility level equal to σ for both players if and only of $F = 2\sigma$. For values of $G < 2$, if F becomes larger than 2σ , first period non-cooperative extraction is the equilibrium. It is only when $F > 4\sigma$ that $u_i > \sigma$, a payoff achievable with much lower resource initial value in a first or second period sharing equilibrium.

The same kind of argument can be repeated at the hedge of the second period non-cooperative extraction equilibrium. This hedge yields utility level $u_i = \frac{G\sigma}{4-F}$ to both players. If F increases, there is a switch of equilibrium to first period non-cooperative extraction. A utility level $u_i \leq \frac{G\sigma}{4-F}$ is achievable only if $F \leq \frac{4G\sigma}{4-F}$. Figure 4.2 maps in grey all combinations of G and F which yield, for both players, a utility level achievable with at least one other combinations of G' and F' with $G' < G$ or $F' < F$ or both.

4.3 Discussion

This basic model allows understanding how rules can help a community to overcome the tragedy of the commons in a dynamic setting. For very large resource growth rate, the only relevant issue is the ability of the community to solve future static inefficiencies, i.e. to prevent non-cooperative extraction in the second period.

Figure 1: Equilibrium strategy for a given σ in function of G and F

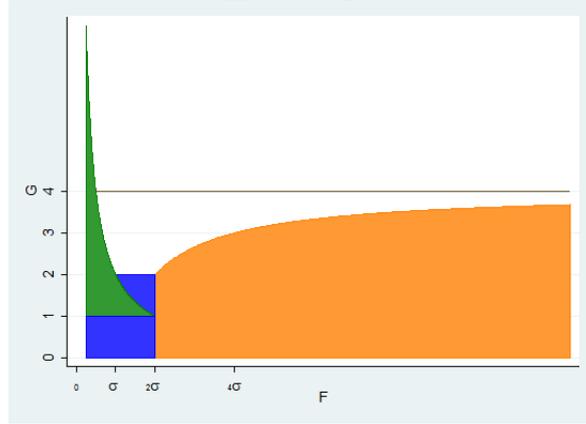
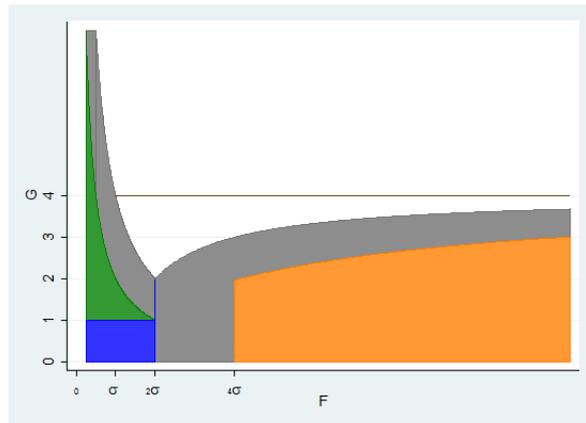


Figure 2: Welfare comparison of equilibrium strategies for a given σ in function of G and F



For intermediate growth rate, we show that it is easier to implement a conservation rule than to immediately share the resource. Dynamic inefficiencies are fully overcome even though static inefficiencies partly remain. For small growth rate, communities with a relatively low ability to implement sanctions can rationally craft rules which lead to a first period sharing equilibrium even if the community is well aware that second period sharing is the social optimum.

The comparative static exercise has broad practical implications. In our model we always consider that the value of the resource and its growth rate are exogenously determined. Very often in practice players can however have some influence on the initial investment. For instance, anecdotal evidence collected in Udaipur district, Rajasthan, India show that some forest users group refrain from planting teak despite its very high value and relatively large growth rate. They prefer to plant species like mango or bamboo trees. The main reason raised by group leaders to justify this investment decision lies in leaders' anticipation that the community of users will not be able to prevent its members from felling teak down before it gets mature, precisely because this species value is too large. At the opposite, bamboo trees grow even faster and have a lower initial value. Rules and associated effective sanctions prevailing in the group are sufficient to deter early logging. It is even more salient for mango trees since the timber in itself is not worth a lot. It is then relatively easy to implement sharing rules of mango fruits.

On top of these positive implications, the model also provide some normative insights. We show that larger G of F can lead to change of equilibrium strategies and to a drop of players' utility. It implies that external intervention affecting the growth rate of the resource can have adverse consequences on receivers. Improved management techniques of natural resources can actually make people worse off and threatened resource conservation. Climate change can also have non-trivial effect on resource conservation by modifying resource growth rate and investment possibilities. Apparently blessed communities might end up doing worse while disadvantaged group will be able to mobilize their pre-existing social fabric to implement better outcomes.

The comparative static on F should also be considered while improving communities access to markets, or more generally when resource value boom consequences have to be forecast. It is not a surprise that a resource initial value rise makes conservation more difficult. Our model adds that if first period sharing is achievable considering a given level of sanctions σ , this equilibrium can never do better than an achievable second period sharing equilibrium. Moreover, the rise of F has to be quite large to leave players better off in a first period non-cooperative extraction than in another achievable equilibrium with lower F .

5 The role of inequalities

In the basic model, agents are assumed to be symmetric. Suppose that instead of having the same effectiveness of effort in the repartition of the resource, fighting ability varies across players.

5.1 Second period Subgames

Like in the basic model with symmetric agents, there exists two second period subgame. We will not discuss the trivial one when the resource is exhausted in the first period. In the other subgame, the wood stock has grown and woodcutters chose their optimal effort such that they maximize their utility:

$$\max_{e_{i2}} u_{i2} = \max_{e_{i2}} \frac{\varphi e_{i2}}{\varphi e_{i2} + e_{j2}} GF_0 - ce_{i2} \quad (8)$$

$$\max_{e_{j2}} u_{j2} = \max_{e_{j2}} \frac{e_{j2}}{\varphi e_{i2} + e_{j2}} GF_0 - ce_{j2} \quad (9)$$

With $0 \leq \varphi$, the appropriation ability of woodcutter i relatively to lumberjack j . The first order condition of loggers i and j are respectively given by the expressions:

$$\frac{\partial u_{i2}}{\partial e_{i2}} = 0 \Leftrightarrow \frac{\varphi e_{j2}}{(\varphi e_{i2} + e_{j2})^2} GF_0 - c = 0 \quad (10)$$

$$\frac{\partial u_{j2}}{\partial e_{j2}} = 0 \Leftrightarrow \frac{\varphi e_{i2}}{(\varphi e_{i2} + e_{j2})^2} GF_0 - c = 0 \quad (11)$$

Solving this system for e_{i2} and e_{j2} yields the same level of effort for both loggers,

$$e_{i2} = e_{j2} = e_2 = \frac{\varphi GF_0}{(1 + \varphi)^2 c} \quad (12)$$

From equation 12 we can compute the respective payoffs of loggers i and j .

$$u_{i2} = \frac{(\varphi GF_0)^2}{(\varphi^2 + \varphi) GF_0} - \frac{\varphi GF_0 c}{(1 + \varphi)^2 c} = \frac{\varphi^2}{(1 + \varphi)^2} GF_0 \quad (13)$$

$$u_{j2} = \frac{\varphi (GF_0)^2}{(\varphi^2 + \varphi) GF_0} - \frac{\varphi GF_0 c}{(1 + \varphi)^2 c} = \frac{1}{(1 + \varphi)^2} GF_0 \quad (14)$$

The non-trivial Second Period Subgame Nash Equilibrium is such that woodcutter i 's payoff is strictly increasing in φ , is equal to zero when $\varphi = 0$ and tends to GF_0 when φ tends to infinity. Similarly to the basic game with symmetric players the social optimum would be to extract the whole resource in the second period with

an arbitrarily small amount of effort ε . If both players choose $e_{i2} = e_{j2} = \varepsilon$, their payoffs are equal to

$$u_i = \frac{\varphi}{1 + \varphi} GF_0 - c\varepsilon \quad (15)$$

$$u_j = \frac{1}{1 + \varphi} GF_0 - c\varepsilon \quad (16)$$

5.2 Game Nash Equilibrium with inequalities

The relevant part of the extensive game form with inequalities is represented in figure 3. The discussion of strategies and payoffs in the first period reduced game is very much similar to the non-trivial second period subgame with inequalities and is therefore omitted. All payoffs that are out of any equilibrium or social optimum have been dropped for reading ease.

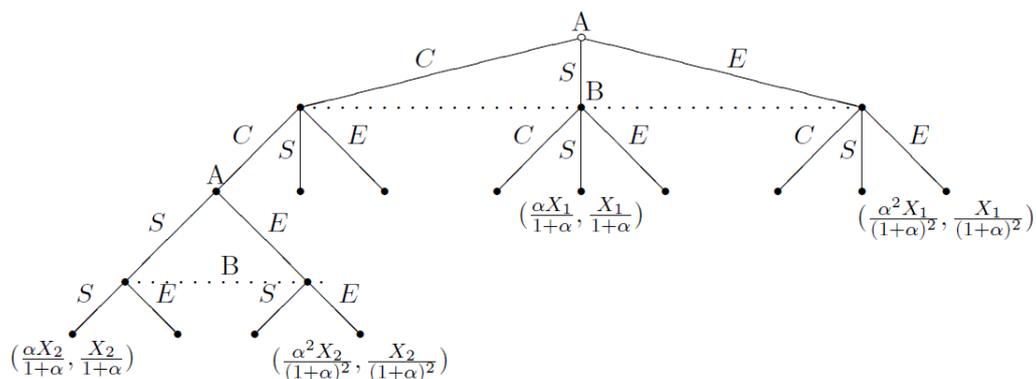


Figure 4: Extensive game form with two periods and heterogeneous players

5.3 extend of inefficiencies with heterogeneous players

Proposition 3. *Compared to the social optimum, the highest static inefficiencies arise when players are symmetric. Larger inequalities strictly reduce the value of wasted effort. At the limit, when one agent is infinitely more productive than the other, the static inefficiencies disappear and the resource is extracted without excessive effort*

Proof. The extend of static inefficiencies can be computed by subtracting the aggregate payoff under competitive extraction from the payoff under the social opti-

mum.

$$F_0 - 2c\varepsilon - \frac{\varphi^2 + 1}{(1 + \varphi)^2} F_0$$

For $\varphi = 0$ or when φ tends to infinity, this expression tends to 0. The maximum of this function is reached at $\varphi = 1$. \square

Static inefficiencies vanishes when a player is infinitely more productive than the other. It is maximal when they are symmetric.

Proposition 4. *For a fixed level of inequalities, as long as the natural resource growth rate is not large enough, any increase of the growth rate lead to larger dynamic inefficiencies. As soon as the growth rate is large enough, dynamic inefficiencies vanish. Homogeneity of players is the least demanding situation to avoid dynamic problem.*

Proof. The dynamic inefficiency is the aggregate welfare loss due to the inability of loggers to reach the second period subgame Nash equilibrium, despite the fact that it would yield a higher payoff. The aggregate welfare loss due to dynamic inefficiency is then given by the expression

$$\frac{(1 + \varphi^2)GF_0}{(1 + \varphi)^2} - \frac{1 + \varphi^2 F_0}{(1 + \varphi)^2} = \frac{1 + \varphi^2 g F_0}{(1 + \varphi)^2} \quad (17)$$

The natural resource growth rate has a positive impact on dynamic inefficiencies. Nevertheless, as shown in the homogeneous case, any increase of G diminishes incentives to extract in the first period. Woodcutter i does not increase his payoff by deviating from a conservationist strategy in the first period when

$$F_0 - \frac{\varphi^2 GF_0}{(1 + \varphi)^2} \leq 0$$

that is when

$$G \geq \frac{(1 + \varphi)^2}{\varphi^2} \quad (18)$$

For lumberjack j the same condition can be derived

$$F_0 - \frac{GF_0}{(1 + \varphi)^2} \leq 0$$

that is when

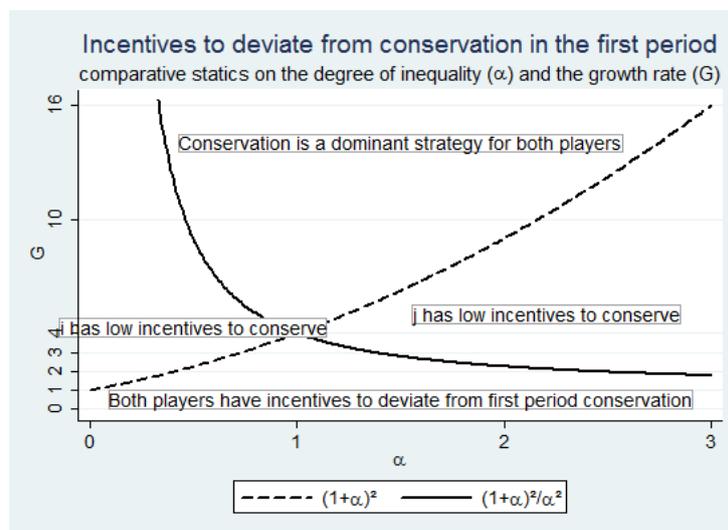
$$G \geq (1 + \varphi)^2 \quad (19)$$

For positive values of φ , any strictly positive increase of φ strictly reduces the incentive of i to deviate and strictly widens the propensity of j to extract the

resource in the first period. If both condition 18 and 19 are fulfilled, no player has an incentive to deviate from a first period conservationist strategy. The lowest growth rate for which both inequalities are met is reached in the homogeneous case where $\varphi = 1$. \square

Proposition 5. *Inequalities diminish static inefficiencies in common pool resources problems. Nonetheless these inequalities have a detrimental effect on dynamic inefficiencies.*

Proof. The proof of this proposition follows directly from the two previous propositions. \square



When discussing the role of inequalities on common property management, different kind of inefficiencies has to be considered. From a static point of view, inequalities may seem beneficial. We show that they may have a huge cost from a dynamic point of view. It may be argued that this result is a consequence of the relative power of the strengthless lumberjack. Indeed, even if loggers have unequal appropriation abilities, the small lumberjack has still the power to clear the whole wood stock if he is left alone on the forest. First, we think that in many real cases it is not a absurd assumption. Secondly, we will relax this assumption in a forthcoming section.

6 Conclusion

This article investigates the determinants of successful management of renewable common-pooled natural resources. We construct a two players, two period non-cooperative game with a growing resource to emphasize the difference between

appropriation and preservation issues. Appropriation issues address static inefficiency by sharing the resource within a time period. Preservation issues tackle the problem of natural resource conservation and thereby dynamic inefficiencies. As broadly investigated in the literature on rent-seeking, competing players exert excessive effort and generate social waste. We also show that competition lead to dynamic inefficiencies, provided that the resource growth rate is not large enough. Players extract too early and prevent themselves to reach a higher second period payoff.

Nevertheless, it appears from field studies that communities are not doomed to mismanage their resources and to fall in the well documented *tragedy of the common*. Some craft rules, monitor and sanction users. We show that contrarily to the eco-socio-anthropological literature it is not necessarily easier for a community to have credible appropriation rules than to set up preservation rules. For intermediate growth rate, preservation can be much more easily implemented than sharing of the resource. Our framework may explain why, in certain circumstances, users may protect a resource till a certain point and then fight to appropriate it.

We also point out that inequalities decrease static inefficiencies but tend to increase dynamic ones. It means that granting property rights to certain users and excluding others may appear as a good short term policy even though it would have highly detrimental effect in the long run.

References

- Agrawal, A. (1994). Rules, rule making and rule breaking: Examining the fit between rule systems and resource use. In Ostrom, E., Gardner, R., and Walker, J., editors, *Rules, games and common-pool resources*, pages 267–282. University of Michigan Press, Ann Arbor, Michigan.
- Arnold, J. and Campbell, C. (1986). Collective management of hill forest in Nepal: The community forestry development project. In Council, N. R., editor, *Proceedings of the conference on common property resource management*, pages 425–454, Washington, DC. National Academy Press.
- Baland, J.-M. and Platteau, J.-P. (1996). *Halting degradation of natural resources - Is there a role for rural communities*. Oxford: Oxford University Press.
- Brander, J. A. and Taylor, M. S. (1998). The simple economics of Easter Island: A Ricardo-Malthus model of renewable resource use. *American Economic Review*, 88(1):119–38.
- Chichilnisky, G. (1994). North-South trade and the global environment. *American Economic Review*, 84(4):851–74.

- Dasgupta, P. and Heal, G. (1979). *Economic theory and exhaustible resources*. Cambridge: Cambridge University Press.
- Dayton-Johnson, J. and Bardhan, P. (2002). Inequality and conservation on the local commons: A theoretical exercise. *Economic Journal*, 112(481):577–602.
- Diamond, J. (2005). *Collapse: How societies choose to fail or succeed*. Viking Press.
- Gordon, H. S. (1954). The economic theory of a common property resource: The fishery. *Journal of Political Economy*, 62:124–142.
- Hardin, G. (1968). The tragedy of the commons. *Science*, 162:1243–1248.
- Levhari, D. and Mirman, L. J. (1980). The great fish war: An example using a dynamic Cournot-Nash solution. *Bell Journal of Economics*, 11(1):322–334.
- Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge: Cambridge University Press.
- Sethi, R. and Somanathan, E. (1996). The evolution of social norms in common property resource use. *American Economic Review*, 86(4):766–88.
- Sethi, R. and Somanathan, E. (2006). A simple model of collective action. *Economic Development and Cultural Change*, 54(3):725–47.
- Tullock, G. (1980). Efficient rent seeking. In Buchanan, J., Tullock, G., and Tollison, R., editors, *Toward a theory of the rent-seeking society*, pages 97–112. Texas and M University Press.

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