Success and Failure of Communities Managing Natural Resources: Static and Dynamic Inefficiencies

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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 N-players, two-period non-cooperative game where a community can impose some exogenous amount of sanctions. We first show that rules preventing dynamic inefficiencies may exist even though static inefficiencies still remain. Second, an increase in the initial value of the resource may lower the utility of all users. The model develop a nuanced view on Ostrom conjecture stating that conservation is harder to implement than sharing.

Keywords: Common-pool resource ; Renewable resource ; Conservation ; Sanctions ; Institutions ;

JEL codes: Q2, O13 , D02 , D23, P48

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> What makes the problem [of free-riding] more difficult in a CPR situation than in a public-goods situation is that unless appropriation problems are resolved, the provision problems may prove intractable.
>
> Elinor Ostrom, 1990, *Governing the Commons*

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. Combined with a growing awareness of environmental issues, this vision frequently supports plans to hand over natural resource management to local communities. Nonetheless, this romantic view should be taken up with caution. Although long-enduring societies have most probably found ways to match their living standards to the available resources, they are not *per se* efficient resource managers. For instance, Diamond (2005) argues that full deforestation of Easter Island has lead to a collapse of a civilization. This example is clearly far away from sustainable development.

When population density is increasing, and natural resources are becoming scarcer relatively to the size of the population, common-pool resources (CPR) use has to be, in some way, restricted (Hardin, 1968). There is now a large consensus over the potential ability of communities to overcome the tragedy of the commons (Ostrom, 1990). In general successful communities somehow craft rules of resource use and preservation, implement them and sanction non-compliers. On the other hand, failure of management is often imputed to a lack of information on the state and the dynamic of the resource by the communities at stake[1]. We want to focus on the former and abstract from the latter. Indeed, information on resource flows becomes more and more widespread without necessarily ensuring resource preservation[2]

This paper builds a N-players and two-period model of a renewable and exhaustible resource extraction to analyse the following conjecture: Ostrom (1990, p. 31) says that in a CPR it is easier to solve the within period distributional issue

[1]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)

[2]Readers interested by the exploitation of common-property resources under uncertainty can, for instance, refer to Antoniadou et al. (2013). Kapaun and Quaas (2013) extensively discuss the optimal fishing strategy with uncertainty on the growth rate through fish life cycle.

than the between period conservation problem[3]. Our model therefore incorporate both static and dynamic inefficiencies. Static inefficiencies refer to an excessive amount of effort exerted within a time period in the aim of appropriating a resource. Dynamic inefficiencies refer to an excessive amount of effort in one time period which prevent the resource to grow until the next period. The model is the first to our knowledge to explicitly incorporate dynamic and static inefficiencies in a regulated CPR context.

Based on this model, we first show that increases in the growth rate of the resource lower incentives to harvest the resource in the first period and facilitates resource conservation. For a large enough growth rate, conservation of the resource becomes the payoff dominant strategy. With moderate growth rate, conservation is not feasible in the absence of exogenous sanctions or reputation building mechanism. The extraction of the resource with the optimal amount of effort also requires such mechanisms. This is true in the model but also in framed field experiments (see e.g. the trout fishing experiment described by Noussair et al. (2015)).

We then introduce limited sanctions and show that conservation of the resource between the two periods can be achieved while the players still engage into wasteful competition in the last period, which clearly violates Ostrom's conjecture. The violation of the conjecture happens with a relatively small number of players, a large enough growth rate and a moderate extraction cost. This suggests that Ostrom conjecture especially applies to large communities with slow growing resources which are relatively costly to harvest. It may explain why Huang and Smith (2014) observed closing days on shrimp fisheries but no regulation preventing congestion in the fishing season, for example by limiting the number of fishing vessels.

Finally, the comparative statics exercise rationalizes the decision of leaders managing community forest user groups observed in Rajasthan, India. Indeed, they prefer to plant mango and bamboo trees over teak. Teak has a much higher value than the former species but is not planted on community land while often observed on private lands close to owners' dwellings. We show that, under limited sanctions, a resource with a higher initial value or a larger growth rate does not necessary improve players welfare and can even decrease their equilibrium payoffs.

The remaining part of the paper is organized in three sections. The second section gives empirical and theoretical foundations to the model of the third sections. The last section concludes.

[3]Ostrom is not the sole author raising this point. Baland and Platteau (1996, p. 232) frame it as a question: *[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?*

2 Related literature and empirical foundations

Since Gordon (1954) and Hardin's tragedy of the commons (1968), it is well-known in the literature that rational users of common pool resources (CPR) tend to over-exploit them. Their argument mostly remains static, without focusing much on resource conservation and future yields. The analysis of the Great Cod War in Levhari and Mirman (1980) introduces dynamic inefficiencies on top of the static over-fishing problem. Hence, the same Cournot-Nash equilibrium repeats over time and is only affected by the size of the fish stock. There is no discussion of institutional arrangement to escape the bad equilibrium. Brander and Taylor (1998) later use the classical Malthusian argument to explain CPR failure in Easter Island, mostly based on the low growth rate of palm trees on these islands compared to other Polynesian islands. Authors however acknowledge that institutional variations within Polynesia might also explain the collapse of Easter Island. One possible change is to convert unregulated common properties into private resources. This is however not necessarily beneficial for users (Baland and Bjorvatn, 2013) and sometimes imply violence (Sekeris, 2014).

Our focus the introduction of exogenous sanctions in an unregulated common property. We therefore analyse a regulated common property, as defined in Baland and Platteau (1996) and characterize conditions under which rules and associated sanctions are sufficient to modify users behaviour. A first layer of rules addresses *'appropriation problems'* by avoiding rent dissipation and reducing conflicts between appropriators (Ostrom, 1990). For instance, rotation systems are largely used to regulate access to scarce resources. (Arnold and Campbell, 1986, p 436) describes *"systems of spatial control"* of access to resources ensuring an equal access for all to both the nearby and the distant areas.

A second level of rules tackles *'provision problems'* and reduce the effect of today extraction on tomorrow harvest (Ostrom, 1990). Based on case studies in Uttarakhand, 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 type of rule does not necessarily involves the existence of the other (Baland and Platteau, 1996, p 210). In the same study in Uttarakhand, Agrawal (1994) found also villages *'where panchayats have not designed rules to match withdrawn [with] regeneration'*. In two forest villages from the six analysed, grass is sold through auctions. The successful bidder has little incentives to hold extracted quantities down. He 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, like in North Carolina where rules on net size, gear type and fishing seasons - partially - prevent to exhaust shrimp stocks but where the industry would be better off by reducing its total number of vessels on the water.

Different modelling options have been used to bring rules in CPR extraction games with static and dynamic inefficiencies. The setup of our model is close to the approach of Sethi and Somanathan (1996). They however tilt their analyses in the direction of evolutionary game theory to analyse the evolution of the proportion of cooperative and self-interested behaviour in a population. They further develop their argument by including reciprocity in a later paper (Sethi and Somanathan, 2006). We prefer to stick to self-interested harvesters and assume an exogenous leader. Our approach then follows the description of motivated leaders of forest users groups in Ethiopia who do not need to be incentivized to sanction non desirable behaviours (Kosfeld and Rustagi, 2015). However, while they empirically analyse the characteristics of leaders easing up successful management of an homogeneous resource, we collapse leaders ability in one parameter. By doing so, we focus on resource characteristics and analyse how they shape incentives of users, and therefore determine sanctions requirements.

3 The model

In this section we present the model and its comparative statics. The one-period set-up of the model is standard in the common-pool resource literature (Chung, 1996; Kotchen and Salant, 2011; Sethi and Somanathan, 1996). We extend it to a two-period model with external enforcement. The model can be applied to any exhaustible resource which total value changes over time. For the clarity of exposure and without loss of generality, we frame it as a timber harvest problem.

3.1 Model setup

N identical, risk-neutral and perfectly informed woodcutters can log trees in a forest of size F_t at time t. The initial forest stock is strictly positive, i.e. $F_1 > 0$. Within each time period, woodcutters simultaneously play. The game lasts two periods[4]. At the end of the first period, total harvested quantities H_1 are subtracted from the initial stock. The remaining stock $F_1 - H_1$ grows at rate g

[4]The second period can be interpreted as the second period present value of remaining periods.

and we define $G = 1 + g$ for ease of notation[5]. In general, the forest stock at the end of period t is $F_2 = G(F_1 - H_1)$.

Aggregate harvest is the sum of individual harvests $H_t = \sum_{i=1}^{N} h_{it}$. Individual harvest h of player i at time t is a piece-wise linear function of forest stock, own effort e_i and others' effort e_{-i}. Effort levels are bounded between 0 and $\bar{e}$, a large enough level of effort which defines a finite action space for each player. The individual harvest function is

$$h_{it} = \begin{cases} e_{it} & \text{if} \quad \sum_{j=1}^{N} e_{jt} < F_t \quad \text{(1a)} \\ \dfrac{e_{it}}{\sum_{j=1}^{N} e_{jt}} F_t & \text{otherwise} \quad \text{(1b)} \end{cases}$$

In the first piece of the harvest function (1a), woodcutter i harvests a quantity equal to his level of effort. The second piece of the harvest function (1b) corresponds to a resource exhaustion situation. If aggregate effort is sufficient to harvest the whole resource, the resource stock is fully depleted and divided among loggers with respect to their relative share of effort[6]. The utility U_i of woodcutter i is linear in both payoff and cost with $0 < c < 1$, the cost of effort[7].

$$U_i(e_{it}, h_{it}(e_{it}, e_{-it}, F_t)) = \sum_{t=1}^{2} (h_{it} - ce_{it}) \quad (2)$$

At any point in time and conditionally on harvesting the whole resource, the efficient level of aggregate effort is such that $\sum_{j=1}^{N} e_{jt} = F_t$. Woodcutters put just enough effort to deplete the forest. They generate an aggregate payoff equal to $(1-c)F_t$. If $G > 1$, the size of the forest grows over time and it is straightforward to show that the social optimum of the game is to efficiently deplete the forest in the last period. It is achieved with effort levels equal to $e_{j1} = 0$ and $\sum_{j=1}^{N} e_{j2} = GF_1$. It yields an aggregate payoff equal to $(1 - c)GF_1$.[8]

[5]We assume that the discount factor is equal to 0. Readers interested by this parameter can read the whole model assuming that $G = \frac{(1+g)}{(1+\delta)}$ with δ the discount factor.

[6]Notice that the first piece of the harvest function can be interpreted as the slope of a strictly monotonic increasing and concave harvest function at the exhaustion point.

[7]$c \geq 1$ is a trivial problem where resource extraction does not strictly increase players' utility.

[8]If $G \leq 1$, i.e. the value of the resource decreases over time, socially optimal extraction happens in the first period with effort level $\sum_{j=1}^{N} e_{j1} = F_1$ and $e_{j2} = 0$. It generates an aggregate payoff equal to $(1 - c)F_1$.

3.2 Nash equilibrium

In an open-access setting with simultaneous moves, each player maximizes one's utility, taking others' effort as given. The game is solved by backward induction. In period two, we know from (1a) that woodcutters harvest the forest since $c < 1$, and thus $\sum_{j=1}^{N} e_{j2} \geq F_2$. Considering the second piece of the harvest function (1b), there is one maximization problem for each player:

$$\max_{e_{i2}} \quad u_{i2} \quad = \quad \max_{e_{i2}} \quad \frac{e_{i2}}{\sum_{j=1}^{N} e_{j2}} F_2 - c e_{i2} \tag{3}$$

Each maximization problem yields one first order condition:

$$\frac{\partial u_{i2}}{\partial e_{i2}} = \frac{\sum_{j \neq i}^{N} e_{j2}}{(\sum_{j=1}^{N} e_{j2})^2} F_2 - c = 0 \tag{4}$$

By symmetry, it is easy to show that $e_{i2} = e_{j2}$ for $\forall i, j$ and for the sake of simplicity, we drop the individual index.

$$\frac{(N-1)e}{N^2 e^2} F_2 = c \quad \Rightarrow \quad e = \frac{(N-1)}{cN^2} F_2 \tag{5}$$

To remain with an interior solution on (1b), we need $Ne \leq F_2$ which is verified iff $c < \frac{N-1}{N}$, or equivalently iff $1 - c > \frac{1}{N}$. We further work with this additional restriction in the range of c. Given the second period subgame perfect Nash equilibrium, each player second period utility is given by the expression:

$$u_2 = \frac{1}{N} F_2 - \frac{N-1}{cN^2} F_2 \quad \Rightarrow \quad u_2 = \frac{1}{N^2} F_2 \tag{6}$$

It is suboptimal since $N u_2 = \frac{F_2}{N} < (1-c) F_2$ if $c < \frac{N-1}{N}$.

In period 1, the maximization problem shrinks to

$$\max_{e_{i1}} \quad U_i \quad = \max_{e_{i1}} \quad u_{i1} + u_{i2} \quad = \quad \max_{e_{i1}} \quad h_{i1} - c e_{i1} + \frac{1}{N^2} G(F_1 - \sum_{j=1}^{N} h_{j1}) \tag{7}$$

Combining (1a) and (7), first period extraction occurs if $G < N^2(1-c)$. It can thus occur although $G > 1$, which is not the socially efficient state. If so, $\sum_{i=1}^{N} e_{i1} \geq F_1$ and (1b) is the relevant piece of the extraction function, which corresponds to resource exhaustion. By a similar argument than in the second period subgame, the equilibrium level of effort in the first period is $e_1 = \frac{(N-1)F_1}{N^2 c}$. It means that the resource is fully exhausted in the first period and woodcutters achieve a payoff equal to $U_i = \frac{F_1}{N^2}$.

To summarize, if $G < N^2(1-c)$ then the game has one pure Subgame Perfect Nash Equilibrium with realized individual payoff equal to $\frac{F_1}{N^2}$ and associated strategy $e_1 = \frac{(N-1)F_1}{N^2 c}$ and $e_2 = 0$. It is a pure prisoners' dilemma. If $G \geq N^2(1-c)$ then the game has one more Subgame Perfect Nash Equilibrium with associated strategy $e_1 = 0$ and $e_2 = \frac{(N-1)GF_1}{N^2 c}$. For each player, it yields a payoff equal to $\frac{GF_1}{N^2}$, bearing in mind that $H_1 = 0$, so that $F_2 = GF_1$. This strategy is payoff-dominant while the previous one is risk-dominant. Notice that when G is large the game combines both characteristics of the prisoners' dilemma and of the stag hunt.

3.3 Static and dynamic inefficiencies

The aggregate payoff differential between the first best and the payoff-dominated Nash equilibrium is equal to $(1-c)GF_1 - \frac{F_1}{N}$. Inefficiencies result both from the absence of resource conservation between periods and from excessive harvesting effort by woodcutters. Two second bests are worth discussing.

First, let us define ***sharing*** as a strategy where all players restrain their effort and share the resource with effort level $\frac{F_t}{N}$, conditionally on others playing $\frac{F_t}{N}$. *Sharing* allows players to extract the resource at one point in time with the efficient level of effort. Compared to *sharing*, the Nash Equilibrium generates aggregate within period inefficiency equal to $(1-c)F_t - \frac{F_t}{N} = (\frac{N-1}{N} - c)F_t > 0$. Sharing in t is however not an equilibrium since the best response to $e_{-it} = \frac{F_t}{N}$ is $e_{it} = \left(\sqrt{\frac{N-1}{Nc}} - \frac{N-1}{N}\right) F_t$ and generates a net additional benefit equal to $\mathbf{d_t} = \omega F_t$, the net deviation payoff from period t *sharing.* ω therefore represent the net share of the resource value that a player gains when he deviates from *sharing.* The value of ω is an increasing function of the number of players N and a decreasing function of the cost of effort c, with $\omega = \frac{N-1}{N} + c - 2\sqrt{c}\sqrt{\frac{N-1}{N}}$ (shown in the appendix). In Ostrom's terminology $\mathbf{d_t}$ is the source of a typical *appropriation problem* referring to static inefficiencies.

Second, let us define ***conservation*** as a strategy where players refrain from extracting in the first period by playing $e_1 = 0$, conditionally on others exerting no effort at all. *Conservation* means that the forest grows between the two periods. If $G < N^2(1-c)$, this strategy is not necessarily an equilibrium since a deviating player could extract the whole resource on his own in the first period and gain a net deviation payoff from *conservation* equal to $\mathbf{d_c} = (1 - c - \frac{G}{N^2})F_1$ (proof in the appendix[9]. By extracting the resource in the first period, players forego a higher second period payoff and generate dynamic inefficiencies. Ostrom refers to inefficiencies related to the inter-temporal evolution of the resource as *provision problems.*

[9] It is obvious that if G is too large given c, $\mathbf{d_c}$ can be negative. Or, equivalently, there exist combinations of c and G such that $\mathbf{d_c} < 0$

Let us finally define B, the set of tuples (c, N, G) for which incentives to deviate from first period sharing and conservation are equal. Any tuple belonging to B is such that $d_1 = d_c$, or more formally

$$B = \left\{(c, N, G) : G = \omega N^2, \quad 0 < c < \frac{N-1}{N}, \quad N, G \in \mathbf{R}^+\right\} \tag{8}$$

Proposition 1. *On incentives to deviate from socially desirable strategies:*

1. *if a tuple (c, n, G) belongs to the strict upper(lower)-contour set of B, then the net deviation payoff from first period* sharing *is strictly smaller (larger) than the net deviation payoff from* conservation*, that is $d_1 < d_c$ ($d_1 > d_c$).*

2. *if the growth rate is larger than a threshold, then there is no benefit of deviating from* conservation*. Formally if $G \geq N^2(1-c)$, then $d_c \leq 0 \leq d_1$*

[Insert figure 1 here]

Figure 1 maps proposition 1 for two players. First, the dashed line maps the contour set B where provision problems are just equal to appropriation problems. Below the dashed line, in the light grey area, players have more incentives to deviate from *conservation* than from *sharing.* Above the dashed line, the growth rate is sufficiently large to reduce incentives to deviate from *conservation* and these incentives become smaller than incentives to deviate from *sharing.* In the white area, deviation from *conservation* is no more beneficial. It corresponds to the second part of proposition 1. Future gains are so high that the second period Subgame Perfect Nash Equilibrium payoff is larger than the payoff associated to a monopolistic extraction in the first period. Conservation is a matter of pure coordination. In this case, the first period appropriation problem is not relevant.

3.4 Governing the commons

In a purely decentralized context, without coordination device nor reputation building mechanisms, there is no way to escape the tragedy of the commons. This is true in theory but also has relevance in the field as shown in (Noussair et al., 2015). However, as put forward by Ostrom (1990), Baland and Platteau (1996) and others, communities are able to design rules, monitor individual actions and impose sanctions to members who deviate from a given behaviour.

We define the conditional sanction σ_s as a direct payoff loss incurred by any player deviating from strategy s. σ_s is the minimal level of conditional sanctions required such that s is a credible strategy, that is σ_s is sufficient to deter any player from deviating from the strategy s. Sanctions in a given game are bounded such that $0 \leq \sigma \leq \bar{\sigma}$. $\bar{\sigma}$ is predetermined and does not change during the game[10]. It refers to the monitoring and sanctioning technology available in the community[11]. We define a rule $\mathcal{R}$ as a strategy s and an associated conditional sanction σ_s. A rule $\mathcal{R}\{s;\sigma_s\}$ is feasible if $\sigma_s \leq \bar{\sigma}$. For the sake of simplicity, we represent the community by a benevolent planner which sets rules, monitor actions and eventually impose sanctions.

From proposition 1, we know that the maximal benefit of deviating from first period sharing is d_1. Therefore, first period sharing is implemented by $\mathcal{R}_1 = \left\{s_1 \equiv \left[e_1 = \frac{F_1}{N}, e_2 = 0\right]; \sigma_{s_1} = d_1\right\}$. Assuming a Nash solution in the second period, the maximal benefit of deviating from conservation is d_c. Conservation is thus implemented by $\mathcal{R}_c = \left\{s_c \equiv \left[e_1 = 0, e_2 = \frac{GF_1}{N^2 c}\right]; \sigma_{s_c} = d_c\right\}$.

Corollary 1. *On Ostrom conjecture:*

If $\bar{\sigma} > \sigma_{s_2}$, then Ostrom conjecture does not hold in the upper-contour set of B and is weakly valid otherwise.

This corollary states that, for any tuple in the upper-contour set of B, it is always possible to find a level of sanctions $\sigma < \bar{\sigma}$, such that conservation ($\mathcal{R}_c$) is feasible while first period sharing ($\mathcal{R}_1$) is not. This is true even if second period sharing is not feasible, that is if $\sigma_2 > \bar{\sigma}$.

The general intuition behind this corollary lies in players anticipations of second period gains when they decide on their first period moves. If the growth rate is sufficiently large, second period payoff is big enough to mitigate individual incentives to extract in the first period, even if a player could be the sole first period harvester. Small sanctions are then sufficient to deter strictly positive first period effort levels, even if these sanctions are not sufficient to sustain an efficient extraction when extraction takes place. The violation of Ostrom conjecture is visible at the equilibrium if $d_c < \bar{\sigma} < d_1 \leq d_2$ which corresponds to the dark grey and white areas in figure 1. Under this conditions, players conserve the resource between the two periods but play Nash in the second period and therefore put too much effort to harvest the resource. In Ostrom's terminology, the provision problem is fixed but the appropriation problem remains open.

Notice that the parameter space in which Ostrom conjecture holds increases as the number of players goes up. Intuitively, if the number of players is large, the resource must be shared between many and incentives are diluted. First period harvest becomes more and more attractive for any woodcutter if others conserve.

[10] We assume $\bar{\sigma}$ as predetermined level of effective sanctions since norms often evolve a a slower pace then the environment.

[11] $\bar{\sigma}$ can be low if outside valuable options exist, while it can be very high if exclusion from the group is very costly or if breaking the rule fills the offender with infinite remorse and regrets. Readers interested in imperfect monitoring can read $\bar{\sigma}$ as the expected sanctions in a game with risk-neutral agents.

On the contrary, for games with few players, static inefficiencies may remain while dynamic inefficiencies would disappear.

To achieve the first best, it is both necessary to deter players from harvesting in the first period and prevent excessive effort in the second period. Conditionally on conservation, d_2 is the maximal benefit of deviating from second period sharing. Conditionally on second period sharing, the maximal benefit of deviating from conservation is $d_{c|s2} = (1-c)F_1 - (1-c)\frac{GF_1}{N} = (1-c)(1-\frac{G}{N})F_1$. This value is smaller than d_c because the second period subgame payoff becomes larger. Sanctions have therefore to be higher than the two thresholds to achieve the first best, with associated rule $\mathcal{R}^\star = \left\{ s^\star \equiv \left[e_1 = 0, e_2 = \frac{GF_1}{N} \right]; \sigma_{s^\star} = \max(d_{c|s2}, d_2) \right\}$. Notice that it is possible to find $\bar{\sigma}$ such that the first best cannot be implemented, despite being able to share the resource in the second period. It is the case when $d_{c|s2} > d_2$. Written in terms of growth rate, this inequality states that $G < \frac{(1-c)N}{\omega N + 1 + c}$. In this case, first period sharing is the sole feasible improvement with respect to the Nash outcome. Last, if $\bar{\sigma} > \sigma_{s^\star}$, the violation of Ostrom conjecture is never apparent because *sharing* will always be implemented. However if the growth rate is large enough, second period *sharing* requires more sanctions than *conservation*.

3.5 Comparative statics

Assuming a given $\bar{\sigma}$, this subsection derives comparative statics for each resource (G, F_1). We first map the different equilibrium strategies, then reinterpret Ostrom conjecture and finally demonstrate that a more valuable resource does not necessary imply a higher payoff for harvesters.

[Insert figure 2 here]

Figure 2 maps the feasible rule achieving the largest payoff given $\bar{\sigma}$ for every values F_1 and growth G of a potential resource. The four graphs correspond to different harvest cost c and the illustration corresponds to a two players game.

By definition, $\mathcal{R}^{\star}$ always achieves the first best. It is feasible only if $G \leq \frac{\bar{\sigma}}{\omega F_1}$ and $G \geq N - \frac{N\bar{\sigma}}{(1-c)F_1}$. It corresponds to the intermediate grey area in figure 2.

First period sharing is feasible as long as $F_1 \leq \frac{\bar{\sigma}}{\omega}$. $\mathcal{R}_1$ is chosen over $\mathcal{R}_c$ if $\frac{(1-c)F_1}{N} > \frac{GF_1}{N^2}$, which yields the condition $G < (1-c)N$. This is the darker grey area in figure 2.

Second period Nash is feasible when $G \geq N^2(1 - c - \frac{\bar{\sigma}}{F_1})$ and is chosen as soon as $G \geq (1-c)N$. It matches with resources in the white area of figure 2. This area also corresponds to resources for which Ostrom conjecture does not hold or is not precise enough.

The white area is divided in two parts by a dashed line. At $G = N^2(1-c)$ the growth rate is just sufficient to reduce the benefit of deviating from conservation to 0. Above this threshold, sanctions are not necessary to reach the second period extraction subgame and conservation is a matter of pure coordination. Appropriation problems do not have to be solved before tackling the provision problem.

In the white area below the dashed line, sanctions are necessary to prevent first period extraction. Notice that there exist a whole range of resources for which first period sharing is feasible but is not chosen. For all values $F_1 \leq \frac{\bar{\sigma}}{\omega}$, $\mathcal{R}_1$ is feasible but, in the white area, conservation yields a higher payoff than first period sharing. Anyway, $\mathcal{R}_1$ is no more feasible if the initial value of the resource lies above the last threshold. Despite this impossibility, the existence of sanctions allow resource conservation in the white area. It means that sanctions prevent dynamic inefficiencies while static inefficiencies remain. This is a clear violation of Ostrom conjecture.

Figure 2 also emphasize the role of c. A larger cost c raises the marginal cost of the appropriation effort and decrease extraction benefit. Both $\mathcal{R}_1$ and $\mathcal{R}_2$ require less sanctions. Increasing the number of players has similar consequences. It has no effect on the cost of appropriation but it lowers the benefit of deviation through the reduction of the initial share for each player in the total effort.

Based on the rule achieving the highest possible payoff for each resource $(G; F_1)$, we derive the following proposition:

Corollary 2. *More is not always better:*

If $0 < \bar{\sigma} < \infty$*, there always exists some resources* $(G; F_1)$ *which generate lower payoffs for players than less valuable resources* $(G'; F_1')$ *with* $G' \leq G$ *or* $F_1' \leq F_1$ *and at least one inequality binding.*

Proof. Suppose that $\mathcal{R}_1$ is just feasible and achieves the highest feasible payoff for the resource $(G; F_1)$. By definition, it means that $d_1 - \bar{\sigma} = 0$. At this frontier, $F_1 = \frac{\bar{\sigma}}{\omega}$. Since sharing in the first period is just feasible, players' payoff are equal to $u_i^{MaxS1} = \frac{(1-c)\bar{\sigma}}{\omega N}$. Another resource $F_1' = F_1 + \varepsilon$, with ε strictly positive and small, would not allow the implementation of $\mathcal{R}_1$. First period Nash extraction would be the only possible outcome. Players utility would then be $u_i = \frac{\bar{\sigma}+\varepsilon}{\omega N^2} < u_i^{MaxS1}$. To achieve a larger payoff than u_i^{MaxS1} under first period Nash, the value of the resource has to be at least equal to $F' \geq \frac{N(1-c)\bar{\sigma}}{\omega}$.

$\mathcal{R}_c$ is just feasible if $d_c - \bar{\sigma} = 0$. Rewritten in terms of resource value it yields $F_1 = \frac{\bar{\sigma}}{1-c-\frac{G}{N^2}}$. F_1 generates individual payoffs such that $u_i^{Nash2} = \frac{G\bar{\sigma}}{N^2(1-c-\frac{G}{N^2})}$. A slightly more valuable resource $F_1' = F_1 + \varepsilon$ would prevent the implementation of conservation followed by Nash extraction in the second period. Players would then extract in the first period and achieve a strictly lower payoff as long as $F_1' < \frac{G\bar{\sigma}}{1-c-\frac{G}{N^2}}$.

A similar argument can be repeated at the frontier of the first best implementation. At the frontier where $GF_1 = \frac{\bar{\sigma}}{\omega}$, where $\mathcal{R}^\star$ is just feasible, players achieve a maximal feasible payoff $u^\star = \frac{(1-c)\bar{\sigma}}{\omega N}$. At the frontier of the first best implementation, where conservation binds, which is defined by the relation $(1-c)(1-\frac{G}{N})F_1 - \bar{\sigma} = 0$, payoffs are equal to $u^\star = \frac{G\bar{\sigma}}{N-G}$. So, at the first of the two frontiers, players need at least a resource such that $GF_1 \geq \frac{N(1-c)\bar{\sigma}}{\omega}$ if conservation remains feasible and $F_1 > \frac{\bar{\sigma}}{\omega}$ if first period sharing is implemented. At the second frontier, the growth rate is so low that first period sharing is the second best option. Under $\mathcal{R}_1$, a resource of value $F_1 \geq \frac{NG\bar{\sigma}}{(1-c)(N-G)}$ is necessary to yield a payoff at least equal to the highest feasible first best payoff. □

This corollary says that if enforcement is imperfect, a resource which is apparently more valuable can yield a lower utility for harvesters. This is not the case if sanctions do not exist or if they are infinite. Without sanctions, payoffs under Nash always increase as the growth rate G or the initial value of the resource F_1 go up. With infinite sanctions, the first best is always implemented and payoffs under the first best always increase in the two arguments.

In the presence of limited enforcement, small increases of the growth rate or of the resource value may lead to switch from one equilibrium to another, less desirable, equilibrium. Small increases in the resource value or growth rate raise incentives to deviate from sharing and conservation by a small margin. Because sanctions are bounded, this might be sufficient to raise the deviation benefit above the value of sanctions and prevent the enforcement of the rule. As a consequence, there is switch from a more desirable to less desirable equilibrium with sanctions and users' payoff decline.

[Insert figure 3 here]

Figure 3 illustrate proposition 2. It maps in grey all combinations $(G; F_1)$ which generate individual payoffs lower than another resource $(G'; F_1')$ with $G' \leq G$ or $F_1' \leq F_1$ and at least one inequality binding. The four graphs consider different cost parameters.

3.6 Discussion

This basic model allows understanding how rules can help a community to overcome the tragedy of the commons in a dynamic setting. First, we show that, as the growth rate of a resource increases, the relative size of incentives to deviate from sharing decreases compared to incentives to deviate from conservation. When the growth rate is large enough, players even do not have any benefit to deviate from conservation. The benefit to deviate from conservation also decreases as the extraction cost goes up since it reduces the value of harvesting. Conservation becomes more difficult as the number of players rises since the value of harvesting with competition in the first period increase.

To escape from the prisoners' dilemma, rules and associated sanctions are necessary. For very large resource growth rates, 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. For intermediate growth rates, 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 rates, 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. However, in practice, field observations report that players may have some influence on the initial investment. An anecdotal evidence collected during field visits in Udaipur district, Rajasthan, India, in August 2012 nicely illustrates this point. Some community forest user groups refrain from planting teak despite its very high value and intermediate growth rate. They prefer to plant species like mango or bamboo trees. Group leaders justify their investment decision by their anticipations of members' future behaviour. They point out that the community of users will not be able to prevent its members from felling teak down before it gets mature, precisely because its value is too large. At the opposite, bamboo trees grow 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 with mango trees. Mango timber in itself is not worth a lot. It is then relatively easy to implement conservation and sharing rules of mango fruits, the value of which increases sharply in a short period of time as fruits get mature.

The question is then why, empirically, achieving conservation often appears more difficult than solving the appropriation problem. The role of the number of players, the characteristics of the resource and the cost of extraction explicit appear in the model. Imperfect information is often cited as an argument against conservation. This is true as shown Antoniadou et al. (2013) for instance, however the spread of scientific knowledge decrease the salience of this argument. Higher inequalities may also make conservation more difficult (Dayton-Johnson and Bardhan, 2002) despite that inequalities reduce static inefficiencies ().

On top of these positive implications, the model also provides some normative insights. If more is always better in failed and in highly effective communities, we show that more can be worse in the presence of a moderately effective community. When sanctions are limited, larger resource growth rate or initial value can lead to a change of equilibrium strategies and consequently to a drop of players' utility. The wide-range causes of such changes include natural resource improved management techniques, climate change consequences, new investment possibilities, improved market access, resource booms. The ability to implement sanctions is key to understand that two communities managing the same resource in the same way might react very differently following an increase in the value of the resource. One community can improve its members' livelihoods while in the other, everyone might end up worse off. From a policy perspective, one should take care while designing external interventions. The sole focus on technical solutions might not be sufficient and special caution should also be given to institutional reinforcement.

4 Conclusion

This article investigates determinants of successful management in a regulated common property, compare to the unregulated case. We construct a N-players, two period non-cooperative game with a growing resource to emphasize the difference between appropriation and preservation issues. Appropriation problems refer to static inefficiency and can be solved by sharing the resource within a time period. Preservation problems tackle the problem of natural resource conservation, closely related to dynamic inefficiencies. As broadly investigated in the literature on rent-seeking, competing players exert excessive effort and generate social waste. We also show that, for low and moderate growth rates, competition lead to dynamic inefficiencies. 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 commons*. Some craft rules, monitor and sanction users. We show that it is not necessarily easier for a community to have credible appropriation rules than to set up preservation rules. For intermediate growth rate and large growth rate our model explains why users may protect a resource until a certain point and then fight to appropriate it.

This paper also stresses that, under imperfect institutions, a more valuable resource can actually decrease players' welfare. This result does not hold in purely decentralized context nor with perfect institutions. It is therefore crucial to correctly understand the ability of a group to solve collective action problems while designing external interventions. Rules may have a limited scope and successful management is also conditional on resource characteristics. Something important to keep in mind, especially when time is needed to achieve changes within institutions.

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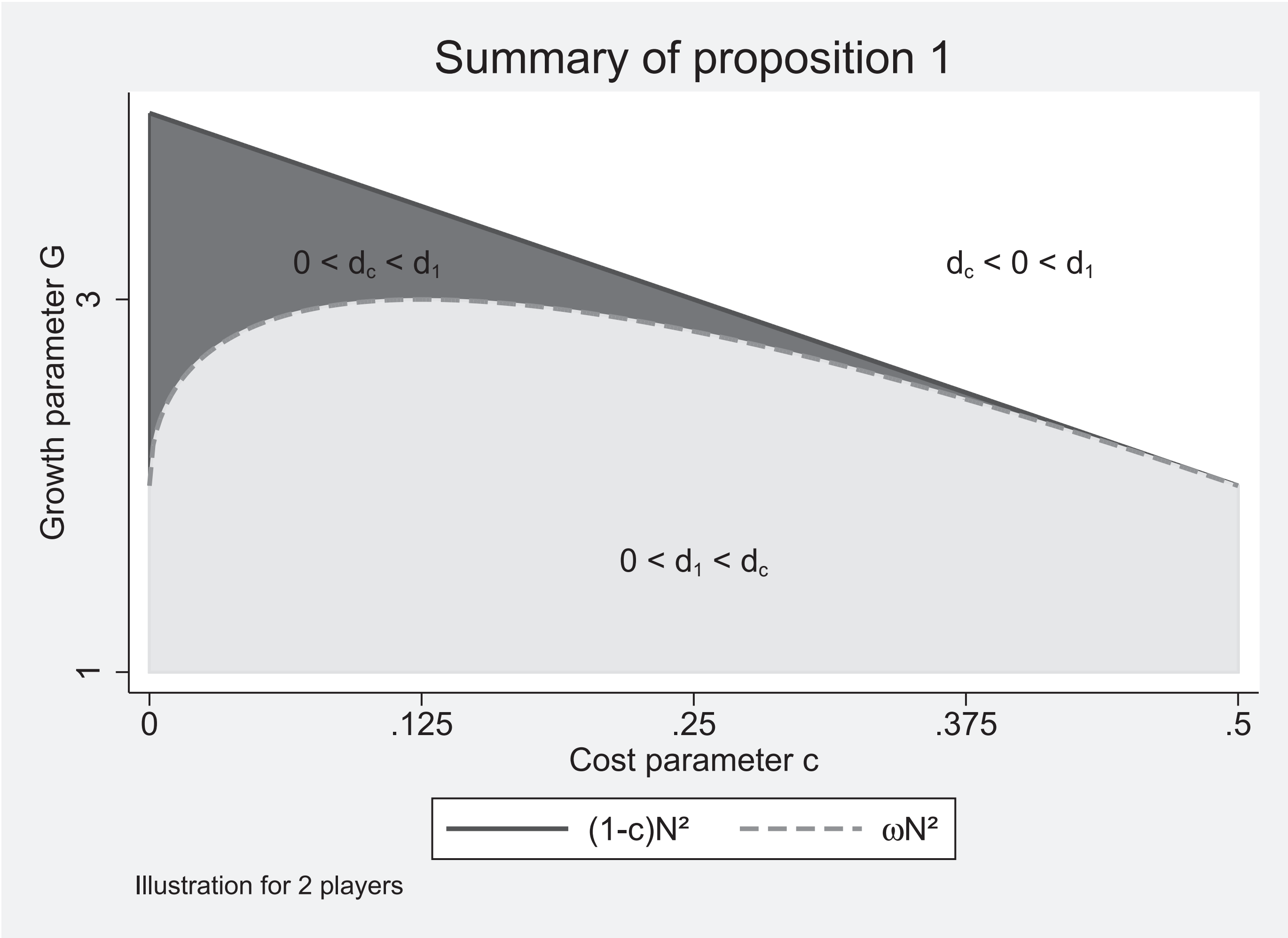

Figure 1: Map of proposition 1

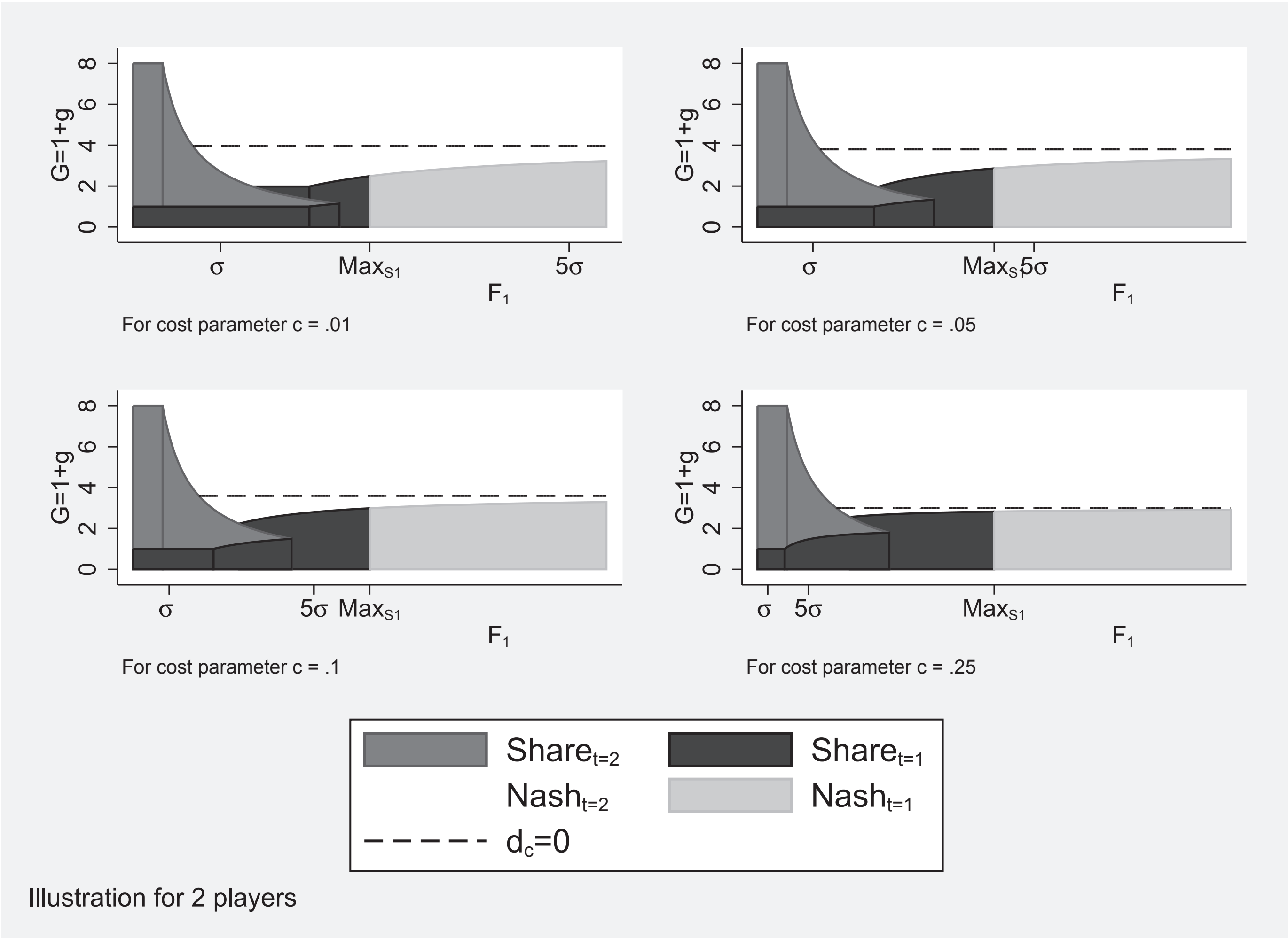

Figure 2: Equilibrium strategies with $0 < \bar{\sigma} < \infty$ statics as a function of resource initial value F_1 and growth G.

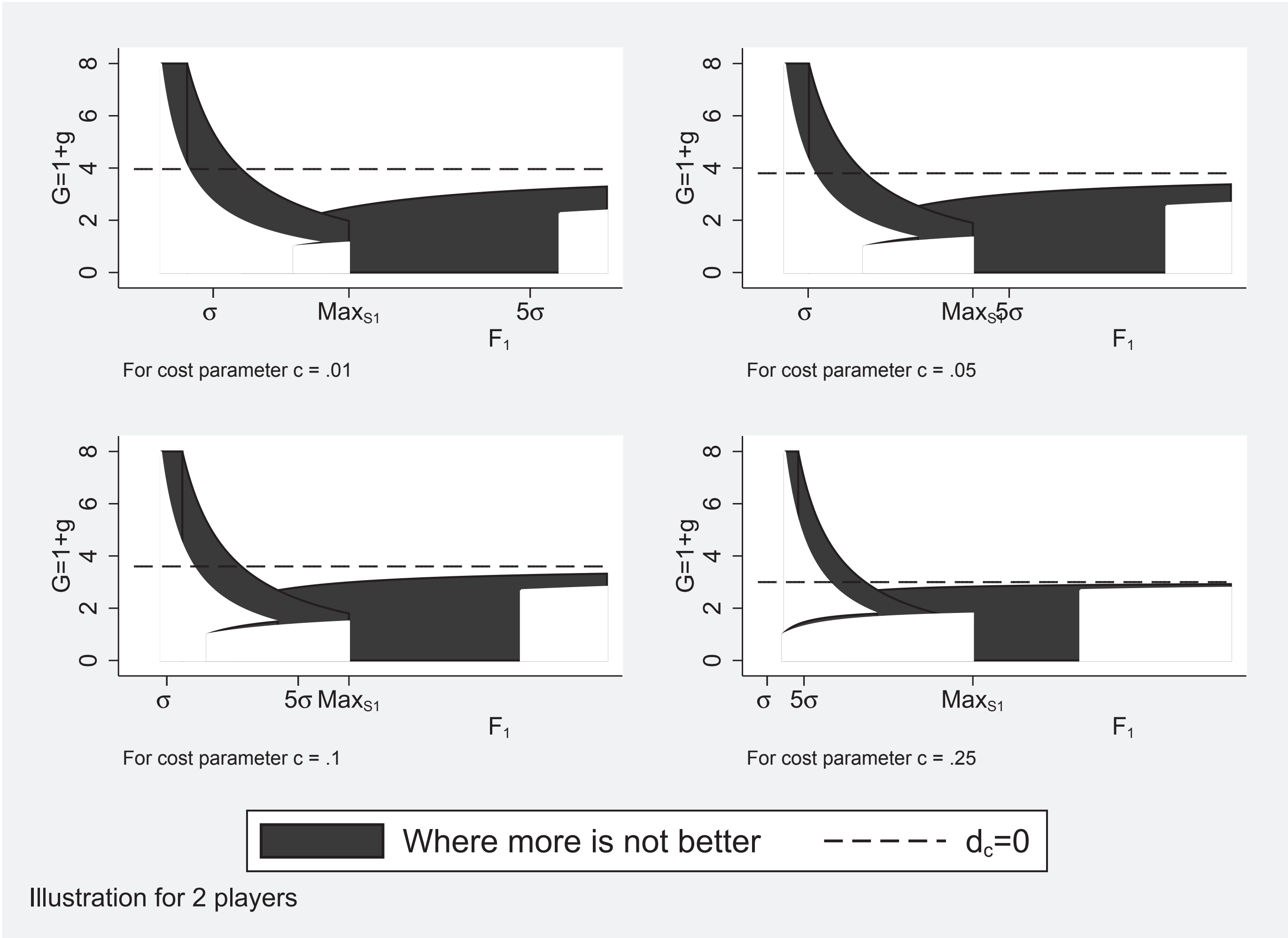

Figure 3: When more can be worse: welfare comparison of equilibrium strategies with limited sanctions.

A APPENDIX

A.1 A. Proof of Proposition 1

Let's first prove that $\mathbf{d_t} = (\frac{N-1}{N} + c - 2\sqrt{c}\sqrt{\frac{N-1}{N}})F_t$. Suppose that all players but i play $e^{\star}_{-it} = \frac{F_t}{N}$. The maximization problem of player i becomes

$$\max_{e_{it}} \quad u_{it} \quad = \quad \max_{e_{it}} \quad \frac{e_{it}}{e_{it} + (N-1)e^{\star}_{-it}} F_t - c e_{it} \tag{9}$$

This yields the first order condition for player i:

$$\frac{\partial u_{it}}{\partial e_{it}} = \frac{(N-1)e^{\star}_{-it}}{(e_{it} + (N-1)e^{\star}_{-it})^2} F_t - c = 0 \tag{10}$$

$$\frac{\frac{(N-1)F_t}{N}}{\left[e_{it} + \frac{(N-1)F_t}{N}\right]^2} F_t - c = 0$$

$$\frac{N-1}{cN} F_t^2 = \left[e_{it} + \frac{(N-1)F_t}{N}\right]^2$$

$$\sqrt{\frac{N-1}{cN}} F_t = e_{it} + \frac{(N-1)}{N} F_t$$

$$e_{it} = \left(\sqrt{\frac{N-1}{cN}} - \frac{N-1}{N}\right) F_t \tag{11}$$

Knowing the best response of player i to $e^{\star}_{-it} = \frac{F_t}{N}$, we can compute the highest utility level achievable by a player deviating from sharing:

$$u_{it} = \left[\frac{\sqrt{\frac{N-1}{cN}} - \frac{N-1}{N}}{\sqrt{\frac{N-1}{cN}} - \frac{N-1}{N} + \frac{N-1}{N}} - c\sqrt{\frac{N-1}{cN}} + c\frac{N-1}{N}\right] F_t \tag{12}$$

$$u_{it} = \left[\frac{\sqrt{\frac{N-1}{cN}} - \frac{N-1}{N} - c\frac{N-1}{cN} + c\frac{N-1}{N}\sqrt{\frac{N-1}{cN}}}{\sqrt{\frac{N-1}{cN}}}\right] F_t$$

$$u_{it} = \left[1 - 2\frac{N-1}{N}\sqrt{\frac{cN}{N-1}} - c\frac{N-1}{N}\right] F_t$$

$$u_{it} = \left[1 + c\frac{N-1}{N} - 2\sqrt{c}\sqrt{\frac{N-1}{N}}\right] F_t \tag{13}$$

To know the net benefit of deviating from *sharing*, the last step is to compare the deviation payoff with the *sharing* payoff.

$$\mathbf{d_t} = \left[1 + c\frac{N-1}{N} - 2\sqrt{c}\sqrt{\frac{N-1}{N}}\right] F_t - (1-c)\frac{F_t}{N} \tag{14}$$

$$\mathbf{d_t} = \left[\frac{N + cN - c - 1 + c}{N} - 2\sqrt{c}\sqrt{\frac{N-1}{N}}\right] F_t$$

$$\mathbf{d_t} = \left(\frac{N-1}{N} + c - 2\sqrt{c}\sqrt{\frac{N-1}{N}}\right) F_t \tag{15}$$

Let's then prove that $\mathbf{d_c} = \left(1 - c - \frac{G}{N^2}\right) F_1$. Suppose that all players but i do not extract in the first period and play Nash in the second period. They therefore opt for a strategy $\left(e_{-i1} = 0; e_{-i2} = \frac{GF_1}{cN^2}\right)$. Player i first period maximization problem shrinks to

$$\max_{e_{i1}} \quad u_i \quad = \quad \max_{e_{i1}} \quad e_{i1} - ce_{i1} + \frac{G(F_1 - e_{i1})}{N^2} \tag{16}$$

It means that i harvests the resource in the first period only if $1 - c - \frac{G}{N^2} > 0$, which can be rewritten as $G < (1-c)N^2$. The net benefit of harvesting in the first period is then equal to the whole surplus that i gets by harvesting the whole resource in the first period minus what i would have received if abstaining from extracting in $t = 1$ and playing Nash in $t = 2$.

$$\mathbf{d_c} = (1-c)F_1 - \frac{GF_1}{N^2} \quad \Longrightarrow \quad \mathbf{d_c} = \left(1 - c - \frac{G}{N^2}\right) F_1 \tag{17}$$

It is straightforward to modify the last proof assuming that second period sharing is implemented. The net benefit of harvesting in the the first period is then equal to

$$u_i - u_i^{Share2} = (1-c)F_0 - \frac{(1-c)GF_0}{N} \quad \Longrightarrow \quad \mathbf{d_{c|s_2}} = (1-c)(1 - \frac{G}{N})F_1 \tag{18}$$

The contour set B is the set of tuples (c, N, G) for which $\mathbf{d_c} = \mathbf{d_1}$. This equality can be written as

$$\left(1 - c - \frac{G}{N^2}\right) F_1 = \left(\frac{N-1}{N} + c - 2\sqrt{c}\sqrt{\frac{N-1}{N}}\right) F_1 \tag{19}$$

or, stated in terms of resource growth rate,

$$G = N - 2N^2 c + 2N^2\sqrt{c}\sqrt{\frac{N-1}{N}} \tag{20}$$