International Journal of Economics, Commerce and Management
United Kingdom ISSN 2348 0386 Vol. VIII, Issue 7, July 2020

http://ijecm.co.uk/

RENEWABLE RESOURCE MANAGEMENT STRATEGIES IN A SMALL COMMUNITY

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Abstract

Overexploitation and degradation of renewable resource such as groundwater overdraft, soil degradation, and deforestation affect the food production, animal feed, agribusiness, and a lot more of our modern life. Market fell short of solving this type of problem simply because they are the common-pool resources which incite overexploitation. To manage this problem, a decentralized common resource utilization model in a small community is considered. We investigate the shunning or excommunication factor intrinsic to a small community to see if it will change the deviator's choice.

Keywords: Common-pool resource, Renewable and Open Access resource, Non-cooperative Overexploitation, Subgames

INTRODUCTION

Overexploitation of renewable and open access resource has become a major problem since the late 20th century because it was misconstrued for its abundant nature and renewable property. For example, people use groundwater when surface water is scarce or polluted. Groundwater can be replenished but at a slow pace in some arid region, and groundwater is the only water resource because of low annual rainfall. However, if used properly, the economy might grow sustainably. The incentive to overexploit stems from the intrinsic "common-pool" nature of those resources and "the tragedy of the commons" (Hardin, 1968) prevailed. In a small community, all members of the community have access rights to use the commons, for example, wood in the common forest for villagers to use as fuel, and grass in the common

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meadow as animal feed. Hardin postulated the overexploitation problem in his paper published in 1968.

Overexploitation happens when all right-holders of the same renewable and open access resource act non-cooperatively or rationally. However, some communities do cooperate and manage their common-pool resources successfully, albeit with costly rule-setting, monitoring, and enforcement mechanism (McCarthy et al., 2001; Coperland and Taylor, 2009). They emphasized on centralized ruling and sanctioning power to implement the mechanism. But centralized authority might not be as effective as we assumed or expected (Agrawal, 2001). Agrawal observed that "in the Kumaon region of the Indian Himalaya, villagers often set the forest on fire, because fire encouraged the production of fresh grasses, government attempts to prevent firing were always to remain a source of complaint". Even with government's "explicit supervision and punitive action to enforce the cooperative agreement", "poverty and government corruption" and international trade surely caused the misuse of common resources (McCarthy et al., 2001; Coperland and Taylor, 2009). Nevertheless, "The threat of exclusion" or excommunication might be effective in a small community but difficult to enforce in a larger community (McCarthy et al., 2001; Ostrom, 1990; Olson,1965). In a larger community, member can easily hide in a crowd, the deviator's action is not easily detected, which is a typical free-rider problem. However, free-rider problem can be easily resolved in a small community, when all members' action can be easily observed, talked about, and sanctioned with low transaction costs by the nosy neighbors (Ostrom, 1990; Olson,1965).

Even in a small community, people might deviate at the risk of being excommunicated if they were caught red-handedly. A framework of a decentralized infinitely repeated game model was used to investigate the effect of shunning or excommunication factor. Our model resonates with the concluding remark made by Agrawal, "The legitimation of authority occurs not through collective visions of dazzling development projects, but by the promise of meeting local needs indefinitely into the future if current consumption is restrained". We will discuss the decentralized game-theoretical model and the ensuing analysis in the following sections.

THE DECENTRALIZED RENEWABLE COMMON RESOURCE UTILIZATION MODEL IN A SMALL COMMUNITY

We consider a small community with N identical right-holders of a renewable open access or common-pool resource. Suppose that every action could be easily observed. Thus, everyone's action is a common knowledge. When dealing with an open access resource, all members in the community would certainly have the access right. We also assume that everyone has long

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memory and unforgiving nature, and a bad reputation would last forever. Therefore, our model deals with an infinitely repeated game.

The infinitely repeated game comprises a three-stage game, which repeats itself infinitely. In the first stage, the community negotiates an agreeable extraction level. If they all agree with the extraction level, they will then choose their action in the second stage, otherwise the game ends there and then. In the second stage, members of the community decide whether they would comply or deviate from the cooperative agreement. If no one deviates in the second stage, they will cooperate to the end. If someone deviates even once, then no one will ever cooperate in the subsequent stages. Therefore, the subgame starting from the third stage is the same as the original game (the whole game), because the game is infinitely repeated. The subgames and payoffs in this game can be characterized into three groups: the cooperative, the deviated, and the non-cooperative groups.

Suppose that S denotes the resource stock, and every member has the same extraction technique which is denoted as α, and α > 0. Member i selects a production level q_i. An extraction function of member i is therefore defined (following Lin, 2016; Coperland and Taylor, 2009; Schaefer, 1957) as $X_i = \alpha q_i S$.

Suppose that the renewable resource stock has a growth rate of β and β > 0, and the total stock could not be more than K. K indicates the carrying capacity (the maximum load or population) the environment could carry or support (Chapman and Byron, 2018; Price, 1999; Seidl and Tisdell, 1999). The regeneration function for the renewable resource is therefore defined as $dS/dt = \beta S(1 - \frac{S}{K})$.

Assume that the resource is sufficient for the initial needs. Setting the regeneration of the resource equal to the total extraction in each period, i.e., ΣX_i, the steady state stock level should be expressed as $S = K\left[1 - \frac{\alpha}{\beta}\sum q_i\right]$. Since S cannot exceed K, the total extraction rate, i.e., $\alpha\Sigma q_i$, should be smaller than the growth rate, i.e., β.

Assume that the production of the community is sold in a competitive market with a relative price of p. Member i's payoff function would be $u_i = pq_i - cq_i(\theta_i \sum X_i)$, where c denotes the constant marginal cost of production, and c > 0. Similar to Lin (2016), we introduce the stress factor to represent the cost of collective overexploitation. The stress factor includes a positive stress parameter θ and the collective extraction. If total extraction is too high, everyone in the community would suffer the added cost of finding a substitution for the depleted resource. But unlike Lin (2016), our stress parameter is not a lump-sum figure for all or a constant parameter. Our stress parameter θ_i differs according to member i's past reputation, and it shows the

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punitive effect of public "shunning". The value of stress parameter would be much higher if the member has the reputation of being a deviator. We assume that $\theta_i \in [0,1]$.

The game-theoretical analysis follows the sequential rationality, that is, a rational player would plan ahead and take all the subsequent decisions and outcomes into consideration at every decision node. So we can apply the backward induction to unravel the optimal decision for every node of the game. After the collective negotiation and agreement has been made in the first stage, the payoff stream starts accruing from then on. Usually, we start the induction process from the last stage and then work through the stages backwardly until we reach the first stage of the game. But in the infinitely repeat game structure, the third stage is the last stage because the game repeated itself over and over again. Thus, the outcome from the third and the "last" stage depends solely on the outcome from the second stage, and we should focus our analysis on the second stage now.

In the second stage, every member should decide whether to comply with or to deviate from the cooperative agreement. We assume members are rational and choose the best outcome for themselves. A member would compare the cooperative outcome, the non-cooperative outcome, and the deviation outcome, before he could decide whether he should comply, disagree and leave, or deviate (or cheat) to gain some windfall. We start our analysis with $\theta_1 = \cdots = \theta_N = \theta$, that is, we start off comparing different payoff streams of the same stress factor (i.e., with a clean slate). Later, we will relax this restriction and analyze the effect of different stress parameters.

The Cooperative Agreement

The objective function of a cooperative negotiation for the community of N members is to maximize total payoffs of the community:

$$\underset{\{q_i\}}{\text{Max}} \quad \sum(p - c\theta_i\alpha S \sum q_i)q_i$$

Solve the first-order condition, the cooperative production is: $q_i^* = \frac{1}{2N} \cdot \frac{p}{c\theta_i\alpha S}$

The payoff for the cooperative member is: $u_i^* = \frac{1}{4N} \cdot \frac{p^2}{c\theta_i\alpha S}$

The Deviation and Its One-Time Windfall

To derive the non-cooperative outcome from a deviation, we assume other members are all complying with the cooperative choice. Member i will deviate if the deviation payoff (i.e., a windfall) is larger than the cooperative outcome.

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The objective function is the following:

$$\underset{\{q_i\}}{\text{Max}} \quad \left[p - c\theta_i\alpha S\left(q_i + \frac{N-1}{2N}\cdot\frac{p}{c\theta_i\alpha S}\right)\right] q_i$$
$$\text{s.t.} \quad q_j = q^* = \frac{1}{2N}\cdot\frac{p}{c\theta_i\alpha S}, \forall\, j \neq i$$

Solve the first-order condition, the deviator will produce: $q_i^d = \frac{N+1}{4N}\cdot\frac{p}{c\theta_i\alpha S}$

The payoff for the deviator is: $u_i^d = \left[\frac{(N+1)}{4N}\right]^2\cdot\frac{p^2}{c\theta_i\alpha S}$

Note that $\left[\frac{(N+1)}{4N}\right]^2 > \frac{1}{4N}$, deviation would only gain a one-time windfall, and no one will cooperate from then on. The aftermath of the deviation will be the perpetual non-cooperative "punishing" payoffs.

The Non-Cooperative Nash Choice

After a deviation, no one will cooperate. Everyone could only maximize his own payoff while assuming other members are using Nash strategy to make their equilibrium choices. The objective function is the following:

$$\underset{\{q_i\}}{\text{Max}} \quad [p - c\theta_i\alpha S \textstyle\sum q_i]q_i$$
$$\text{s.t.} \quad q_j = q_j^e \quad \forall j \neq i$$

Solve the first-order condition, the non-cooperative production is: $q_i^e = \frac{1}{N+1}\cdot\frac{p}{c\theta_i\alpha S}$

The Nash payoff is: $u_i^e = \frac{1}{(N+1)^2}\cdot\frac{p^2}{c\theta_i\alpha S}$

Note that $\frac{1}{4N} > \frac{1}{(N+1)^2}$, this means the cooperative payoffs is definitely larger than the non-cooperative payoffs, thus the "punishment" for a deviation is the perpetual payoff degradation for the rest of the game. By comparing the three payoffs, we find that the deviator may have the incentive to cheat and gains a one-time windfall, which is larger than the cooperative payoff. Nevertheless, cooperation gains more payoff than non-cooperative Nash strategy, i.e. $u^d > u^* > u^e$, which means a perpetual non-cooperative Nash payoffs might be punishment enough to deter a cheater. And after comparing the three equilibrium production choices, we find that the deviator extracts the most resources, and the cooperator extracts the least resources, i.e. $q^d > q^e > q^*$. In other words, the cooperator acts more sustainably than the others.

The Choice and the Conditions for Not Cheating

To calculate the present value of the payoffs for different strategies, we need to focus on the third stage. All the subgames can be categorized into three different subgame groups, that is, 1.) everyone cooperate to the end, 2.) only one member deviates, while all the other members are cooperative and 3.) all members disagree with each other and act non-cooperatively from the start of the game.

The first type of subgames is the cooperative subgames, and the third type of subgames is the non-cooperative subgames. Once a member deviates, the rest of the game will be non-cooperative, so the subgames with deviation would have only one deviator. We can call these type of subgames the deviated subgames.

For the cooperative subgames, all members cooperate to the end. Suppose that the discount factor is δ, and $\delta > 0$. The present value of payoffs for the cooperative subgame is: $V^* = \frac{1}{4N} \cdot \frac{p^2}{c\theta_i \alpha S} (\frac{1}{1-\delta})$

For the deviated subgames, deviator earns more payoffs than non-deviators, so we focus on the deviator's payoffs to investigate the incentive to deviate. If you were in a deviated subgame, you better act fast and be the deviator yourself. The present value of payoffs for the deviator is: $V^d = \frac{(N+1)^2}{16N^2} \cdot \frac{p^2}{c\theta_i \alpha S} + \frac{\delta}{1-\delta} \frac{1}{(N+1)^2} \cdot \frac{p^2}{c\theta_i \alpha S}$.

Finally, for the non-cooperative subgames, the present value of payoffs is: $V^e = \frac{1}{(N+1)^2} \cdot \frac{p^2}{c\theta_i \alpha S} (\frac{1}{1-\delta})$.

Comparing the three present values, we find that non-cooperative outcome is the worst outcome, which means that non-cooperation would not be the best choice for any member. Nonetheless, we still have to check the incentive for deviation. The direct incentive for deviation should be the windfall. But the deviator would be punished by the perpetual Nash payoffs. By calculating the difference between the present value of deviation payoffs and the present value of cooperative payoffs, we get: $V^d - V^* = \left(\frac{N-1}{4N}\right)^2 \frac{p^2}{c\theta_i \alpha S} + \frac{\delta}{1-\delta} \cdot \frac{-(N-1)^2}{4N(N+1)^2} \cdot \frac{p^2}{c\theta_i \alpha S}$.

The first part of the difference is the deviation windfall in addition to the cooperative payoffs, i.e. $\left(\frac{N-1}{4N}\right)^2 \frac{p^2}{c\theta_i \alpha S}$, which is positive, so this part is the direct incentive for deviation. The second part of the difference is the difference between non-cooperative payoffs and the cooperative payoffs, i.e. $\frac{\delta}{1-\delta} \cdot \frac{-(N-1)^2}{4N(N+1)^2} \cdot \frac{p^2}{c\theta_i \alpha S}$, which is obviously negative. So this part is the punishment for deviation. If the punishment is large enough, potential deviation may be deterred. Setting $V^d - V^* \leqq 0$, we get the condition for no incentive to cheat as: $\frac{\delta}{1-\delta} \cdot \frac{1}{(N+1)^2} - \frac{1}{4N} \geq 0$. This condition should be self-enforcing if it is satisfied. However, it is a difficult condition to fulfill. Recall that $\frac{1}{4N} > \frac{1}{(N+1)^2}$ when $N > 1$, which means when a community with more than one member, the condition for not cheating would be satisfied only when $\frac{\delta}{1-\delta}$ is very large. Therefore, even a self-

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enforcing condition in a decentralized mechanism might not be robust enough to hold everyone in check.

Nevertheless, in a "close-knit community", if you are a good neighbor, people would offer you trust, amenity, goodwill, support, and many conveniences. If your reputation is bad enough, people might shun you and exclude you from any access to amenity, which might cost you dearly. We call this the "excommunication type of stress factor" and the excommunicated member would have a larger θ_i. After we relax the restriction of a egalitarian θ and assume that θ_1 is the stress parameter for the "Cooperative member", θ_2 for the "Non-cooperative member", and θ_3 for the "selfish deviator (the cheater)". Assuming that people distrust and dislike the deviator more than the non-cooperator, then we have $\theta_3 \geq \theta_2 \geq \theta_1$. And the community retaliate the deviator after the fact, i.e., the stress parameter changes from θ_1 to θ_3 after the act of deviation for the deviator. So the windfall for a deviation is $u^d - u^* = \left(\frac{N-1}{4N}\right)^2 \frac{p^2}{c\theta_1 \alpha S}$, and the perpetual punishment is $\frac{\delta}{1-\delta}(u^e - u^*) = \frac{\delta}{1-\delta} \cdot \frac{-(N-1)^2}{4N(N+1)^2} \cdot \frac{p^2}{c\theta_3 \alpha S}$. If the windfall is greater than the punishment, deviation would definitely occur, but if the windfall cannot cover the loss of the perpetual punishment, deviation would not occur. Thus, for a decentralized mechanism to be effective, the following condition has to hold:

$$\frac{\theta_3}{\theta_1} \leq \frac{\delta}{1-\delta}\frac{4N}{(N+1)^2} \qquad (1)$$

Under this condition, it is easily shown that If we differentiate (1) with respect to δ and hold N constant, we will get a positive marginal effect, i.e. $\frac{\partial}{\partial \delta}\left(\frac{\delta}{1-\delta}\right) = \frac{1}{(1-\delta)^2}$, which means if δ increases, δ/(1-δ) will increase. The higher δ is, the more people cares about future costs and benefits, so the punishment (future low payoffs) would be felt more acutely, and the condition in (1) is more likely to be satisfied. In another word, a potential deviator may change his mind and would be more inclined to comply if δ is very large. Furthermore, if the size of the community is getting larger, the deviation outcome would be more likely to occur, i.e. $\frac{\partial}{\partial N}\left(\frac{4N}{(N+1)^2}\right) = \frac{(1+N)(1-N)}{(N+1)^4} < 0$, if N > 2. This effect is similar to the "free-rider" effect.

Notice that $\frac{1}{4N} > \frac{1}{(N+1)^2}$ when N > 1, so no matter what the stress factor ratio for non-cooperators and cooperators, people would definitely prefer to cooperate in order to gain more benefits.

CONCLUSION

A decentralized mechanism is easily enforced if all the conditions are met. In a small community with nosy and well-informed neighbors, cooperative agreement can be sanctioned and implemented, without government's coercion and oversight. If all members who have open

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access rights to the common-pool resource really care about the future, the decentralized mechanism may be able to implement the cooperative and a more sustainable outcome.

We found in our model that a small community with common knowledge about everyone's action, the grim strategy and punishment would be sufficient to deter the cheater from deviation. We actually assume that transaction costs are negligible. However, the problem may occur if the transaction costs for everyone to conform are quite large. Transaction costs include gathering information, making the information public, and getting everyone to act collectively and cooperatively. If the information about everyone's action is not the common knowledge, the transaction costs would be large. And if the community are large enough to hide someone's action, in this case, the information is certainly not the common knowledge, then it may require a more extensive investigation and modeling about the issue of transaction costs and the necessary mechanism to deter a cheater. A more comprehensive form of the information transmission mechanism may be our next step to solve this problem.

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