Power and Conflict in the Contested Commons: A Model and Application to Uluabat Lake, Turkey

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Abstract

Many problems of environmental degradation are adequately captured by standard models of overexploitation of a common pool resource and the failure of those exploiting the resource to avert the 'tragedy of the commons'. But in some cases, the tragedy is exacerbated by external actors who reduce the commons' capacity for sustainable exploitation. This leads to another collective action problem: how can the resource users cooperate in political actions to provide incentives or constraints inducing the external actors to protect the common pool resource. The model developed in this paper formalizes this second aspect of collective action problem by way of a tri-partite, game theoretical model of conflict. An industry pollutes a lake, reducing income from fishing, and employs fishers offering them an alternative livelihood, thus, deterring political action by fishers that would result in state intervention and stricter regulations on the industry. The industry, thus, has the power to shape the incentive structures of fishers affecting their economic and political activities, while fishers have the power to constrain the choices of the industry through the threat of political action. The model is based on field research on a specific case—that of Uluabat Lake, Turkey—but it provides a general framework to analyze the specific ways power asymmetries interact with the more commonly studied coordination failures resulting in environmental degradation and suggests local empowerment strategies that might counter these effects.

Keywords: Power, Conflict, Collective Action, Externality, Noncooperative Game Theory, Asymmetric Information

JEL Classifications: C72, D62, D74, D82, Q52

1. Introduction

In discussions of the economics-environment nexus, the established literature points to two reasons why coordination failures occur. The first one is the public goods aspect, which Hardin (1968) famously termed 'the tragedy of the commons', namely situations where the motivation to free-ride on fellow commons users may result in the degradation of nature. The argument is that while it may be in the interest of all agents to preserve a common resource, if an adequate formal or informal institutional framework is lacking, people may refrain from making personal sacrifices in hopes that others will shoulder the cost.[1] While this framework continues to provide the theoretical basis for many explanations, the commons may be degraded even if, as is often the case, the first coordination problem is adequately addressed by those who rely on the commons. The second coordination failure, occurs due to the 'externalities' identified by Pigou (1932) and Marshall (1930), and refers to situations where agents engaged in production and consumption activities enjoy a lack of liability to third parties, who suffer various negative "spillovers" as a result. Here, the coordination failure arises from the difficulties that the injured third parties may face in acting collectively to impose liabilities on the source of these negative external economies.

These problems are closely related, as there are externalities in the public good case as well; however, an important difference is that externalities are symmetrical in the first one and asymmetrical in the second. In other words, the public goods aspect of the problem is a horizontal one where the actors bear a similar relationship to the resource as, for example, in the cases of fishermen or herders. The externalities aspect, on the other hand, is often vertical and power asymmetries play an important role, as when offshore oil drilling by a major international corporation depletes the stock of fish exploited by a community of fishermen. Here, the coordination problem facing those who rely on the commons is to impose constraints or incentives on the external sources of commons degradation either directly or, more often, indirectly through the state.

The public goods problem as applied to environmental issues has been extensively modeled, but coordination problem arising from the externality dimension and its associated power asymmetries has been less thoroughly analyzed. Motivated by this, I aimed to focus on a specific local environmental problem in order to reveal the specific ways through which power asymmetries manifest themselves in mediating environmental conflict. Though inspired by and making reference to a specific case, the model provides a general framework for similar cases.

2. Overview

For the local environmental conflict I have chosen the Uluabat Lake, which is situated in Turkey's Marmara Region. Of a considerable size (150 km2), the lake is not only habitat

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[1]The prediction of resource collapse underlying the tragedy of commons is not supported under conditions that enable harvesters and local leaders to self-organize effective rules to manage a resource, and when combined with communication, even engaging in costly punishment generates gross benefits (see, e.g., Berkes, 1989; Ostrom, 1990; Ostrom, 2009; Janssen *et al.*, 2010).

for a large amount of fish stock that has an economic value but also has a Ramsar[2] status as a major wintering site for Pygmy Cormorant (*Phalacrocorax Pygmeus*), Dalmatian Pelican (*Pelecanus crispus*) and the Otter (*Lutra lutra*). Despite its economic and ecological values, it has been facing severe environmental damage in the form of increased pollution and a decrease in water volume. Through a field study, conducted between 2008-2009 and comprising of a series of in-depth interviews, focus-groups and a survey of a size of 607 to local people, I collected qualitative as well as quantitative data with regard to the political economy of the ongoing degradation.[3]

My analysis on the Uluabat Lake showed that all groups, apart from the industry, are bearing the costs of the degradation: Fishermen, farmers and environmentalists. Not bearing any costs, though being the main source of pollution, the industry reaps benefits in terms of savings from pollution abatement costs. The state, due to its modernist position, prioritizes economic growth over environmental concerns, as a result of which the environmental regulations are not effectively implemented.[4] Hence, the case provides an affirmative example of the argument that "[d]isparities of power and wealth influence not only how nature's pie is sliced, but also its overall magnitude" (Boyce, 2002, p.5). Then, the question becomes why the winners of environmental degradation, the industry in this case, are able to impose costs on the losers. Besides the possibilities that the losers may lack information about the costs imposed on them or the case that the losers do not exist yet, that is the costs to be borne by future generations, another possible explanation is that the losers lack enough power to prevent winners from imposing costs onto them.

My field study indicated that two groups may be singled out as the main players in the conflict: fishermen and the industry. Fishermen are hurt worst by pollution since their main source of livelihood is directly affected, especially for those residing in villages where no other viable source of income is available. Fishermen are well aware of the costs brought about by the pollution and they are also aware that the main source of pollution is the industry. The survey results revealed that 90% of fishermen stated that they would take part in an action against the industry so as to make the state play a more active role in terms of monitoring and make the industry reduce the pollution level. The problem then turns out to be a collective-action problem in organizing such an action, as being part of such an activity will come with a cost while the benefits, in case it succeeds, are non-excludable. Consequently, overcoming the free-rider dilemma, viz. the problem of not being able to make a big enough difference in the outcome to compensate for the costs one bears, becomes essential.

In this paper, a game theoretical model is formulated based on the observed relation between the industry and fishermen, whereby the industry imposes costs on fishermen and keeps their opposition under control by offering employment. The set-up is formulated as a contested commons problem, where the main focus is on the collective action of

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[2]The Ramsar Convention that went into effect in 1971 is an international treaty for the conservation and sustainable utilization of wetlands. The convention also produced a list of wetlands of international importance, referred commonly as 'Ramsar Sites'.

[3]The main findings are discussed in my joint companion paper; see Akbulut and Soylu, 2009.

[4]For a comprehensive analysis of the tension between environmental protection and economic development see Adaman & Arsel (2005).

fishermen in resisting the pressure of the industry and the role of power in this process; and, it is formalized as an infinitely repeated game which is analyzed for the cases of identical and heterogeneous fishermen.

To restate the main line of argument: Abatement is costly and the state is unwilling to implement the anti-pollution regulations; therefore, the industry can pollute the lake used by fishermen. Pollution reduces the number of fishes, hence, the income of fishermen. As fishing becomes less rewarding, fishermen face three options: they can seek employment in the industry, or they can remain as fishermen in which case they can either organize a political action and put pressure on the state to implement environmental regulations, or they do not take any action and carry on fishing given the pollution level chosen by the industry. Political action refers to some action calling for the attention of the state and/or general public such as blocking the highway nearby the lake or initiating a media campaign against the industry so as to make the state play a more active role in monitoring the industry or to change the incentives of the industry through creating a bad public image so that it pollutes less for a better public image. Political action is costly and it is assumed that both the total cost and the per-capita cost is decreasing in the number of fishermen participating in the action. Political action will be successful with some probability, which is increasing in the number of fishermen taking action. After a successful political action, it is assumed that the state—acting as a social planner— sets a pollution level which maximizes the planner's social welfare function, p^s, and this level acts as an upper-bound for the pollution level chosen by the industry. After each successful action the state sets a lower level of p^s; therefore, a successful action incurs costs on the industry. Hence, offering jobs to fishermen may also be profit maximizing for the industry so as to weaken the opposition and, thereby, prevent or at least weaken political action by fishermen.

For the benchmark case where fishermen are identical, if there is any action in equilibrium, all fishermen participate; otherwise, no fisherman takes action. The action decision of an individual fisherman depends on his belief regarding the number of others participating. The equality of payoffs from action and nonaction yields two critical values of belief such that if the actual level of belief is in the range defined by these critical levels, all fishermen take action. If fishermen believe that more than the greater of the two critical values will participate, then their participation will not matter and they will not join the action. Correspondingly, if fewer than the lower critical value will participate, the action will surely fail even if the fisherman does participate, so he does not.

Accordingly, there are three possible paths regarding the action. Depending on the present values of the expected unconstrained profit (the profit level such that the industry does not set the levels of pollution and employment so as to prevent the action by fishermen) and of the constrained profit (the industry prevents action), the industry decides whether or not to prevent the action in the first period. The first possible path is that the action is prevented in all periods and fishermen never take action. The second path is the one in which the action is not prevented in the first period, fishermen take action but the action fails and fishermen never take action in the subsequent periods. Alternatively, the action of fishermen in the first period can succeed and the state is called to act. This is repeated until p^s is decreased to a level which makes it optimal for the industry to prevent the action. From this point onwards, the first path comes into

play. Depending on the parameter values, the game follows one of these three paths. The results show that there is a positive relation between the pollution level and the number of fishermen employed in the industry—in order to pollute more the industry needs to employ more fishermen.

In the heterogeneous fishermen case, on the other hand, each fisherman is assigned a type (denoting the subjective valuation of being a fisherman and his position regarding the industry), which is private information. The value of each fisherman's type enters in his utility function as a multiplier. The main difference between heterogeneous and identical fishermen cases is that in the heterogeneous case some fishermen may decide to take action while others do not participate due to the difference in subjective valuations of payoffs. Moreover, contrary to the identical fishermen case, the threat of action might lead the industry to set a lower level of pollution even if the industry is not concerned with preventing action. Unlike the identical fishermen and complete information case, under asymmetric information, the industry cannot calculate the payoffs of fishermen from action and nonaction. Individual action decision still depends on the number of others being expected to participate in action. As a remedy for asymmetric information, self-consistent beliefs are considered.

The inspiration for the model was taken from the model by Acemoglu and Robinson (2006), where they analyze a social conflict between different groups—the elites and the citizens—over policy choices under democracy and nondemocracy in a game-theoretic framework. Asking why the elites do not always use their power under authoritarianism to repress democracy, they conclude that it is sometimes more costly to repress pressure for democratization relative to the cost of making concessions. This is the source of the citizens' power to place constraints on the elites, namely the "revolution constraint", even though they have no power at the formal institutional level. Their model and the model presented here resemble in terms of the general underlying idea of having two groups with different kinds of power: the first is the power to determine the parameters of the game and the second is to impose some constraints on the decision maker's choices. However, the model presented here departs from that of Acemoglu and Robinson by merging democracy and nondemocracy in the sense that if the action by fishermen succeeds, the state will then decide the level of pollution; hence, as in the democracy case considered by Acemoglu and Robinson, there is a social planner deciding on the basis of maximizing a weighted sum of the payoffs to each group. These weights are considered in their framework as the "political power" of each group and this is perfectly compatible with the model in this paper. Another point of departure is with regard to the assumptions made about the groups. Acemoglu and Robinson assume both the elites and the citizens to be identical. The groups are also assumed to have solved their collective-action problems and, therefore, each group is taken as a single entity. Here, as mentioned above, I assume that the industry is a single entity but, for fishermen, although initially I assume them identical (considered with their collective-action problem nevertheless), I later regard them as heterogeneous.

3. The Model

3.1. Structure of the Model and Definitions

There are two groups: fishermen and the industry. There are a finite number of fishermen. The total number of fishermen is denoted by N. I begin with the assumption of identical fishermen and common knowledge, and then consider the model with heterogenous fishermen and informational asymmetries. The industry is assumed to be a single entity since they do not have conflict of interest within themselves with respect to variables under consideration. Both prices, the price of the industrial output and the price of fish, are normalized to 1.

Pollution abatement is costly and, as a result of the unwillingness of the state to implement the anti-pollution regulations, the industry pollutes the lake used by fishermen. Pollution reduces the number of fish, hence, the income of fishermen. As fishing becomes less rewarding, fishermen face three options: they can seek employment in the industry or they can remain as fishermen in which case they can either organize a political action and put pressure on the state to implement environmental regulations, or they do not take any action and carry on fishing given the pollution level chosen by the industry. Political action refers to some action calling for attention of the state and/or general public such as blocking the highway nearby the lake or initiating a media campaign against the industry so as to make the state play a more active role in monitoring the industry or to change the incentives of the industry through creating a bad public image so that it pollutes less for a better public image. Political action is costly and I assume that both the total cost and the per-capita cost are decreasing in the number of fishermen participating in action. Political action will succeed with some probability, which is increasing in the number of fishermen taking action. Those who have given up fishing to work in the industry do not participate in the political action. After a successful political action, it is assumed that the state—acting as a social planner—sets a pollution level which maximizes the planner's social welfare function and acts as an upper-bound for the pollution level chosen by the industry. In the repeated setting to be described below, it is assumed that after each successful action the state sets a lower level of pollution, therefore, a successful action incurs costs on the industry. Thus, the industry has an incentive to hire fishermen additional to their marginal revenue product so as to prevent or at least weaken political action by fishermen, and thereby reduce the likelihood of more costly environmental regulations. Accordingly, the industry has two options: either it sets the employment and pollution levels such that fishermen do not take action or it deviates and does not prevent action but reduces the likelihood of success of action by employing fishermen.

An important aspect of the model is the constraint placed on the industry by fishermen through the threat of political action. However, fishermen have to overcome the collective-action problem that arises due to the public good aspect of action, that is, there is a cost associated with action and no one can be excluded from the benefits once action becomes successful. This implies, in turn, that whatever the outcome is–success or failure–if the individual believes that his participation does not have any significant effect on the success probability of action, the payoff from not taking part in action is always greater than the payoff from taking part. However, since fishermen are a small group, it is unlikely that the marginal effect of an individual fisherman's participation on the success probability

of action will be insignificant. In particular, in the framework considered here, individual decision on participation depends on the belief of the individual on the number of other fishermen who will participate. The individual fisherman does not participate unless he believes that the marginal effect of his participation on the probability of success is sufficient to make the payoff from participating in action greater than the payoff from non participation.

There is an infinitely repeated set-up. The structure of a single period is represented by the following game tree:
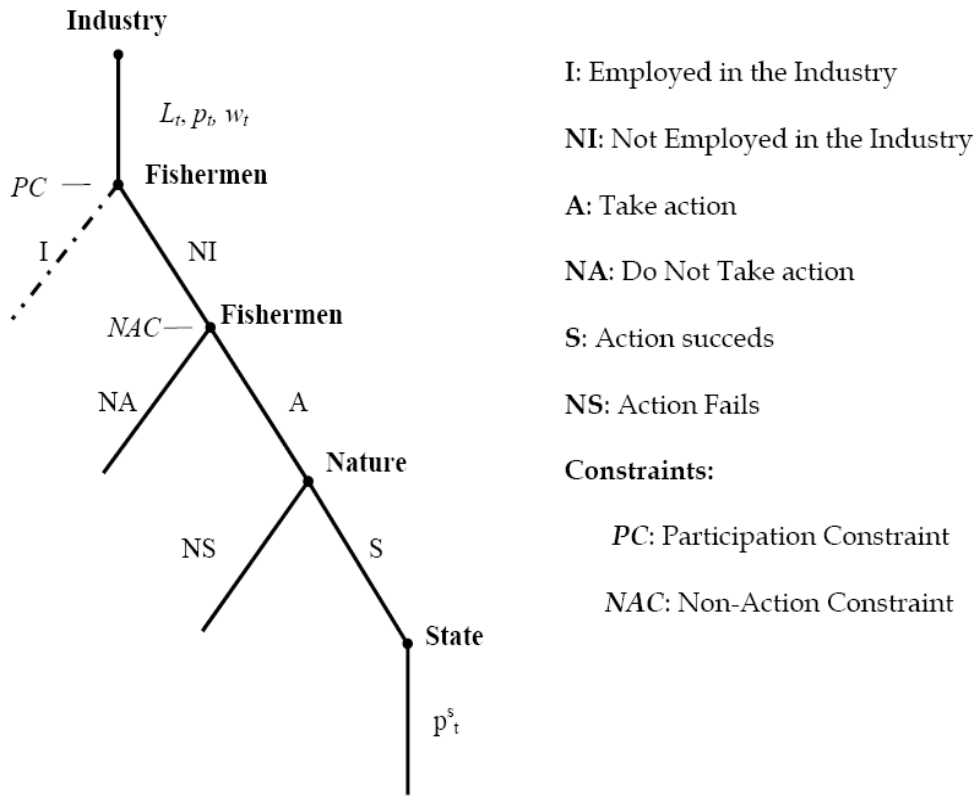

Industry

L_t, p_t, w_t

Fishermen

PC —

I

NI

NAC — **Fishermen**

NA

A

Nature

NS

S

State

p^s_t

I: Employed in the Industry

NI: Not Employed in the Industry

A: Take action

NA: Do Not Take action

S: Action succeds

NS: Action Fails

Constraints:

   PC: Participation Constraint

   NAC: Non-Action Constraint

Figure 1. The game tree

In period t, there is a given level of p^s_{t-1}, set in period $t-1$ following a successful action. The industry moves first by announcing the levels of L_t, p_t and w_t, such that $p_t \leq p^s_{t-1}$. If the participation constraint (PC), that is the wage paid by the industry should be greater than or equal to the fallback position of fishermen, is satisfied, then L_t fishermen accept employment in the industry; otherwise, they remain as fishermen. Fishermen (a total of N in case the PC is not satisfied and $n_t = N - L_t$ in case the PC is satisfied) decide whether to take action against the industry or not. If the non-action constraint (NAC), that is the payoff from not taking action should be greater than or equal to the expected payoff from taking action (as described below), is satisfied, fishermen do not take action; otherwise, they take action. If action is taken, the nature determines if it is successful[5], and if so,

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[5]The success probability of action, described below, depends on some exogeneous parameters that are assumed to be determined by the nature, and the number of fishermen participating in action.

the state moves and sets the optimal level of pollution (maximizing the planner's social welfare function), p_t^s with $p_t^s < p_{t-1}^s$, i.e. it is assumed that the weight of the industry profit at the planner's social welfare function decreases after each successful action.[6] p_t^s acts as an upper-bound for the pollution level in period $t+1$, hence the payoffs of period t are determined by L_t and p_t. On the other hand, if action is taken but it fails, p_{t-1}^s proceeds to period $t+1$. Moreover, it is assumed that following a failed action fishermen are discouraged and their belief regarding the number of fishermen who will participate in action is decreased such that fishermen do not take action in the following periods. However, if the action succeeds, then, all the following attempts will also be successful. These assumptions imply that a failed action can be observed only in the first period. Now, bearing in mind these assumptions, I will define the possible paths the game can follow starting from the first period.

Consider the first period. The game starts with a given level of p_0^s. Then, there are three possibilities depending on the choices of the industry: i) fishermen do not take action; ii) fishermen take action but the action fails; iii) fishermen take action and the action succeeds. Note that, if the first one is the case, the initial optimization problem of the industry will not be changed in the second period and the corresponding choices of the industry will still satisfy the *NAC*. The same argument holds for all the subsequent periods and, therefore, the first period will be repeated forever. In the second case, fishermen will not take action in any of the subsequent periods. Hence, the second period will be repeated forever. In the third case, there will be action in subsequent periods, and the state will set a lower level of p^s after each successful action, until the level of p^s is decreased to a level, p^{s*}, such that it becomes optimal for the industry to prevent action. After this period, there is no action and so the period is repeated forever. Given this general structure, it is assumed that if there is a successful action in the first period, the level of p^s jumps to p^{s*}. Accordingly, the game can be analyzed as a two period game, where the second period is repeated forever.

The following three cases (as formalized below) summarize the arguments made so far:

Case 1 *NO ACTION (NA): The industry sets the first period levels of L and p such that the NAC is satisfied and fishermen do not take action. This will be the case only if the profit level such that the NAC is satisfied is greater than the expected profit the industry would get otherwise. If it is true for the first period, it will be true for the next period as well since p^s is not changed, and the industry will set the same levels of L and p. This is true for all the subsequent periods. Hence, the industry and fishermen receive an infinite stream of their first period payoffs and fishermen never take action.*

Case 2 *FAILED ACTION (FA): The levels of L and p set in the first period do not satisfy the NAC and fishermen take action but the action fails. This is the case if the profit level such that the NAC is satisfied is less than the expected profit the industry would get otherwise. It is assumed that once an action fails, fishermen's belief regarding the number of other fishermen who would take part in action decreases such that, in the following periods, fishermen do not take action. The second period is repeated forever.*

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[6]Decreasing levels of p^s can also be interpreted as increasing levels of monitoring, which is not taken as a parameter in the model.

Case 3 *SUCCESSFUL ACTION (SA): The levels of L and p set in the first period do not satisfy the NAC, fishermen take action and the action succeeds. The state moves in and sets the level of p^{s*} which will be effective in the second period and will ensure that the industry satisfies the NAC. Accordingly, fishermen do not take action in the subsequent periods and the second period is repeated forever. The industry receives the shirking profit in the first period by not satisfying the NAC while from the second period onwards it receives a lower level of profit. Fishermen, on the other hand, receive a low level of payoff in the first period but an infinite stream of high payoff from second period onwards.*

3.1.1. Relevant Functions

The industry production function is denoted by $f(L)$ with $f_L > 0$ and $f_{LL} < 0$.[7] It is assumed that f has continuous derivatives and higher order derivatives are equal to zero. As mentioned above, the source of conflict is the pollution disposed to the lake by the industry. Pollution is formulated as a by-product. More specifically, unabated level of pollution is given by $P = ef(L)$ where $e \geq 0$ is the constant emmission-output ratio.[8] The actual level of pollution, p, might be less than or equal to this total level depending on the abatement decision of the industry. The cost of abatement is a convex function denoted by $h(ef(L) - p)$, where $ef(L) - p$ is the level of abatement, with $h'(0) = 0$. Therefore, the industry has two choice variables: the level of employment, $L \in (0, N]$, and the pollution level, $p \in (0, ef(L)]$.[9] The industry profit function for period t is:

$$\pi_t = f(L_t) - w_t L_t - h(ef(L_t) - p_t) \quad for \ \forall t \tag{1}$$

The choices made by the industry determine fishermen's income as well. More specifically, fishermen's production function for period t is denoted by $F(n_t, p_t)$, where $n_t = N - L_t$ is the number of remaining fishermen, i.e. those who are not employed in the industry, and p_t is the level of pollution. F has the following properties:

$$F_n > 0, F_p < 0, \frac{\partial^2 F}{\partial n^2} < 0, \frac{\partial^2 F}{\partial p^2} < 0$$

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[7]The industry is assumed to have a fixed level of capital and therefore it is not considered in the analysis. However, this simplifying assumption does not have any implication for the results. It just enables to focus on the relation between the employment and pollution levels, which, as it will be made clear, forms the basic tenet of the model.

[8]In a dynamic setting it would be more plausible to allow for a variable emmission-output ratio since the ratio can be decreased by technological investment. For example, in the *SA* and *NA* cases, as defined above, it might be optimal for the industry to make such an investment. However, the main focus of the model is on the effect of the threat of action, rather than that of the emission-output ratio, on industry's choice of pollution level. Therefore, e is assumed to be constant.

[9]The case where the industry employs no fishermen, i.e. $L = 0$, is ruled out. Assuming that the average product from fishing for high levels of pollution–the fallback position of fishermen in case they do not take action–will be lower than the marginal revenue product in the industry, the industry will hire fishermen even in case there is no threat of action. Hence, the pollution level is set high. In case there is threat of action, the industry will employ fishermen in order to prevent or reduce the success probability of action. $L = 0$ would be the case only if the level of p_0^s is such that the *NAC* is satisfied even if the industry does not employ any fishermen; and, this would be another possible path where fishermen never take action and the initial level of p_0^s is never changed. However, this path is not considered here as it does not provide any insight for analysis of the conflict.

F is also assumed to have continuous derivatives and higher order derivatives are assumed to be 0. We further assume that the marginal product of a fisherman is less than the average product he receives which implies that the average product from fishing is increasing in L, that is, $\frac{\partial}{\partial L}\left(\frac{F(n,p)}{n}\right) > 0$. Therefore, as the number of fishermen decreases, remaining fishermen will have a smaller total catch but the average product will increase. This is why, given p, the industry has to offer a higher wage to employ more fishermen.

Following Boyd et $al.$ (2010), the per-capita cost of action at time t is defined as:

$$c_t = \frac{C}{(n_t^A)^\gamma} \tag{2}$$

where n_t^A is the number of fishermen who participates in action with $n_t^A \in [0, n_t]$ and $n_t = N - L_t$, and C is a constant. The total cost at time t is then defined as $C_t^T = n_t^A c_t$. I assume $\gamma > 1$, therefore, both the total cost and the per-capita cost are decreasing in the number of fishermen participating. Note that, while comparing the payoffs from participating and not participating in action, fishermen consider their beliefs regarding the number of others participating. Therefore, in terms of individual participation decision, n_t^A represents the expected number of participants rather than the final level which is observed only when the action is actually taken.

As mentioned above, after a successful action, the state will move in and set the level of pollution, p_t^s, by maximizing the planner's social welfare function. The planner's social welfare function (SWF) is defined as a weighted sum of the industry profit and the total payoff of the fishermen. Hence, the level of p_t^s is given by the solution to:

$$\max_{p_t} SWF_t = q_t(f(\widehat{L}_t) - \widehat{w}_t \widehat{L}_t - h(ef(\widehat{L}_t) - p_t)) + (1 - q_t)\left[F(\widehat{n}_t, p_t)\right] \quad for \; \forall t \tag{3}$$

where $\widehat{L}_t$ is the industry's best response function for given level of p^s. In the case of a successful action, the level of p_t^s will be lower than p_{t-1}^s since it is assumed that after each successful action q is decreasing by a given amount and that $\frac{d\pi}{dp} > 0$ while $\frac{dF}{dp} < 0$. In particular:

$$q_{t+1} = q_t - d_t \xi \tag{4}$$

where ξ is a positive constant and d is a dummy variable with $d_t = 1$ if there has been a successful action in period t and $d_t = 0$ otherwise. If a successful action happens, p^s will continue to decrease until p^{s^*} is reached but I do not model this process explicitly and assume that after the first successful action p^s jumps to the level of p^{s^*} which ensures that the industry satisfies the NAC. Hence, the state solves the planner's social welfare maximization only once, in the first period, and only in case of a successful action. Therefore, the only level of q that is to be considered is the level which yields p^{s^*} as the solution to the social welfare maximization.

The probability of success of action depends on the number of participants and the strength of opposition that fishermen will face. As mentioned above, individual participation decision depends on the marginal effect of his participation on success probability given his belief about the number of others participating. Intuitively, the shape of the

success probability function should be such that the marginal effect of individual participation on success probability should be very low for both low and high levels of belief regarding the number of others participating, while, for intermediate levels of belief the marginal effect should be high.[10] In other words, the slope of the success probability function should be low for low and high levels of belief and the slope in between should be high. The implied S-shaped function is provided by the class of functions named as contest success functions, which shows how the probability of winning in a conflict depends on the resources invested by the parties involved (Hirschleifer, 1989; Tullock, 1967). The specific functional form used here is denoted by $r(n_t^A)$ and defined as follows:

$$r(n_t^A) = \frac{(n_t^A)^\nu}{(n_t^A)^\nu + (\varphi)^\nu} \tag{5}$$

where φ is a proxy measuring the strength of the opposition that fishermen face, e.g. the number of police forces and whether they are armed or not, ν is a parameter measuring the curvature of $r(n_t^A)$ with $\nu > 0$. In general, φ can be thought of as a proxy for the state's position regarding the conflict in question. For example, if the state is more concerned with growth and, hence, with the interests of the industry, φ will be high and, as a result, the probability of success will be low. Similarly, the state might choose to ignore the action and, moreover, to suppress the media so that the action is not heard off to the general public. As in the cost function, n_t^A represents the expected number of participants at time t in the context of individual participation decision whereas it represents the actual number of participants in the context of industry's expected profit maximization problem.[11] It is important to note that, the probability of success of action decreases if more fishermen are employed in the industry, i.e. $\frac{\partial r}{\partial L} < 0$. This is why employing fishermen is in the interest of the industry.

Figure 2 shows the $r(n^A)$ function for $\nu = 5$ and $\varphi = 75$.

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[10]Individual fisherman will not participate if he believes that very few of others will participate. Similarly, if he believes that most of the others will participate, he will think that his participation will not have any significant effect on the result either.

[11]Note that, expected profit maximisation will be relevant only in case the NAC is not satisfied. In the identical fishermen case, the industry knows that if action is ever taken, all fishermen will participate. Hence, the relevant argument of success probability function for the industry expected profit maximisation is $N - L_t$.
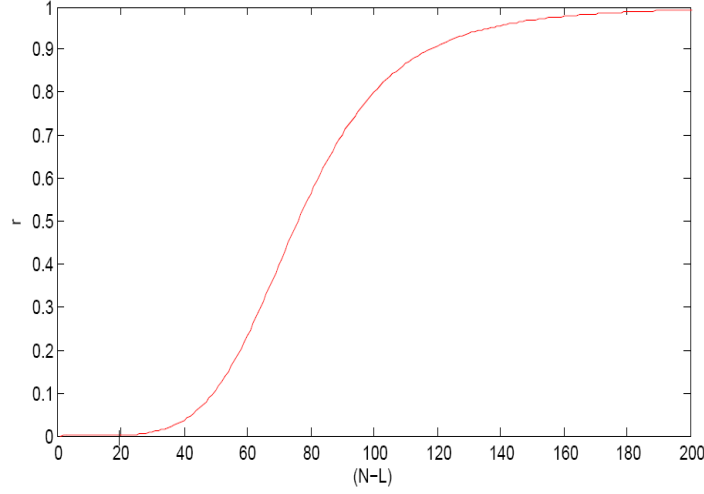
Figure 2. The success probability function for $\nu = 5$ and $\varphi = 75$.

As suggested by the shape of the $r(n^A)$ function, $\frac{\partial r}{\partial n^A} = 0$ in the lower and upper flat regions implying that the marginal increase in r brought about by a unit increase in the number of participants is close to zero in these regions.

Given this set-up, the analysis of the game will be conducted considering only two periods. The analysis depends on the assumption of fishermen being identical or heterogeneous. The case of identical fishermen will be discussed first. Then I will move on to the discussion of heterogeneous fishermen.

3.2. Identical Fishermen

The assumption of identical fishermen has two major implications for the model. First, if fishermen are identical, then the ones who will be employed in the industry, as long as the PC is satisfied, are selected randomly. Second, with respect to the decision regarding whether to take action or not, since fishermen all have the same payoff functions and beliefs, and simultaneously choose whether to act or not, they will either all take action, as long as the NAC is not satisfied, or no action will be taken.

With the relevant functions defined as above, I can now define the two constraints, the PC and the NAC, for the case of identical fishermen.

3.2.1. The Non-action Constraint (NAC)

The NAC tells that, for an individual fisherman, payoff from non-action should be greater than or equal to the expected payoff from action. What determines the decision of an individual fisherman is the marginal impact of his participation on the success probability of action, given his belief about the number of other fishermen participating. If the marginal effect of an individual fisherman's participation on the success probability of action is sufficient to make action his optimal strategy, he will not prefer to free ride.

The marginal effect of an individual fisherman's participation depends on his belief about how many other fishermen, i.e. what fraction of those who remained as fishermen, will take action. Denote the belief of a fisherman, at time t, about the fraction of other fishermen participating as a_t, hence the belief about the number of other fishermen who will take action is given by $a_t(N - L_t)$. Since fishermen are identical, a_t is a common prior. It is also assumed that a_t is common knowledge (hence, also known to the industry) and

that it is endogenous. More specifically, following a failed action, a is assumed to decrease to 0 as fishermen are discouraged. It is also assumed that $r'(1) = 0$. These assumptions imply that no fisherman will take action once an attempt has failed. On the other hand, after each successful action, a is assumed to increase by a given amount defined by:

$$a_{t+1} = a_t + \varrho s_t \tag{6}$$

where ϱ is a positive constant and s is a dummy variable with $s_t = 1$ if there has been a successful action in period t and and $s_t = 0$ otherwise. Note that, as mentioned above, rather than a series of successful actions, the analysis here considers only one such action after which the level of p^s jumps to p^{s^*} which ensures the the industry satisfies the NAC in the subsequent periods. Therefore, as for the formal analysis, only the first period level of a will be relevant. However, the endogeneity of a is still an important aspect of the process which is to be explained below in more detail.

In the two periods set-up defined above (where the second period is repeated forever), if fishermen ever take action, it takes place in the first period. Hence, in the first period, fishermen compare the payoffs from participating in action, $EU(A)$, and free-riding on other fishermen, $EU(NA)$. These payoffs are given by[12]:

$$\begin{aligned} EU(A) \quad = \quad & r(a(N-L)+1)\frac{F(N-L^{s^*}, p^{s^*})}{N-L^{s^*}} \\ & +(1-r(a(N-L)+1))\frac{F(N-L,p)}{N-L} - \frac{C}{[a(N-L)+1]^\gamma} \end{aligned} \tag{7}$$

$$EU(NA) = r(a(N-L))\frac{F(N-L^{s^*}, p^{s^*})}{N-L^{s^*}} + (1-r(a(N-L)))\frac{F(N-L,p)}{N-L} \tag{8}$$

It is assumed that individual fisherman will choose not to take action if he is indifferent. Then, the levels of a which satisfy $EU(A) = EU(NA)$ are the critical levels of belief. Note that, since $\frac{d^2r}{da^2}$ changes sign only once, there are two critical levels due to the assumed shape of the success probability function.[13] These levels, denoted by $\underline{a}$ and $\bar{a}$, define the lower and upper bounds of the range of beliefs for which $EU(A) > EU(NA)$. In other words, if $\underline{a} < a < \bar{a}$ fishermen will take action, otherwise there will be no action. These cutoff levels are given by the solutions to $EU(A) = EU(NA)$:

$$[r(a(N-L)+1) - r(a(N-L))]\left[\frac{F(N-L^{s^*}, p^{s^*})}{N-L^{s^*}} - \frac{F(N-L,p)}{N-L}\right] \tag{9}$$

$$= \frac{C}{[a(N-L)+1]^\gamma}$$

---

[12]Note that the time subscripts are dropped as we are considering only the first period decision.
[13]The S-shaped $r(n^A)$ function implies that fishermen will not take action for both low and high levels of belief (in the lower and upper flat parts of the graph where $r'(n^A)$ is close to zero) while taking action will be optimal for intermediate levels of belief.

NAC requires $EU(A) \leq EU(NA)$:

$$[r(a(N-L)+1) - r(a(N-L))] \left[\frac{F(N-L^{s^*}, p^{s^*})}{N-L^{s^*}} - \frac{F(N-L,p)}{N-L} \right] \tag{NAC}$$

$$\leq \frac{C}{[a(N-L)+1]^\gamma}$$

An individual fisherman does not take action as long as the cost of action is greater than or equal to the marginal increase in the success probability times the differential payoff to be received if action is successful.

Proposition : *If there exists a level of n^A such that the NAC is not satisfied, then there exist two levels n_L^A & n_H^A, with $n_L^A < n_H^A$, such that the NAC is satisfied for n^A if $n_L^A > n^A$ and $n_H^A < n^A$.*

Proof. For the values of n^A in the lower and upper flat parts of the $r(n^A)$ function, $\frac{dr(n^A)}{dn^a} = 0$ and, therefore, the NAC is satisfied. Take a level of $n^A \in (0, N-L)$ such that NAC is not satisfied. Then there exists a level, n_L^A, such that for the levels of n^A below n_L^A the NAC is satisfied. Similarly, there exists a level n_H^A such that for levels of n^A above n_H^A, the NAC is satisfied. ∎

Since, it is costly to satisfy the NAC for the industry–it requires lower p and higher L compared to the case in which the industry is unconstrained–the NAC will be satisfied as an equality if it is ever satisfied. Considering the NAC as an equality and totally differentiating, we obtain that $\frac{dL}{dp} > 0$; higher levels of p imply higher levels of L. The industry can increase the level of pollution and still ensure that the NAC is satisfied as long as it increases the level of employment as well. Moreover, since $\frac{\partial^2 NAC}{\partial L \partial p} < 0$ for all levels of L and p, L and p are strategic substitutes. Hence, increasing the level of employment decreases the effect of decreasing the level of pollution on satisfying the NAC.

I now examine how the level of a affect the level of average product that the industry must ensure, due to the choices of L and p, in order to satisfy the NAC. In Figure 2 (above), the x-axis can be interpreted, for current purposes, as $a(N-L)$, that is, the expected, rather than the actual, number of participants. For a given level of $(N-L)$, starting from a low level of belief, the level of average product from fishing needed to satisfy the NAC is increasing as the level of belief increases and moves to the steep region of $r(n^A)$, since the RHS of the NAC is decreasing and $r'(n^A)$ is increasing. As it reaches the point on the steep region where $r'(n^A)$ starts to decrease, the LHS of the NAC starts to decrease as a increases. For the whole range of beliefs, the relation between the level of $\frac{F(N-L,p)}{N-L}$ which satisfies the NAC and the level of beliefs is given by $\frac{d\left(\frac{F(N-L,p)}{N-L}\right)}{da}$ and is obtained by totally differentiating (9). Denoting $\frac{F(N-L,p)}{N-L}$ as y^F, $\frac{F(N-L^{s^*}, p^{s^*})}{N-L^{s^*}}$ as y^S and using $[r(a(N-L)+1) - r(a(N-L))]$ as an approximation for $r'(n^A)$, the total differentiation yields:

$$\frac{dy^F}{da} = \frac{(y^S - y^F)\frac{d^2 r(n^A)}{da^2} + \frac{\gamma(N-L)C}{(a(N-L))^{\gamma-1}}}{\frac{dr(n^A)}{da}} \tag{10}$$

The denominator in (10) is always positive, and so are $(y^S - y^F)$ and $\frac{\gamma(N-L)C}{(a(N-L))^{\gamma-1}}$. Then, (10) shows that, as stated above, $\frac{dy^F}{da} > 0$ for $\frac{d^2 r(n^A)}{da^2} > 0$. After the point where $r'(n^A)$ starts to decrease, hence, $\frac{d^2 r(n^A)}{da^2}$ becomes negative, the sign of $\frac{dy^F}{da}$ depends on whether $(y^S - y^F)\left|\frac{d^2 r(n^A)}{da^2}\right|$ is greater or less than $\frac{\gamma(N-L)C}{(a(N-L))^{\gamma-1}}$. Thus, the level of a which makes the numerator zero, a^*, is the level of beliefs for which the level of y^F needed to satisfy the NAC is at its maximum level. For $a > a^*$, $\frac{dy^F}{da}$ becomes negative. a^* is given by:

$$a^* = (N - L)^{\frac{2-\gamma}{\gamma-1}} \left[\frac{\gamma C}{(y^S - y^F)\left|\frac{d^2 r(n^A)}{da^2}\right|} \right]^{\frac{1}{\gamma-1}} \tag{11}$$

Figure 3, below, shows the level of y^F which satisfies the NAC for different values of a, for a given level of $N - L$. The NAC is not satisfied below the curve but it is satisfied on the boundary and above the curve. Starting from a point below the curve, such as points x and y, after a successful action, there are two forces in effect: the next period level of a increases–leading to an increase in next period level of y^F if the initial level of a is less than a^* (e.g. point x) or a decrease in y^F if initial level of a is greater than a^*(e.g. point y)–and the next period level of p^s decreases–leading to an increase in the next period level of y^F. Therefore, starting from a point below the curve, after each successful action we get closer to the curve and when the curve is reached the NAC is satisfied and fishermen do not take action. This is the SA case described in section 2.1.
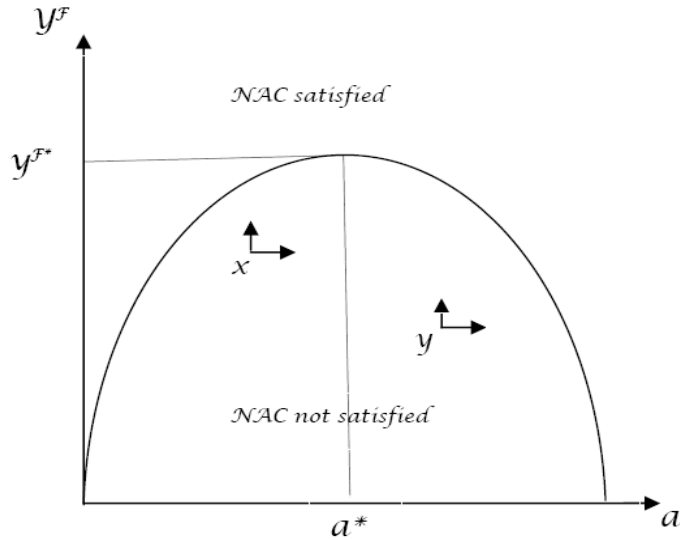

Figure 3. The level of y^F needed to satisfy the NAC for different levels of belief (for a given level of $N - L$). While low and high levels of belief yield a low average income for fishermen, intermediate levels of belief yield higher income.

3.2.2. The Participation Constraint (PC)

The PC means that the wage offered by the industry should be greater than or equal to fishermen's fall-back positions which is equal to the average product from fishing in case NAC is satisfied and, otherwise, to the expected payoff from action:

$$w \geq \max \left\{ \frac{F(N-L,p)}{N-L}, \right.$$
$$\left. (1-r(n^A))\frac{F(N-L,p)}{N-L} + r(n^A)\frac{F(N-L^{s^*},p^{s^*})}{N-L^{s^*}} - \frac{C}{[n^A]^\gamma} \right\} \tag{PC}$$

where $n^A = a(N-L)$ since the fall-back position refers to the expectation of fishermen prior to the action decision, hence, the success probability is calculated for the expected number of participants.

3.2.3. Analysis

The three cases described in section 2.1–NA, SA and FA–imply that in the first period the industry compares the payoffs from constrained and unconstrained optimization and accordingly either satisfies the NAC and prevents action or lets fishermen take action. As explained above, the analysis will be conducted by collapsing the repeated framework into two periods where the second period is repeated forever. In this section, I will move on to the analysis of the unconstrained and constrained optimization problems of the industry, and the corresponding problems of the state and fishermen, in the aforementioned two periods set-up.

In both constrained and unconstrained cases, to solve the problem of profit maximization in the first node the industry needs to know the level of p^{s^*}. The level of p^{s^*}, in turn, is given by the solution to the planner's social welfare maximization and depends on the best response function of the industry with respect to labour. Therefore, the whole game is solved by backward induction in three steps. First, profit maximization of the industry after a successful action is solved, for a given level of p, to obtain $\widehat{L}(p)$, the labour best-response function of the industry.[14] Then, given $\widehat{L}(p)$, the planner's social welfare maximization is solved to determine p^{s^*}. Finally, p^{s^*} and the corresponding level of L^{s^*} (given by $\widehat{L}(p^{s^*})$) is substituted in the NAC, and, given p^{s^*}, the industry solves the profit maximization at the initial node. The solution to this problem gives the initially announced levels of L and p. Note that, the first two steps of backward induction yield the same solutions for constrained and unconstrained problems. Therefore, before moving on to the constrained and unconstrained profit maximization problems, I will describe these two steps.

The first step of backward induction, the problem of profit maximization, given p, is the following:

$$\max_L \pi = f(L) - wL - h(ef(L) - p) \tag{12}$$

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[14]Note that, the state moves only after a successful action which implies that the NAC has not been satisfied, i.e. the relevant case is the SA case. Then, while deriving the best response function of the industry, the state considers the unconstrained profit maximisation (as described below) where NAC is not considered and p is set to its upper-bound level, that is, the level of p^s.

where $w = \frac{F(n,p)}{n}$ due to PC. Denote the abatement level, $ef(L) - p$, by p^{abt}. The FOC is given by:

$$\frac{df}{dL}\left(1 - e\frac{dh}{dp^{abt}}\right) = \frac{N}{(N-L)^2}F(n,p) - \frac{L}{N-L}\frac{\partial F}{\partial L} \tag{13}$$

The solution to (13) gives the labour best response function, $\widehat{L}(p)$. Given this best response function, the problem of social welfare maximization is solved. Substituting w with $\frac{F(n,p)}{n}$, the problem of social welfare maximization can be written as:

$$\max_{p} SWF = q(f(\widehat{L}) - \frac{F(\widehat{n},p)}{\widehat{n}}\widehat{L} - h(ef(\widehat{L}) - p)) + (1-q)\left[F(\widehat{n},p)\right] \tag{14}$$

Denote $f(\widehat{L}) - \widehat{w}\widehat{L} - h(ef(\widehat{L}) - p)$ as $\widehat{\pi}(p)$, and $F(\widehat{n},p)$ as $\widehat{y}^F$. Then the FOC for (14) is given by:

$$q(\widehat{\pi}_L\widehat{L}_p + \widehat{\pi}_p) + (1-q)\left(\widehat{y}_p^F + \widehat{y}_L^F\widehat{L}_p\right) = 0 \tag{15}$$

The solution to (15) gives p^{s*}. With $\widehat{L}(p^{s*})$ as the level of employment given p^{s*}, the industry profit level after a successful action is calculated.

Unconstrained Optimization

The industry is not concerned with satisfying the NAC, hence it has no incentive to set the level of pollution below its upper-bound level. Thus, the first period pollution level is given by $p_1 = p_0^s$. If the action fails, the level of p^s is not changed, and if the action succeeds, p^s is set to p^{s*}. As, in both cases, fishermen do not take action in the subsequent periods, the problem of the industry in the second period is:

$$\max_{L} \pi = f(L) - wL - h(ef(L) - p^s)$$

where $w = \frac{F(n,p^s)}{n}$ due to the PC and p^s is given by p_0^s in the failed action case and by p^{s*} in the successful action case. The FOC to this problem is the same as (13). Denoting the solution to the profit maximization problem in the failed action case as π^{FA} and the one in the successful action case as π^{SA}, the profit maximization in the first period is given by:

$$\max_{L} E\Pi^U = (1 - r(n^A))\begin{bmatrix} f(L) - wL - h(ef(L) - p_0^s) \\ +\sum_{t=2}^{\infty}\beta^{t-1}\pi^{FA} \end{bmatrix} \tag{16}$$

$$+r(n^A)\left[f(L) - wL - h(ef(L) - p_0^s) + \sum_{t=2}^{\infty}\beta^{t-1}\pi^{SA}\right]$$

where $n^A = N - L$ and $w = (1 - r(n^A))\frac{F(N-L,p)}{N-L} + r(n^A)\frac{F(N-L^{s*},p^{s*})}{N-L^{s*}} - \frac{C}{[n^A]^{\gamma}}$ since the NAC is not satisfied in the first period, hence, the fallback positions of fishermen is the expected payoff from action. The FOC is given by:

$$\frac{df}{dL} + \frac{dr}{dn^A}(-a)\left[\sum_{t=2}^{\infty}\beta^{t-1}\left(\pi^{FA} - \pi^{SA}\right)\right] = L\frac{dw}{dL} + w + \frac{dh}{dp^{abt}}e\frac{df}{dL} \tag{17}$$

Hence, the optimal level of L should be such that the marginal cost of increasing L, the RHS of (17), consisting of the increase in the total wage bill and the cost of abatement, should be equal to the marginal benefit, consisting of the marginal product of labour and the marginal increase in the expected differential payoff to deviation in the subsequent periods–marginal increase in the probability of obtaining the differential payoff, $\pi^{FA} - \pi^{SA}$, times the discounted sum of the differential payoffs to be received *ad infinitum.*

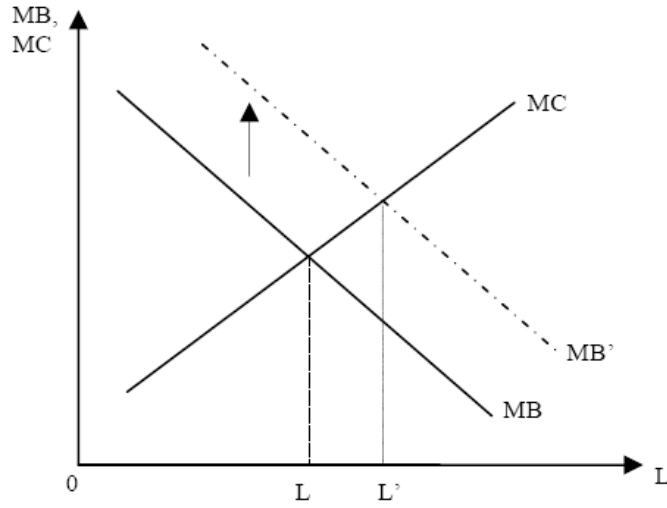Figure 3 below shows a graphical representation of $(17)^{15}$:

Figure 3. The effect of the threat of action on the FOC of profit maximization for the unconstrained case. The threat of action shifts the MB curve upwards leading to a higher level of employment.

MB and MC denote the marginal benefit and marginal cost, respectively, of increasing the employment level by one unit for the case where there is no threat of action. To focus on the effect of industry's will to prevent action on the profit maximizing level of employment, assume that the industry still employs fishermen in case there is no threat of action.[16] Then, MC is the same for the cases with and without threat of action and is given by the RHS of (17). On the other hand, MB is given by $\frac{df}{dL}$ in case there is no threat of action and by the LHS of (17) when the threat of action is introduced. The effect of threat of action and the industry's will to decrease the success probability is shown as an upper shift of MB curve to MB'. Accordingly, the profit maximizing level of L shifts to L'.

Constrained Optimization

The industry solves profit maximization subject to the NAC. This is the path described in the NA case above, that is, the NAC is satisfied in all periods and fishermen never take action. Therefore the industry solves a constrained optimization in the first period and

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[15]Clearly, the marginal benefit and the marginal cost are not linear but my aim here is not to depict the functional forms but to point out the effect of the threat of action.

[16]As mentioned before, this assumption is plausible since it would be easier for the industry to satisfy the PC in case there is no threat of action.

finds the optimal levels of L and p such that the three constraints–the PC, the NAC and that $p \leq p_0^s$–are satisfied. As there will be no action, the level of p_0^s, hence the optimal levels of L and p, will be the same for all the subsequent periods. Therefore, the problem is formulated as a one period constrained optimization where the industry receives and infinite stream of the first period profit. Also note that, since the NAC will be satisfied, expected payoff from participating in action will be less than the average product from fishing, hence, PC implies that the wage offered should be greater than or equal to the average product from fishing.

$$\max_{L,p} \pi = f(L) - wL - h(ef(L) - p) \tag{18}$$

$$subject \quad to \quad w \geq \frac{F(n,p)}{n} \quad (PC)$$

$$[r(a(N-L)+1) - r(a(N-L))]\left[\frac{F(N-L^{s^*},p^{s^*})}{N-L^{s^*}} - \frac{F(N-L,p)}{N-L}\right] \leq \frac{C}{[a(N-L)]^\gamma} \quad (NAC)$$

$$p \leq p_0^s$$

Note that the PC will be satisfied as an equality. Substituting the PC to the profit function, the Lagrangian of this problem is:

$$\begin{aligned}
\pounds &= \left[f(L) - \frac{F(n,p)}{n}L - h(ef(L)-p)\right] \tag{19}\\
&+ \lambda_1 \left[\frac{C}{[a(N-L)]^\gamma} - [r(a(N-L)+1) - r(a(N-L))]\left(\frac{F(N-L^{s^*},p^{s^*})}{N-L^{s^*}} - \frac{F(N-L,p)}{N-L}\right)\right]\\
&+ \lambda_2 \left(p_0^s - p\right)
\end{aligned}$$

The first order conditions are given by:

$$\frac{\partial \pounds}{\partial L} = \frac{\partial \pi}{\partial L} + \lambda_1 \frac{\partial NAC}{\partial L} = 0 \tag{20}$$

$$\frac{\partial \pounds}{\partial p} = \frac{\partial \pi}{\partial p} - \lambda_2 = 0 \tag{21}$$

where:

$$\frac{\partial NAC}{\partial L} = \frac{\gamma C}{a^\gamma (N-L)^{\gamma-1}} + \frac{d^2 r}{dn^{A2}} \left(y^S - y^F \right) + \frac{dr}{dn^A} \frac{\partial y^F}{\partial L} \tag{22}$$

$$\frac{\partial \pi}{\partial L} = \frac{df}{dL} \left(1 - \frac{dh}{dp^{abt}} e \frac{df}{dL} \right) - y^F - L \frac{\partial y^F}{\partial L} \tag{23}$$

$$\frac{\partial \pi}{\partial p} = -L \frac{\partial y^F}{\partial p} + \frac{dh}{dp^{abt}} \tag{24}$$

The complementary slackness conditions defined as:

$$\lambda_1 NAC = 0 \tag{25}$$

$$\lambda_2 \left(p_0^s - p \right) = 0 \tag{26}$$

Note that the Lagrange multipliers, λ_1 and λ_2, are the shadow prices of the two constraints. In particular, λ_1 is the cost of preventing the action by satisfying the NAC and λ_2 is the cost of a marginal variation in the pollution upper bound constraint. It was shown above, in the unconstrained optimization case, that in order to reduce the probability of success of action the industry employs more fishermen compared to the case where there is no threat of action. However, even that level of employment is not enough to satisfy the NAC. In the constrained optimization case, the employment level will even be higher since now the industry satisfies the NAC.

To sum up, the analysis so far showed that, there are three possible paths that the game can follow. Depending on the present values of the unconstrained and constrained profits, the industry decides whether or not to satisfy the NAC in the first period, and, accordingly, one of the three cases–the NA, FA and SA– is realized. The profit of the industry, hence its decision regarding preventing action or not, depends on the success probability of action which, in turn, depends on the beliefs of fishermen concerning the number of other fishermen who would take part in action. The action decision of fishermen depend on these beliefs as well, besides the level of pollution and employment set by the industry. The underlying assumption so far was that fishermen are identical which implied that they all have identical beliefs and payoff functions, hence, either they all take action or no one takes action. In the following section, the same analysis will be conducted by dropping this assumption.

3.3. Heterogenous Fishermen

Fishermen are considered to be heterogeneous with respect to their individual characteristics, i.e. types. Each fisherman's type is determined by a composite parameter consisting mainly of how much each fisherman values being a fisherman–"identity value of fishing"–, how much he is opposed to the industry, how much he values living in that area and his level of political activism.[17] Each fisherman's type is given by his parameter value and is private information. The random parameter determining types are drawn from a distribution with density function g and cumulative density function G. The distribution of types is common knowledge.

Let the value of a fisherman's parameter value, hence his type, be denoted by δ_i with $\delta_i > 0$. The type space is $\boldsymbol{\delta} = \{\delta_1, ..., \delta_N\}$. It is assumed that $\delta_i \neq \delta_j$ for $i \neq j$, and that fishermen are distributed uniformly along the type space. The type of each fisherman enters his payoff function as a multiplier–as a weight–, that is, the payoff each fisherman receives is equal to his material payoff times his identity value parameter. Therefore, same material payoff is valued differently by fishermen of different types. In particular, for period t, the payoff to fisherman i from fishing is:

$$u_{it}^F = \frac{F(n_t, p_t)}{n_t} \delta_i$$

where, as before, $n_t = N - L_t$ is the number of fishermen at time t and p_t is the pollution level. The value of δ_i is assumed to be time invariant.

In the identical fishermen case, it was assumed that the fishermen who are to be employed in the industry are selected randomly. In the heterogenous fishermen case, this assumption can be relaxed. In particular, the L fishermen who are employed in the industry will be the ones with types $\{\delta_1, ..., \delta_L\}$ where the types are put in ascending order.

Remember, in the identical fishermen case, it was shown that if the belief of fishermen regarding the portion of other fishermen who will take action, a, is in the range of the two critical levels, all fishermen take action. In the heterogeneous case, a similar analysis is conducted, with the additional feature of self-consistent beliefs. Since it is no longer the case that either all fishermen will take action or there will be no action, it is possible to define a relation between the level of belief and the number of fishermen who would actually take action given that level of belief. Accordingly, we need to check whether the beliefs are self-consistent, that is whether the belief is equal to the number of fishermen who would actually take action given that level of belief (for a given level of average income from fishing, y^F).[18] The intuition behind self-consistency is the following: for given level of y^F, consider some level of belief regarding the number of fishermen who would take action, K, then for each fisherman calculate the expected payoffs from action and nonaction and find whether he will participate or not. If the number of fishermen

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[17]Heterogeneity might include aspects like wealth and productivity, however, since it is assumed that fishermen share the aggregate product from fishing and also that they have no other income, these aspects do not apply to this model.

[18]Self-consistency assumes some form of communication among fishermen by way of which they share their beliefs and see whether it is consistent with the beliefs of everyone else. At the end of this process, fishermen come up with a self-consistent belief such that they know exactly the number of fishermen who will take action.

who will participate is K, then K is self-consistent. The corresponding expected payoffs for fisherman i is defined as:

$$EU(A)_i = r(K+1)\frac{F(n^{s*}, p^{s*})}{n^{s*}}\delta_i + [1 - r(K+1)]\frac{F(n, p)}{n}\delta_i - \frac{C}{(K+1)^\gamma}\delta_i \tag{27}$$

$$EU(NA)_i = r(K)\frac{F(n^{s*}, p^{s*})}{n^{s*}}\delta_i + [1 - r(K)]\frac{F(n, p)}{n}\delta_i \tag{28}$$

where n^{s*} and p^{s*} are defined as before. Equating these payoffs we get:

$$[r(K+1) - r(K)]\left[\frac{F(n^{s*}, p^{s*})}{n^{s*}} - \frac{F(n, p)}{n}\right] = \frac{C}{(K+1)^\gamma} \tag{29}$$

which is the same as equation (9) except for the levels of beliefs. Hence, as in the identical fishermen case, if the NAC is ever failed to be satisfied for some level of y^F, then there are two critical values of belief, defining the range of beliefs for which the NAC is not satisfied (see proposition 4 above). Denote these lower and upper levels of belief as $\underline{K}$ and $\overline{K}$ such that, for $K > \overline{K}$ and for $K < \underline{K}$ (the upper and lower flat regions of the $r(n^A)$ graph shown in figure 2), the NAC is satisfied. Figure 4 shows these critical levels of beliefs. The $z(K; y^F)$ function is the function of the number of fishermen who would actually take action, z, for each level of belief, K, for a given level of average income from fishing, y^F. Self-consistency of beliefs imply that $K = z(K; y^F)$. Hence, self-consistent beliefs are given by the intersection of the $z(K; y^F)$ function and the self-consistency constraint–the ray from the origin with a slope of 1.
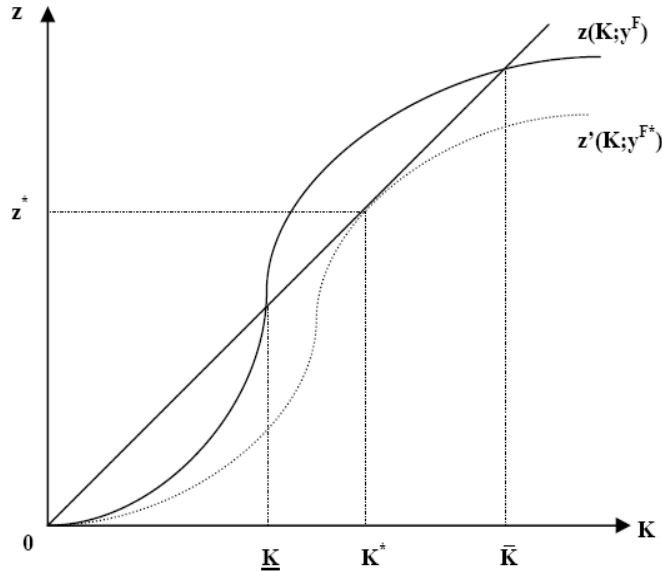

Figure 4. The $z(K; y^F)$ function gives the number of fishermen who would actually participate, z, for different values of beliefs, for a given level of average income from fishing. As y^F increases (decreases), the $z(K; y^F)$ function shifts downward (upward).

The levels of beliefs $K = 0$, $K = \overline{K}$ and $K = \underline{K}$ are self-consistent. Are they self-correcting? Consider the dynamics of beliefs defined previously. Now, modifying the

notation, the dynamics is defined as:

$$dK = m(z(K; y^F) - K) \tag{30}$$

where m is a positive constant. Hence, for $K < \underline{K}$, $z(K; y^F)$ is less than K and therefore $dK < 0$, i.e. beliefs are revised downwards. Similarly, for $K > \underline{K}$, $z(K; y^F)$ is greater than K and therefore $dK > 0$, i.e. beliefs are revised upwards. Thus, though self-consistent, $\underline{K}$ is not self-correcting. Perturbations around $\underline{K}$, lead to excursions to either $K = 0$ or to $K = \overline{K}$. Therefore, only the values of $K = 0$ and $K = \overline{K}$ (if it exists) are relevant for our analysis. I will not consider $K = 0$ as well since the argument is straightforward: if a fisherman believes that no other fisherman will participate, he will not participate as well since $r'(1)$ is assumed to be 0.

How is the NAC defined in this case? That is, what should be the levels of L and p which prevent action? The industry can prevent action if there is only one self-consistent level of belief and the NAC is satisfied for that level of belief. In figure 4, starting from $z(K; y^F)$ as depicted in the graph, as y^F increases the $z(K; y^F)$ function shifts downward as a result of which $\overline{K}$ decreases. Hence, by offering a higher level of y^F, the industry can reduce participation. In order to prevent action, $z(K; y^F)$ must shift to $z'(K; y^{F*})$ where y^{F*} is such that the NAC is satisfied given K^*.[19] Since the $z'(K; y^{F*})$ function is tangent to the self-consistency constraint, the NAC can now be written as:

$$\frac{dz(K; y^F)}{dK} = 1 \quad \& \quad \frac{z}{K} = 1 \tag{31}$$

where the first condition implies the tangency of $z(K; y^F)$ curve to the self-consistency line and the latter implies that the beliefs are self-consistent. If a lower level of y^F is offered, such that $y^F < y^{F*}$, then there will be action.

How is the PC defined? As in the identical fishermen case, the PC requires that the wage offered by the industry should be greater than or equal to the fall-back position of fishermen which is, in the heterogeneous case, dependent on the type of fishermen. In other words, depending on his type value, every fisherman has a different participation constraint. Due to the asymmetric information structure, the industry does not know the types of fishermen, hence it cannot determine with certainty the level of wage that would ensure that exactly L fishermen will accept employment. Moreover, in case the NAC is not satisfied, the w function has a kink at the level of L corresponding to the cutoff level of types, that is the lowest type value among the fishermen taking action, since the fall-back position for fishermen below the cutoff level is their payoff from fishing while for the ones above the cutoff level it is the expected payoff from action. The cutoff value of types, $\underline{\delta}$, is defined as the value corresponding to the level of $\overline{K}$ and is given by:

$$\overline{K} = (1 - G(\underline{\delta}))N \Rightarrow \underline{\delta} = G^{-1}\left(\frac{\overline{K}}{N}\right) \tag{32}$$

where G is the cumulative distribution function of the distribution of types. The argument here follows from the fact that, for given level of a self-consistent (and self-correcting)

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[19]Note that, given K^*, for any level of $y^F > y^{F*}$, $dK < 0$. However, it will not be profit maximizing for the industry to set $y^F > y^{F*}$ since the NAC is already satisfied for y^{F*}.

belief, $\overline{K}$, if the NAC is not satisfied, there will be a fisherman on the margin, i.e. indifferent between action and nonaction, and all fishermen with type values greater than that of the marginal fisherman, i.e. $\delta_i > \underline{\delta}$, will find it optimal to take action. Note that, as $\overline{K}$ is determined by equating the expected payoffs from action and nonaction, it is, indeed, dependent on the levels of L and p. A higher y^F implies lower $\overline{K}$ and, accordingly, higher $\underline{\delta}$. This is how the industry reduces participation by offering a higher y^F.

If the industry knew the types of fishermen, the w function it considers would be:

$$w = \begin{cases} \boldsymbol{\delta}_L \left(r(K^*)\frac{F(n^{s*},p^{s*})}{n^{s*}}\delta_L + [1 - r(K^*)]\frac{F(n,p)}{n}\delta_L - \frac{C}{K^\gamma}\delta_L \right) & if \quad \delta_L \geq \underline{\delta} \\ \delta_L \frac{F(n,p)}{n} & if \quad \delta_L < \underline{\delta} \end{cases} \tag{33}$$

Note that the industry can still estimate the type of fisherman L:

$$L = NG(\delta_L) \Rightarrow \delta_L = G^{-1}\left(\frac{L}{N}\right) \tag{34}$$

One might think that, given the estimations, the industry could employ only the fishermen above the cutoff level. However, it is not possible due to the selection problem.[20] The industry might still find the level of w which would ensure that L fishermen accept employment through a process of trial and error, i.e. by increasing the wage offered until the level of employment reaches L.[21]

So, how are the optimal levels of L and p are determined in this case? For the identical fishermen case, three possible paths were discussed. Whichever one of them is realized is said to be dependent on the parameter values that determine whether the industry will find it optimal to satisfy the NAC in the first period or not. In the heterogeneous case, the same argument applies.

Also, the overall backward induction analysis of the previous section applies here as well. The first step of backward induction, profit maximization of the industry following a successful action, is still given by (12). The second step is the same as the previous section as well since we are assuming that the state considers only the material payoffs while solving the social welfare maximization problem and the social welfare function is the same as the identical fishermen case. Therefore, the planner's problem of social welfare maximization is still given by (14). The final step of the backward induction, profit maximization at the initial node, however, is now different due to heterogeneity and asymmetric information structure. However, the underlying logic of comparing the constrained and unconstrained profit levels is still the same.

3.3.1. Unconstrained Optimization

The industry does not satisfy the NAC in the first period and fishermen take action. Due to the previous assumptions, if action fails, fishermen will never take action again:

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[20]Suppose the industry wants to employ k fishermen above the cutoff level and accordingly offers a wage which satisfies the participation constraint of the kth fisherman above the cutoff level. Hence the participation constraint is satisfied for fishermen below that level as well. The industry, however, cannot identify the k fishers above the cutoff level.

[21]As it was assumed that there is no wage discrimination, the indsutry increases the wage also for the fishermen who have already been employed.

and, if it succeeds, the state will move in and set p^{s^*} so that it will be optimal for the industry to satisfy the NAC from the second period onwards. Then the problem of the industry in the first period is to find the level of $\overline{K}$ minimizing the success probability, hence, maximizing the expected profit. Define $\overline{z} = z(\overline{K}; y^F)$. The expected profit of the industry in this case is given by:

$$
\max_{L,p} E\Pi^U = (1 - r(\overline{z})) \left[f(L) - wL - h(ef(L) - p) + \sum_{t=2}^{\infty} \beta^{t-1} \pi_h^{FA} \right] \tag{35}
$$
$$
+ r(\overline{z}) \left[f(L) - wL - h(ef(L) - p) + \sum_{t=2}^{\infty} \beta^{t-1} \pi_h^{SA} \right]
$$

where, as before, β is the discount factor, π_h^{FA} is the unconstrained profit level after a failed action where $p = p_0^s$; π_h^{SA} is the profit level after a successful action where L and p are such that the NAC is satisfied. Note that, in contrast to the identical fishermen case, now it might be optimal for the industry to set the level of pollution below its upper bound level even if it is not concerned with satisfying the NAC. In the identical fishermen case, if the industry is not concerned with satisfying the NAC, all fishermen will take action, hence the industry will try to reduce success probability by increasing the level of employment. Since the level of pollution does not affect the success probability, the industry has no incentive to set a pollution level lower than the upper bound level. On the other hand, in the heterogenous fishermen case, even if the NAC is not satisfied, the industry still has an incentive to set a low level of pollution through its effect on y^F, which in turn affects–through the mechanisms described above–the level of participation. In this case, both L and p work through their affect on the level of y^F.

Define $\pi = f(L) - wL - h(ef(L) - p)$. Then, the FOCs with respect to L and p are given by:

$$
\frac{d\pi}{dL} = \frac{\partial r}{\partial z} \frac{\partial z}{\partial L} \left[\sum_{t=2}^{\infty} \beta^{t-1} \pi_h^{FA} - \sum_{t=2}^{\infty} \beta^{t-1} \pi_h^{SA} \right] \tag{36}
$$

$$
\frac{d\pi}{dp} = \frac{\partial r}{\partial z} \frac{\partial z}{\partial p} \left[\sum_{t=2}^{\infty} \beta^{t-1} \pi_h^{FA} - \sum_{t=2}^{\infty} \beta^{t-1} \pi_h^{SA} \right] \tag{37}
$$

These two first order conditions conform to the argument that both L and p act through the same channels, namely through their effect on y^F, hence, on the level of participation. Accordingly, as revealed also by the FOCs, the optimal levels of L and p depend on their relative effect on z (which determines their marginal benefit in terms of increasing the probability of receiving the differential profit between the cases of FA and SA–the RHS of the FOCs) and their net marginal cost to the industry (the LHS of the FOCs).

3.3.2. Constrained Optimization

The industry satisfies the NAC in the first period and fishermen never take action. This problem is defined as:

$$\max_{L,p} \pi = f(L) - wL - h(ef(L) - p) \tag{38}$$

subject to :

$$w = \begin{cases} \delta_L \left(r(K^*) \frac{F(n^{s^*}, p^{s^*})}{n^{s^*}} \delta_i + [1 - r(K^*)] \frac{F(n,p)}{n} \delta_i - \frac{C}{K^\gamma} \delta_i \right) & if \quad \delta_L \geq \delta^* \\ \delta_L \frac{F(n,p)}{n} & if \quad \delta_L < \delta^* \end{cases} \quad (PC)$$

$$\frac{dz(K; y^F)}{dK} = 1 \quad \& \quad \frac{z}{K} = 1 \quad (NAC)$$

$$p \leq p_0^s$$

The interpretation of this constrained problem, in terms of Lagrange multipliers, is the same as the corresponding problem in the identical fishermen case.

4. Conclusion

The tripartite model of conflict—fishermen, industry, the state—developed here is aimed at analyzing the specific ways power asymmetries operate in mediating environmental conflicts. In general terms, the model identifies three aspects of power: strategic, structural and collective. The first aspect, strategic power, is the power of the industry over its employees (à la Bowles and Gintis). The structural aspect of power is the ability of the industry to alter the circumstances in which fishers make choices. In particular, the industry has the power to change the incentive structure of fishermen by employing them. Once employed in the industry, the incentives of the individual will be defined by those of a worker rather than a fisher. Moreover, the industry, due to its control on the employment and pollution levels, determines the income of fishermen and the success probability of action (for given values of the exogenous parameters). The industry also affects the critical range of beliefs for which fishers will decide to take action. Fishers, on the other hand, have the power to constrain the choices of the industry by threatening political action, which constitutes the collective aspect of power.

Nevertheless, the threat of action acts as a constraint on the decisions of the industry ensuring higher level of employment, compared to the case where there is no threat of action, regardless of the fact that the industry satisfies the non-action constraint or not. In the identical fishermen case, the industry's willingness to prevent action leads to a lower level of pollution; otherwise, the threat of action has no effect on the pollution level. In the heterogeneous fishermen case, the threat of action still leads to a lower level of pollution if the industry is willing to prevent action, and, depending on the relative costs of abatement and labor, it might lead to a lower level of pollution even if the action is not prevented. The latter follows from the effect of L and p on the level of beliefs in the heterogeneous case. In this respect, the analysis above rested on the industry's response to the incentives that the prospect of collective action provides. It should be extended for an exploration of the conditions under which heterogeneity of fishermen may result in

greater or lesser levels of pollution via its effect on the collective action problem regarding political action.

The model can be extended by relaxing the simplifying assumptions made in the above analysis. For example, the industry is assumed to be a single entity. In case there are more than one firms, there will be a collective action problem on part of the firms as well. Moreover, if the firms are heterogeneous in the amount of pollution they produce, the ones who pollute the most will be the ones who will want to prevent action by fishermen the most. The ones who pollute less, on the other hand, will prefer to free-ride on the efforts of other firms to prevent action by fishermen.[22] This problem can be formulated by an analysis akin to the heterogeneous fishermen case. Each firm can be assigned a type value denoting how much they pollute the lake. Note that, the number of firms is likely to be small, compared to the number of fishermen; hence, the ones which pollute the most might provide the public good—preventing the action by fishermen—for the group as a whole.

Another assumption is regarding the heterogeneity of fishermen. It is assumed that fishermen are distributed uniformly along the type space. An alternative distribution might be one where the distances between the high levels of types are low and the distance is increasing as we move to lower type values. This is due to the accumulating externality effect in the sense that as the cutoff level of types (determined by the cutoff level of beliefs in the above analysis) is moved to the lower type values, the number of fishermen participating in action will increase. Hence, even though the difference between the adjacent type values is high, the effect of high level of participants might lead to a jump from one individual to the other. However, this argument is valid for the types in the nonflat region of the success probability function.

Finally, the analysis rests on the assumption of self-interest which has been heavily criticized in the last decades and, now, there is ample evidence suggesting that individuals act on motives other than self-interest, such as alturism and reciprocity, as well (Rabin, 1993; Fehr & Gachter, 2000). This assumption can be relaxed by letting some or all fishermen have reciprocal or alturistic preferences and defining the type of each fishermen in terms of these characteristics; alternatively, and more substantively, by considering a collective action model where subjective benefits depend on the magnitude of the gains to be had if the action is successful, not primarily because these gains are a likely consequence of one's individual participation but because the magnitude of the gains to be had is related to the strength of the norms motivating the action (see the collective action model in chapter 12 in Bowles, 2003).

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[22]In the case of Uluabat Lake, one of the industrial firms stated that, unlike other firms, they are abiding by the environmental regulations and, hence, they are in favor of stricter regulations which would limit pollution by other firms.

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