On the Enforcement of Territorial Use Rights Regulations: A Game Theoretic Approach

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Abstract

Territorial Use Rights (commonly known as TURFs in the literature) consists in the allocation of fishing rights to individuals and/or groups to fish in certain geographical locations. A requisite for these communities to be granted fishing rights is the formulation of a management and exploitation plan (MEP). While thus far the literature on TURFs has been centred on the biological and technical aspects of it, to our knowledge there is no work squarely dealing with the issue of enforcement of the MEP that the community, once granted the fishing use rights, have to comply with. We formally explore this issue from an economic perspective by formulating a static game of norm compliance in a regime of common property resource exploitation. The key characteristic of this game is a monitoring and sanctioning mechanism, where fishermen monitor and sanction one another. We found that in the absence of any endogenous regulation *from the part of the fishing community, TURFs can not avoid the economic over-exploitation of the fishery. We discuss the importance of economic incentives (and disincentives) in the formulation of endogenous regulations aimed at ensuring compliance of the MEP. Our results on the* *relevance of economic incentives in the context of a TURF regulation can also be used to highlight the importance of less conventional enforcement tools.*

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Resumo

Direitos de Uso Territorial (comumente conhecidos como TURFs na literatura) consistem na alocação de direitos de pesca a indivíduos e/ou grupos para pescar em certas localidades geográficas. Um requisito para que estas comunidades recebam os direitos de pesca é a formulação de um plano de gerenciamento e exploração (MEP). Enquanto a literatura sobre TURFs até agora tem sido centrada em seus aspectos biológicos e técnicos, em nosso entendimento não há trabalho tratando diretamente com a questão de como fazer cumprir o MEP que a comunidade, uma vez adquiridos os direitos de pesca, tem que seguir. Nós exploramos formalmente esta questão de uma perspectiva econômica através da formulação de um modelo de jogos estático de cumprimento da norma em um regime de exploração de recursos de propriedade comum. A característica básica deste jogo é o mecanismo de monitoramento e sanção, onde os pescadores monitoram e sancionam uns ao outros. Nós encontramos que na ausência de uma regulação endógena da parte da comunidade de pescadores, TURFs não podem evitar a exploração excessiva da pesca. Discutimos a importância dos incentivos econômicos (e desincentivos) na formulação de regulações endógenas que objetivam assegurar o cumprimento do MEP. Nossos resultados sobre a relevância dos incentivos

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econômicos no contexto de uma regulação TURF podem ser usados para mostrar a importância de instrumentos de implementação menos convencionais.

1 Introduction

In recent times, regulatory authorities have increasingly started to implement decentralised management systems in fisheries. One regulatory system that has recently started to attract the attention of policymakers regarding artisanal fisheries is that of Territorial Use Rights (commonly known as TURFs in the literature). TURFs basically consists in the allocation of fishing rights to individuals and/or groups to fish in certain geographical locations (Charles (2002); Christy (1982, 1992, 2000); Townsend and Charles (1997)). In practice, TURFs have typically been assigned to communities or fishing organisations which have a long-standing tradition of efficient/sustainable use of the marine resources. An example in this regard can be given by referring to the Japanese case, where fishery community management can be dated back to the XVIII century (for details, see inter alia: Yamamoto (1995); Akimichi (1984); Ruddle (1987, 1988, 1989); Kalland (1984); and Akimichi and Ruddle (1984). TURFS however were formally established only in 1949 once enacted, the so-called, "New" Fisheries Law (Ruddle (1989)). A requisite for these communities to be granted fishing rights, is the formulation of a fishery management plan that must be prepared by a Fishery Coordination Committee (FCC), which includes among its members; fishermen, fishery resource experts and representatives of the community in general (the latter appointed by the regional authority). The Japanese Fisheries Law demands that this plan must consider the views of the fishermen and the community and for that purpose the FCC must organise a public hearing, before delivering this proposal to the Prefecture Government (regional authority), which is in charge of issuing the fishing rights and licenses. Once approved this fishery management plan, this formal regulation establishes that the only people allowed to exploit the coastal fisheries are those belonging to legally constituted fisher/household associations, known as Fisheries Cooperative Associations (FCAs), which are given the fishing rights for 10 years (Yamamoto (1995, 2000)).

This type of property rights regime clearly involves the idea of *self-regulation*, since FCAs are the main responsible of enforcing the management and exploitation plan, being in charge of ensuring an equitable, efficient and sustainable operation of the fisheries (Akimichi (1984)). In general, FCAs operate fisheries under their control by continuing their long tradition of informal regulations in the form of *social norms*, which allow them to enforce membership, specific regulations on fishing effort levels, catch levels, location use rights, etc. (Akimichi (1984); Ruddle (1989)). While the Japanese case is probably one of the most well known TURFs systems, it is not unique and similar formal regulations have been established in other countries in fisheries with long-standing tradition of community management. This is, for instance, the case of Vanuatu (Johannes (1988); Amos (1993)), Philippines (Siar et al. (1992); Ferrer (1991), Garcia (1992), Russ and Alcalá (1999) and Fiji (Adams (1993)).

Mainly due to the excellent results achieved in some TURFs, some countries have started to evaluate the possibility of pushing this type of regulation forward and introduce territorial use rights even in coastal fisheries were *property rights have never been in place.*[1] This type of "de novo" implementation is not

[1] Prince et al. (1998), for instance, critically discuss the potential incorporation of TURF regulation in the Australian Abalone fishery and Freire and Garcia-Allut (2000) consider the introduction of

without its critics (see, for instance, Christy (2000)), and at present just a few countries have formally implemented this sort of regulation. Thus far, Chile represents the most important and ambitious initiative in this respect, establishing in its General Fisheries and Aquaculture Law (GFAL), enacted in 1991, the allocation of TURFs among fishing communities exploiting benthonic resources[2] (see *inter alia*, Parma et al. (2003); Castilla (1994, 1997, 1999); Castilla and Defeo (2001); Castilla et al. (1998); Castilla and Fernández (1998); Orensanz (2001); and Gonzalez (1996)). Specifically, Chilean fishery legislation allows the establishment of areas especially reserved for the use of artisanal fishing communities. These areas are known as "Areas for Management and Exploitation of Benthonic Resources" (AMEBR), and may be allocated to specific fishing communities. In order to be granted an AMEBR a community must constitute a legal organisation (e.g. artisanal fishermen's associations and fishermen's cooperatives, among others) and present a management and exploitation project proposal (Gonzalez (1996)). This proposal must include a baseline study, describing the benthonic resources existing in the area in terms of species, quantities, location (depth), etc., and a management and exploitation plan (MEP), specifying a set of actions directed to ensure the sustainable management of the fishery. The MEP is based on the baseline study of the area and includes a proposal of a yearly exploitation plan of the requested area, specifying harvest periods and techniques, as well as the criteria applied to determine the quantity to be harvested of the main species (Gonzalez (1996)). In other words, the MEP establishes the aggregate effort level to be used in the fishery. Upon submission and approval of this management and exploitation project proposal the fishing community can be granted the AMEBR for a two-year period.

TURFs in the selfish fisheries of Galicia (NW Spain)).

[2] For instance, Chilean abalone, sea urchins and macha clams.

According to GFAL (D.S. 355, 12 June 1995), there are two main aims associated with the allocation of AMEBRs. First, the reduction of aggregate fishing effort in Chilean coastal fisheries, reverting thus the uncontrolled increment in effort seen in the past, mainly induced by attractive markets in the presence of open access conditions (see also, Barros and Aranguez (1993); Chamorro (1993); Gonzalez (1996); Jerez and Potocnjak (1993); Pavez (1993)). Second, to improve the enforcement of coastal fisheries regulations by transferring management responsibilities from a central authority to artisanal fishing communities (see also, Chamorro (1993); Gonzalez (1996)). Obviously, these two issues are very related, since if enforcement is not properly designed, even a very restrictive management and exploitation plan will not necessarily have the desired impact in terms of reducing the aggregate effort used in the fishery. This raises the issue of designing enforcement of the MEP. While the external regulatory authority enforces the fishing property rights granted to the community, it is the own fishermen community which must enforce and guarantee that the MEP will be complied. Clearly, in order to do this, each community must organise and set some norms or rules of behaviour aimed at restricting the exploitation of the resource (e.g. number of boats per person, number of days fishing per person, number of hours per day fishing per person, etc.). However, unlike the Japanese case, where there exists a long-standing tradition of informal regulation in the form of social norms, in the Chilean case such a form of co-operative management has never been in place in coastal fishery management (in fact Chilean coastal fisheries have been characterised by a lack of property rights and economic over-exploitation). Can then fishing communities, with no tradition in co-operative management, be able to enforce the MEP, achieving appropriate levels of compliance in terms of the aggregate effort level used in the fishery? While thus far the literature on TURFs in general, and the Chilean regulation in particular, has been centred on the biological and technical aspects of it (e.g. the description of the benthonic community existing in the area, the qualification of the main species, etc.), to our knowledge there is no work squarely dealing with this specific question. [3] Hence, the main aim of this paper is to formally explore the problem of enforcement of the management plan from an economic perspective.

Specifically, here we examine this issue from a game theoretic perspective, by assuming that once a fishermen's association/cooperative has been granted fishing rights, a norm aimed at enforcing the MEP is set in place. This norm prescribes, for each individual within the fishing community, a particular extraction level. We call this type of informal regulation, *endogenous*, since this norm is not necessarily legally enforceable, constituting a code of conduct among fishermen, set independently of the external regulatory authority. The key characteristic of the *game of norm compliance*, we propose here, is that it involves a monitoring and sanctioning mechanism, where fishermen monitor and sanction one another. Unlike most theoretical papers on social norms in common property resource (CPR) exploitation that consider perfect, deterministic, enforcement of norms, here we consider an *imperfect norm enforcement system*, where not every violator is detected and sanctioned. [4] We assume that whenever a fisherman is detected violating the norm, a monetary fine is imposed upon him. While we assume that monitoring and

[3] For literature on TURFs analysing the Chilean case see, for instance, the following works: Parma et al. (2003), Castilla (1994, 1997, 1999), Castilla and Defeo (2001), Castilla et al. (1998); Castilla and Fernández (1998) and Orensanz (2001). While these are some of the leading authors in the area, in their work there is no a detailed analysis of the economic considerations of this type of regulation, instead these articles focus on the biological and technical aspects of it.

[4] See, for instance, Sethi and Somanathan (1996, 2001)) and Ostrom et al. (1992); Ostrom and Gardner (1993).

sanctioning are costly activities, we also depart from most of the previous theoretical literature in the sense that these activities also involve the possibility of a monetary reward subject to the effective detection and sanction of a violator. In particular, we suppose that the fine charged to a violator goes entirely to the fisherman that detected and reported him. This provides an economic incentive for fishermen to monitor the effort levels of the other members of the community.[5] This feature of the model is included here mainly because it is thought that in a context of little tradition in co-operative management, individuals can not only free-ride in terms of using a high fishing effort level (higher than the norm adopted by the community) but also in terms of helping monitor the rest of the population. We analyse what happens in terms of monitoring if this mechanism is in place and what if it is not. Particularly, the main issues we examine with this static game are the following. First, the norm compliance decision, namely what is the compliance condition associated with the decision confronted by the fishermen of whether or not to abide by the norm and what are the relevant variables involved in this decision. Second, the monitoring decision, namely what is the condition to monitor other agents, and also what are the relevant variables involved in this decision.

The paper has been structured as follows. First, we analyse what would happen in the absence of endogenous regulation. Clearly,

[5] This type of social norm where agents monitor each other has empirical support in the context of CPR exploitation. As Casari and Plott (2003) report for the case of pasture and forest management of 13th-19th century communities in the Italian Alps: "For centuries villages in the Alps employed a special system for managing their common propertiesIndividual users could inspect other users at their own cost and impose a predetermined sanction (a fine) when a free rider was discovered. The fine was paid to the user who found a violator."

in the best scenario, assuming that restricted access to the fishery is effectible enforced by the external regulatory authority, the TURFs legislation transform the open access problem in a common property problem, and therefore the economic overexploitation of the fishery is not necessarily avoided. We formally explore this issue in section 2. Second, in section 3 we formulate a static game of social norm compliance in a regime of common property resource exploitation. The key characteristic of this game is a monitoring and sanctioning mechanism, where fishermen monitor and sanction one another. Within this game theoretic framework, we then specifically address the norm compliance and monitoring decisions. In particular we consider two cases when the choices of fishing and monitoring efforts are independent decisions and when they are dependent. Finally, in section 4 some concluding remarks are offered. Based on the economic model proposed in sections 3, we offer here some specific policies recommendations regarding the enforcement design of the MEP in the context of TURF regulations. Additionally, we also suggest some avenues for future research in the area.

2 TURFs in the Absence of Endogenous Regulation

Regulations based on TURFs require that the fishing community manage the resource according to the management and exploitation plan. While the implementation of TURFs typically ensures that the number of exploiters is reduced to only those associated with the community or fishing organisation to which the exploitation of the resource has been guaranteed, a question that arises is whether or not this ensures the optimal exploitation of the resource. Belonging to the fishing organisation is guaranteed by law, so any stranger to the organisation caught fishing in the regulated territory can be brought to justice. However, this does not ensure that people belonging to the community do not use fishing effort levels higher than those that on aggregate ensure the compliance of the MEP. This obviously requires some form of internal organisation, where the members of the TURFs agree on some "norms" (not necessarily enforced by law) restricting the exploitation of the commonly owned resource. In the absence of these norms the problem is reduced to the exploitation of a common property resource. Hence, in this section we briefly discuss through a game theoretic explanation what would happen if this endogenous regulation would not be in place.

Consider a population consisting of n agents, with $n \geq 2$. Each agent has access to a common property resource and can exploit the resource using a particular effort level which may include labour and fishing equipment. The resulting action profile (outcome of the game) $e = (e_1, \ldots, e_{i-1}, e_i, e_{i+1}, \ldots, e_n)$ represents the fishing effort level chosen by each player. In particular, let e_i denote the fishing effort level used by individual i and e_{-i} the list of elements of the action profile e for all players except i, that is $e_{-i} = (e_1, \ldots, e_{i-1}, e_{i+1}, \ldots, e_n)$. Hence, we also can express the action profile e as $e = (e_i, e_{e-1}$. In addition, denote the aggregate extraction effort devoted by all the n individuals by E. Formally, $E = e_1 + \ldots + e_n = \sum_{i=1}^{n} e_1$.

The total product is given by a differentiable real function H which, in this static version of the common pool resource (CPR) game, is only a function of extractive effort, that is $H \equiv H(E)$. Some standard assumptions of the static model of common property resource use are the following. First, there are decreasing returns to effort, that is $H(0) = 0$, $H'(E) > 0$, $H''(E) < 0$, and $\lim_{E \to \infty} H'(E) = 0$. This, in turn, implies that the average product lies above marginal product, i.e. $\frac{H(E)}{E} > H'(E)$ and that the average product goes to zero, i.e. $\lim_{E \to \infty} \frac{H(E)}{E} = 0$. Second, we assume that the part of the total product obtained by each individual is directly proportional to her share of effort in total effort, i.e. $e_i \frac{H(E)}{E}$. Since the average product $H(E)/E$ is a diminishing function of E, it is clear that the individual product of any agent not only depends upon her extractive effort but also upon the effort introduced by the rest of the agents exploiting the common resource. Third, we suppose that the markets for the resulting product and inputs are perfectly competitive, so that the prices for both are constant at all levels of input and output. We then normalise the price of a unit of the resulting product as one and denote the individual cost of a unit of effort by c. Fourth, we suppose that, $0 < c < H'(0)$, which guarantees that an interior solution is obtained. Finally, we assume that the fishing effort level used by each individual is bounded in such a way that overcrowding can never be so extreme as to yield cero or negative payoffs, that is, we assume that $\frac{H(E)}{E} > c$.

Assume that fishing effort is continuously divisible. A strategy for agent i is the choice of a fishing effort level, e_i. Assuming that the strategy space is $[0, \infty)$ covers all the choices that could possibly be of interest to the agent. The individual profit of each fishing firm can be written as the revenue resulting from the sale of the amount of resource extracted by the individual minus the cost of the individual's extractive effort. Thus the payoff to agent i, denoted by R_i, from using a fishing effort level e_i when the effort levels used by the other agents in the fishery are $e_{-i} = (e_1, \ldots, e_{i-1}, e_{i+1}, \ldots, e_n)$ is:

$$R_i\left(e_i, e_{-i}\right) = e_i \left[\frac{H\left(e_1 + \cdots + e_{i-1} + e_i + e_{i+1} + \cdots + e_n\right)}{\left(e_1 + \cdots + e_{i-1} + e_i + e_{i+1} + \cdots + e_n\right)} - c\right], \tag{1}$$

Consequently, the CPR game can be formally described by

$G^{cpr} = \{e_1, \ldots, e_n; R_1, \ldots, R_n\}$. Hence, if $(e_1^*, \ldots, e_n^*)$ is to be a Nash equilibrium of G^{cpr} then, for each i, e_i^* must maximise (1) given that the other agents choose $e_{-i}^* = (e_1^*, \ldots, e_{i-1}^*, e_{i+1}^*, \ldots, e_n^*)$. As proposition 1 formally shows below, the Nash equilibrium effort level introduced by each fisherman will be larger than the Pareto efficient, socially optimum, level, existing therefore an economic over-exploitation of the common fishery.[6]

Proposition 1: *Let $G^{cpr} = \{e_1, \ldots, e_n; R_1, \ldots, R_n\}$ be a game satisfying the assumptions discussed above, and let $\bar{E} = \bar{e}_i + \ldots + \bar{e}_n$ denote the socially optimum, efficient, fishing effort, and $E^* = e_1^* + \ldots + e_n^*$ the Nash equilibrium fishing effort. We then have that the Nash equilibrium effort level is larger than the Pareto efficient, socially optimum, level, i.e. $E^* > \bar{E}$ and therefore there will be economic over-exploitation of the common fishery.*

Proof of Proposition 1: *See Appendix 1.*

In terms of Territorial Use Rights regulations, this result basically implies that even though the access to the stock can be legally restricted to a limited number of fishermen, if there is no any *endogenous regulation* from the community, restricting the use of the commonly owned resource, there will still be economic over-exploitation. In other words, fishermen will use more effort than that which is socially optimal, i.e. where marginal revenue equals marginal cost.

[6] For versions of this result see, inter alia, Cornes et al. (1986), Dasgupta and Heal (1979), Funaki and Yamoto (1999), Gordon (1954), Roemer (1989), Somanathan (1995), Stevenson (1991), and Weitzman (1974).

3 A Static Game of Norm Compliance

If the community establishes an endogenous type of regulation, where the own users of the fishery are responsible for the enforcement of the effort levels agreed on in the management and exploitation plan, the result found above will not necessarily hold. In this section we model this situation by means of a static game based on a *social norm* that restrains the use of the common property resource. In particular, this rule of behaviour involves a monitoring and sanctioning mechanism, where players monitor and sanction one another. Agents who use an effort level greater than the norm, which we assume here is set equal to the Pareto efficient effort level of the basic CPR game presented in the previous section, are sanctioned. Thus, in formal terms, an agent violates the social norm whenever her individual effort, e_i, is above the norm, $\bar{e}$, that is: $e_i - \bar{e} > 0$.

Unlike previous theoretical work on social norms in CPR exploitation that consider perfect, deterministic, enforcement of norms, here we consider an *imperfect norm enforcement system*, where not every violator is detected and sanctioned. In particular, in terms of monitoring, we suppose that each player can monitor other players using a particular effort level. The associated action profile $m = (m_1, \ldots, m_{i-1}, m_i, m_{i+1}, \ldots, m_n)$ represents the monitoring effort level chosen by each player within the population. Denote by m_i the *total* monitoring effort level used by player i, to monitor all the rest of the population, namely the other $(n-1)$ agents exploiting the commonly owned resource. Similarly we denote by m_{-i} the list of elements of the action profile m for all players except i, i.e. $m_{-i} = (m_1, \ldots, m_{i-l}, m_{i+1}, \ldots, m_n)$. Thus, the action profile m can be expressed as $m = (m_i, m_{-i})$. Consequently, we assume that there exists a probability of being detected and sanctioned which depends on the level of monitoring effort devoted by the rest of the population. Specifically, we denote by $\theta_{i,j}$ the probability that agent i detects and sanctions agent j. We assume that the more monitoring effort devoted by i the higher the probability that she will detect agent j. By contrast, we suppose that the monitoring effort exerted by j, does not affect the probability $\theta_{i,j}$, i.e. agent j does not monitor herself. We also assume that the monitoring effort used by the rest of the population, namely the monitoring effort of all other agents besides players i and j, will reduce $\theta_{i,j}$, since this diminishes the chances that player i will be the one that detects agent j. Formally, we denote by $m_{-(i,j)} = (m_1, \ldots, m_{i-1}, m_{i+1}, \ldots, m_{j-1}, m_{j+1}, \ldots, m_n)$ the monitoring effort of all other agents besides players i and j. Hence we define $\theta_{i,j} = \theta_{i,j}(m_i, m_{-(i,j)})$. Similarly, we denote by $\theta_{j,i}$ the probability that at least one agent j detects and sanctions agent i, and define it as follows: $\theta_{j,i} = \theta_{j,i}(m_{-i})$.[7] Formally, our assumptions on $\theta_{i,j}$ can be written as follows: $\frac{\partial \theta_{i,j}}{\partial m_i} > 0$, $\frac{\partial^2 \theta_{i,j}}{\partial m_i^2} \leq 0$, and that $\frac{\partial \theta_{i,j}}{\partial m_k} < 0$, $\frac{\partial^2 \theta_{i,j}}{\partial m_k^2} \geq 0 \ \forall \ k = 1, \ldots, n$ with $k \neq i$ and $k \neq j$. Likewise, for $\theta_{j.i}$ we have: $\frac{\partial \theta_{j,i}}{\partial m_{-i}} > 0$, $\frac{\partial^2 \theta_{j,i}}{\partial m_{-i}^2} \leq 0$. We further assume that $\theta_{ij}(0, m_{-(i,j)}) = 0$, i.e., the probability that agent "i detects agent j" is zero whenever the monitoring effort exerted by i is zero, which also applies for $\theta_{j,i}$, that is $\theta_{j,i}(0) = 0$.

[7] We notice here that because we assume that an agent can be sanctioned only once, her decision is likely to be based upon the perceived probability that at least one agent detects her in violation. Considering that the relevant sample space is composed by the finite number of events: agent 1 detects a violation of agent i, agent 2, detects a violation of agent i, etc., it can be shown that the probability that at least one of those events occurs is found by adding the probability of each event, then subtracting the probabilities of two-ways intersections, adding the probability of all three-way intersections, and so forth. That is the so called inclusion-exclusion principle. For details, see for example, Grinstead and Snell (1997).

However, we suppose that the marginal probabilities of detection and sanctioning at zero monitoring level are greater than zero, i.e. $\frac{\partial\theta_{i,j}(0,m_{-i,j}))}{\partial m_i} > 0$, and $\frac{\partial\theta_{j,i}(0)}{\partial m_{-i}} > 0$.

In terms of the costs associated with monitoring and sanctioning, this model also deviates from the previous theoretical literature on CPR exploitation in the sense that these are not only costly activities for agents, but also involve the possibility of a monetary reward subject to the effective detection of a violator. Here we also distinguish between monitoring and sanctioning costs. The former is given by the function $\varphi(m_i)$, which accounts for the total cost of monitoring for agent i. Formally, we assume that this function is strictly increasing and convex in monitoring effort, i.e. $\frac{\partial\varphi}{\partial m_i} > 0$, $\frac{\partial^2\varphi}{\partial m_i^2} \leq 0$. The latter is denoted by γ, which is an exogenous variable, and represents the transaction costs associated with reporting one agent.[8]

Regarding the benefits of monitoring and sanctioning other agents, here we suppose that whenever an agent is detected violating the norm, a monetary fine will be imposed upon her. This fine goes entirely to the agent that detected and reported her. Moreover, we assume that the magnitude of the fine depends upon the extent of the violation. Thus, if a player decides not to abide by the effort limit, if caught, the penalty is given by, $s = s(e_i - \bar{e})$, with $\frac{\partial s}{\partial e_i} > 0$, $\frac{\partial^2 s}{\partial e_i^2} \geq 0$, $\forall\ e_i > \bar{e}$ and $s(e_i - \bar{e}) = 0$, for $e_i - \bar{e} \leq 0$. We also assume that this penalty is zero for zero

[8] For instance, this could be the case of a sanctioning system where the monitoring agent must report any violation to the board of the fishermen's association/co-operative, which finally decides, after an inspection, whether or not the reported agent is violating the social norm or not. In other words, here we assume that not only monitoring other agents is costly, but also reporting a violator, to be sanctioned, involves a cost. This idea has empirical support in local commons, for a particular example see Casari and Plott.

violation, i.e. $s = s(0) = 0$, but that the marginal penalty for zero violation is greater than zero, i.e. $\frac{\partial s(0)}{\partial e_i} > 0$.

Considering the assumptions discussed above the expected profit of individual i is given by:

$$\pi_i = R_i\left(e_i, e_{-i}\right) - \theta_{j,i}\left(m_{-i}\right) s\left(e_i - \bar{e}\right) + \sum_{j \neq i}^{n} \theta_{(i,j)}\left(m_i, m_{-(i,j)}\right)\left[s\left(e_j - \bar{e}\right) - \gamma\right] - \varphi\left(m_i\right) \tag{2}$$

where $R_i(e_i, e_{-i})$ represents agent i's net payoff under the basic CPR setting presented in section 2, see equation (1). We assume that agent i can choose the amount of her effort, which depending of its value, can involve or not a violation of the social norm, formally $e_i - \bar{e} \geq 0$. If agent i, is detected violating the norm she will have to pay a fine proportional to her violation, that is $s(e_i - \bar{e})$. As it was argued before, since, monitoring is imperfect, the detection of her violation by at least one agent within the population, say agent j, will depend upon the probability $\theta_{j,i}(m_{-i})$, which is function of the monitoring effort put by agent j and that of the rest of the population. The total expected cost for agent i of being caught violating the norm is given by $\theta_{j,i}(m_{-i})s(e_i - \bar{e})$.

Agent i also chooses her monitoring effort level, which is restricted to be non negative, i.e. $m_i \geq 0$. Given this level of monitoring effort, player i can be able to detect a violator and receive the associated payment, given by the fine levied to the offender. We have that the expected reward to agent i for effectively detect and sanction a violator j is given by $\theta_{i,j}s(e_j - \bar{e})$, that is the probability that agent i detects agent j multiplied by the associated monetary reward given by the fine charged to agent j. Similarly, the expected cost for agent i of sanctioning agent j is $\theta_{i,j}\gamma$. Since we assume that given her monitoring effort, agent i can monitor and sanction all the rest of the population, that is $(n-1)$ players, the net expected payoff associated with sanctioning other agents who violate the norm is given by $\sum_{j \neq i}^{n} \theta_{i,j}(m_i, m_{-(i,j)})[s(e_j - \bar{e}) - \gamma]$.[9]

Finally, in terms of the choices of fishing and monitoring effort we assume that they are bounded by a total effort level which we normalize as one. Formally, we assume that $e_i + m_i \leq 1$.

The norm compliance game can be formally described by $G^{nc} = \{(e_1, \ldots, e_n), (m_1, \ldots, m_n); \pi_1, \ldots, \pi_n\}$ which corresponds to an n-person normal form game where (e_i, m_i), with $e_i \geq \bar{e}$ and $m_i \geq 0$, $\forall\ i = 1, \ldots, n$, denote the action sets given by the extraction and monitoring effort levels, and π_i, $\forall\ i = 1, \ldots, n$, the *material* payoff functions, given by the expected profit presented in equation (2).

Consequently, we have that the Nash equilibrium of this norm compliance game, given by the pair (e^*, m^*), is found by solving the following optimization problem.[10]

$$\max_{e_i, m_i} \pi_i = R_i\left(e_i, e_{-i}\right) - \theta_{j,i}\left(m_{-i}\right) s\left(e_i - \bar{e}\right) + \sum_{j \neq i}^{n} \theta_{i,j}\left(m_i, m_{-(i,j)}\right)\left[s\left(e_j - \bar{e}\right) - \gamma\right] - \varphi(m_i) \qquad (3)$$

$$s.t. \qquad e_i - \bar{e} \geq 0$$

[9] The cost of monitoring peers is intended to represent the fact that such effort might require the use of some monitoring equipment, or other inputs.

[10] Throughout the paper we assume that agents are risk neutral and maximise expected profits. We denote by an asterisk optimal choices.

$$m_i \geq 0$$
$$1 - e_i - m_i \geq 0$$

The Lagrange equation for (3) is:

$$\begin{aligned} L = & R_i\left(e_i, e_{-i}\right) - \theta_{j,i}\left(m_{-i}\right) s\left(e_i - \bar{e}\right) \\ & + \sum_{j \neq i}^{n} \theta_{i,j}\left(m_i, m_{-(i,j)}\right)\left[s\left(e_j - \bar{e}\right) - \gamma\right] - \phi(m_i) \\ & + \mu m_i + \eta\left(e_i - \bar{e}\right) + \lambda\left(1 - e_i - m_i\right) \end{aligned} \tag{4}$$

and the Kuhn-Tucker conditions are:

$$\frac{\partial L}{\partial e_i} = \frac{\partial R_i\left(e_i, e_{-i}\right)}{\partial e_i} - \theta_{j,i}(m_{-i}) \frac{\partial s\left(e_i - \bar{e}\right)}{\partial e_i} + \eta - \lambda = 0 \tag{5a}$$

$$\frac{\partial L}{\partial \eta} = e_i - \bar{e} \geq 0, \eta \geq 0, \quad \eta\left(e_i - \bar{e}\right) = 0 \tag{5b}$$

$$\frac{\partial L}{\partial m_i} = \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m_i, m_{-(i,j)})}{\partial m_i}[s(e_j - \bar{e}) - \gamma] - \frac{\partial \varphi(m_i)}{\partial m_i} + \mu - \lambda = 0 \tag{5c}$$

$$\frac{\partial L}{\partial \mu} = m_i \geq 0, \quad \mu \geq 0, \quad \mu m_i = 0 \tag{5d}$$

$$\frac{\partial L}{\partial \lambda} = 1 - e_i - m_i \geq 0, \quad \lambda \geq 0, \quad \lambda\left(1 - e_i - m_i\right) = 0 \tag{5e}$$

We assume that (5a-e) are necessary and sufficient to determine the agent optimal allocation of extraction and monitoring effort. [11]

[11] In general terms, Kuhn-Tucker sufficiency requires π_i being a concave function and that the feasible set contains only convex functions $\forall\ i = 1, \ldots, n$.

3.1 Fishing and Monitoring as Independent Decisions

It should be noted that the formulation of the optimization problem presented in (4) allow us to study both cases, when the choices of fishing and monitoring efforts are independent decisions and when they are dependent. In the former case we can assume that $1 > e_i + m_i$, which implies that the choices of fishing and monitoring effort are lower than the total effort level available to each individual. Therefore in this case there is no a trade-off between devoting resources to fishing or monitoring activities. In the latter case, by contrast, we assume that $1 = e_i + m_i$ so any amount of effort dedicated to monitoring will reduce the amount of effort that the individual can spend on fishing and *vice versa*. Let us first analyse the case when the choices of fishing and monitoring efforts are independent decisions, that is $1 > e_i + m_i$. In particular we will derive some results related to the compliance conditions and the optimal level of monitoring effort under this setting.

Result 1: *Given* $1 > e_i + m_i$*, a necessary condition for violating the norm, i.e.* $e_i = e^* > \bar{e}$*, is the following:*

$$\frac{\partial R_i\left(e^*, e^*_{-i}\right)}{\partial e_i} = \theta_{j,i}\left(m_{-i}\right)\frac{\partial s\left(e^* - \bar{e}\right)}{\partial e_i}. \tag{6}$$

Proof of Result 1: Since we assume that $1 > e_i + m_i$ by (5e) we obtain $\lambda = 0$. Suppose now that $e_i > \bar{e}$. Then, if this choice of e_i is optimal, $\frac{\partial L}{\partial e_i} = 0$. Since, from (5b), $e_i > \bar{e}$ implies $\eta = 0$, then the following condition is clearly necessary for $e_i > \bar{e}$ to be an optimal choice:

$$\frac{\partial R_i\left(e_i, e_{-i}\right)}{\partial e_i} - \theta_{j,i}\left(m_{-i}\right)\frac{\partial s\left(e_i - \bar{e}\right)}{\partial e_i} = 0. \tag{7}$$

Restricting our attention to symmetric equilibria, we can denote the Nash equilibrium extraction effort level $e_i = e^*$, for all players i, with $e^* > \bar{e}$. Thus, an equilibrium strategy must satisfy condition (6). **Q.E.D.**

Result 1 shows that an individual violates the social norm to the extent that her marginal revenue from using a fishing effort level higher than the socially allowed level, i.e. $\frac{\partial R_i(e^*,e^*_{-i})}{\partial e_i}$ with $e^* > \bar{e}$, offsets the expected marginal costs associated with her violation, i.e. $\theta_{j,i}(m_{-i})\frac{\partial s(e^*-\bar{e})}{\partial e_i}$. In particular, the expected marginal cost from violating the norm depends on the marginal sanction, $\frac{\partial s}{\partial e_i}$, and the probability of detection and sanctioning, $\theta_{j,i}\ \forall\ j = 1,\ldots,n$ with $j \neq i$. By definition the marginal sanction is increasing in fishing effort, and therefore an increase in fishing effort will increase the expected marginal cost of violating the norm. Similarly, an increase in the individual level of monitoring will also trigger an increase in the probability of being caught and consequently will increase the expected marginal cost of violating the norm. In terms of the agent's marginal revenue (see equation (A3) from Appendix 1) we have that this is function of the average product of fishing effort, $\frac{H(E)}{E}$, the marginal product of fishing effort,$H'(E)$, the individual cost of fishing effort, c, and the number of fishing firms sharing the CPR, n. Hence, we have that an increase in the average product, and the marginal product will trigger an increase in the marginal revenue from using a fishing effort level higher than the socially allowed level. By contrast, an increase in the individual cost of fishing effort and the number of fishing firms sharing the CPR will reduce the marginal revenue from violating the norm.

It should also be noted that from Result 1 it is clear that in this setting, the individual's optimal choice of fishing effort is independent of her choice of monitoring effort, m_i. However, as already noted the individual decision does depends on the individual monitoring level devoted by all other individuals, that is the individual monitoring level of all other individuals, $m_{-i} = (m_1, \ldots, m_{i-1}, m_{i+1}, \ldots, m_n)$. In other words, each individual decision regarding her level of violation is dependent of the other agents' enforcement strategy.

We can also derive the condition ensuring that an individual complies with the social norm. Our next result presents a necessary and sufficient condition for norm compliance.

Result 2: *Given $e_i + m_i < 1$, an agent chooses to comply with the social norm, i.e. $e_i = e^* = \bar{e}$, if and only if*

$$\frac{\partial R_i\left(e^*, e^*_{-i}\right)}{\partial e_i} \leq \theta_{j,i}\left(m_{-i}\right)\frac{\partial s(0)}{\partial e_i} \tag{8}$$

Proof of Result 2: Since we assume that $e_i + m_i < 1$ by (5e) we obtain $\lambda = 0$. Suppose now that $e_i = \bar{e}$. Then, if this choice of e_i is optimal, $\frac{\partial L}{\partial e_i} = 0$. Since, from (5b), $e_i = \bar{e}$ implies $\eta \geq 0$, then by equation (5a) the following condition is clearly necessary for $e_i = \bar{e}$ to be an optimal choice.

$$\frac{\partial R_i\left(e_i, e_{-i}\right)}{\partial e_i} - \theta_{j,i}\left(m_{-i}\right)\frac{\partial s(0)}{\partial e_i} \leq 0 \tag{9}$$

Restricting our attention to symmetric equilibria, we can denote the Nash equilibrium extraction effort level by $e_i = e^*$, for all players i, with $e^* = \bar{e}$. Thus, an equilibrium strategy must satisfy condition (8). To show sufficiency, suppose to the contrary that (8) holds but $e_i - \bar{e} > 0$. Given $e_i - \bar{e} > 0$, equation (5b) implies that $\eta = 0$. This in turn implies by equation (5a) that:

$$\frac{\partial R_i\left(e_i, e_{-i}\right)}{\partial e_i} = \theta_{j,i}\left(m_{-i}\right)\frac{\partial s\left(e_i - \bar{e}\right)}{\partial e_i} \tag{10}$$

Since $\frac{\partial^2 s}{\partial e_i^2} \geq 0$, we have that $\theta_{j,i}(m_{-i}\frac{\partial s(0)}{\partial e_i} < \theta_{j,i}(m_{-i})\frac{\partial s(e_i-\bar{e})}{\partial e_i}$, which implies that equation (10) contradicts equation (8). Hence we have established the sufficiency of (8) for an optimal choice of $e^* = \bar{e}$. **Q.E.D.**

From Result 2, an agent will be compliant if the marginal revenue from using a fishing effort level equivalent to the one established by the social norm, $\frac{\partial R_i(e^*, e^*_{-i})}{\partial e_i}$ with $e^* = \bar{e}$, is lower or equals the expected marginal penalty it would pay at the zero violation level, $\theta_{j,i}(m_{-i})\frac{\partial s(0)}{\partial e_i}$.

As in Result 1, it is obvious that in this setting the compliance decision is independent of the agent's own monitoring effort, but dependent of the population's enforcement strategy, $m_{-i} = (m_1, \ldots, m_{i-1}, m_{i+1}, \ldots, m_n)$. An important conclusion that can be inferred from Result 2 is that if there is no monitoring effort within the fishery, compliance is not a possible outcome. We formally present this additional result in Corollary 1 as follows:

Corollary 1: *Norm compliance is not possible without monitoring effort being carried out in the fishery.*

Proof of Corollary 1: From equation (8), zero monitoring effort within the fishery, i.e. $m_j = m_{-(i,j)} = 0$, implies that: $\frac{\partial R_i(e^*, e^*_{-i})}{\partial e_i} \leq 0$, which never holds, since we assume that $\frac{H(E)}{E} > c$. **Q.E.D.**

Results 1 and 2 can be better explained through a graphical analysis. Figure 1 below shows the solution to equations (6) and (8) for particular forms of the penalty function, s, and probability function, $\theta_{j,i}$.

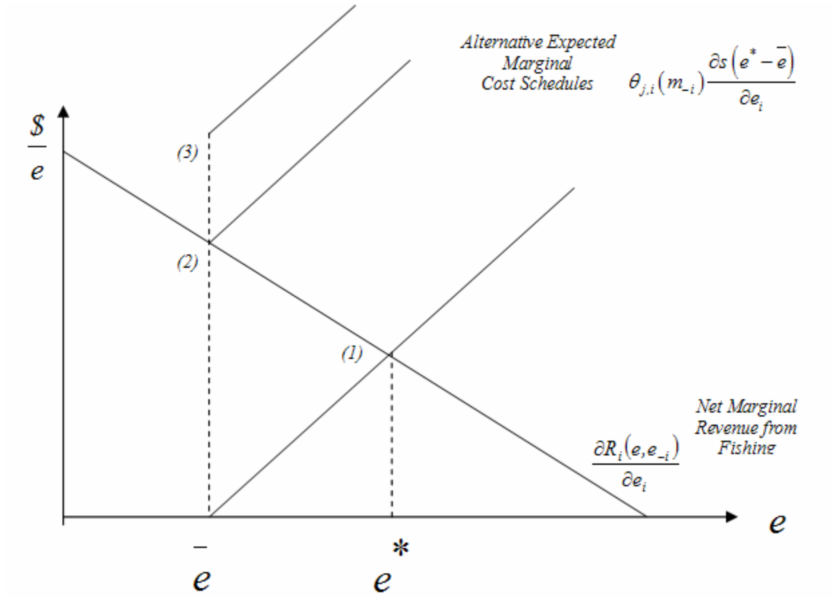


Fig. 1. The Norm Compliance Decision with Independent Fishing and Monitoring Choices

From Figure 1 (see point (1)), it is clear that the firm sets its fishing effort to a level e^* in excess of the norm, $e^* > \bar{e}$, where marginal revenue (net of extractive effort costs) equals the expected marginal cost associated with the respective violation level.[12] In general, the individual will violate the norm whenever

[12] If there were no sanction for using a fishing effort beyond $\bar{e}$ or if there were no chance of being detected and sanctioned (i.e. either $s = 0$ or $\theta_{j,i} = 0$), the firm would set its catch at the equilibrium fishing effort level of the basic CPR setting which is greater than the socially optimum fishing effort. This fishing effort level corresponds to the firm's optimal choice of fishing effort obtained in section 2, see Appendix 1. Here it should also be noted that as access is limited to just n fishermen (n finite) they will still accrue positive rents in this equilibrium (see, Dasgupta and Heal (1979: 58)). If we drop the assumption of limited entry, i.e. we are no longer in a common property

the expected marginal cost schedule intersects the marginal revenue schedule at any fishing effort level greater than the norm, i.e. $e_i > \bar{e}$. By contrast, if the expected marginal cost schedule lies above the marginal revenue schedule for all $e_i > \bar{e}$ (see point (3)) or intersects the marginal revenue schedule at $e_i = \bar{e}$ (see point (2)), the individual will comply with the social norm. In this latter case of optimal compliance, the marginal revenue, obtained by using the efficient effort level, is lower or equals the expected marginal sanction the individual would pay at the zero violation level. Consequently, increases in the probability of being detected and sanctioned decrease the individual's effort as the expected marginal cost schedule shifts up. Similarly, increases in the marginal sanction also decrease the individual's fishing effort as the marginal cost schedule becomes steeper. With respect to the marginal revenue schedule, increases in the effort level of the rest of the population also diminish the agent's fishing effort level as the marginal revenue schedule shifts down. By contrast, an increase in the social norm shifts the expected marginal cost schedule to the right and therefore increases the individual's fishing effort.

Now, let us focus on the agent's optimal choice of monitoring effort. Result 3 provides a necessary condition for ensuring that monitoring activity will be performed by agents.

Result 3: *Given $e_i + m_i < 1$, a necessary condition for monitoring, i.e. $m^* > 0$, is that*

$$\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i} s(e_j - \bar{e}) = \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i} \gamma + \frac{\partial \varphi(m^*)}{\partial m_i} \tag{11}$$

regime but in an open-access one, then the fishery will reach equilibrium at a point where economic rents are totally dissipated (see, Stevenson (1991: 35-37)).

Proof of Result 3: Since we assume that $e_i + m_i < 1$ by (5e) we obtain $\lambda = 0$. Suppose now that $m_i > 0$. Then, if this choice of m_i is optimal, $\frac{\partial L}{\partial m_i} = 0$. Since, from (5d), $m_i > 0$ implies $\mu = 0$, then by equation (5c) the following condition is clearly necessary for $m_i > 0$ to be an optimal choice.

$$\sum_{j \neq i}^{n} \frac{\partial \theta \left(m_i, m_{-(i,j)} \right)}{\partial m_i} \left[s \left(e_j - \bar{e} \right) - \gamma \right] - \frac{\partial \varphi \left(m_i \right)}{\partial m_i} = 0 \qquad (12)$$

Restricting our attention to symmetric equilibria, we can denote the Nash equilibrium extraction effort level by $m_i = m^*$, for all players i. Thus, an equilibrium strategy m^* must satisfy condition (11). **Q.E.D.**

This result implies that monitoring will be carried out to the extent that the marginal benefits from monitoring and sanctioning, $\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i} s(e_j - \bar{e})$, equals the marginal costs associated with monitoring, $\frac{\partial \varphi(m^*)}{\partial m_i}$, and sanctioning, $\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i} \gamma$ activities. From Result 3, it also becomes evident that in this setting the optimal choice of monitoring effort does not depend upon the effort level used by the individual. However, it does depend on the effort level chosen by the rest of the population. Moreover, an important conclusion that can be inferred from this result is that if monitoring and sanctioning are costly activities, and there is no reward awarded to those agents who detect and report a violator, monitoring will never be performed by rational fishermen. We formally present this result in Corollary 2 as follows:

Corollary 2: *In the absence of a monetary reward for those agents who detect and sanction a violator, monitoring will never be carried out by rational agents.*

Proof of Corollary 2: From equation (11), zero monetary reward for detecting and sanctioning a violator, i.e. $s = 0$, implies that: $\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i}\gamma + \frac{\partial \varphi(m^*)}{\partial m_i} = 0$, which never holds since by definition $\frac{\partial \varphi(m^*)}{\partial m_i} > 0$, and $\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i}\gamma > 0$. **Q.E.D.**

3.2 Fishing and Monitoring as Dependent Decisions

We now consider the case when the choices of fishing and monitoring effort are dependent decisions, that is $1 = e_i + m_i$, and analyse the norm compliance and monitoring optimal choices.

Result 4: *Given* $e_i + m_i = 1$, *a necessary condition for violating the norm* $(e_i = e^* > \bar{e})$ *without carrying out monitoring effort* $(m^* = 0)$, *is the following:*

$$\frac{\partial R_i\left(e^*, e^*_{-i}\right)}{\partial e_i} \geq \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}\left(0,0\right)}{\partial m_i}\left[s\left(e^* - \bar{e}\right) - \gamma\right] \qquad (13)$$

Proof of Result 4: Since we assume that $e_i + m_i = 1$ by (5e) we obtain $\lambda \geq 0$. Then, given an optimal choice of e_i and m_i combining equations (5a) and (5c) we get:

$$\frac{\partial R_i(e_i, e_{-i})}{\partial e_i} - \theta_{j,i}(m_{-i})\frac{\partial s(e_i - \bar{e})}{\partial e_i} + \eta = \qquad (14)$$

$$\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m_i, m_{-(i,j)})}{\partial m_i}[s(e_j - \bar{e}) - \gamma] - \frac{\partial \varphi(m_i)}{\partial m_i} + \mu$$

Suppose now that $e_i > \bar{e}$ and $m_i = 0$, then from (5b) and (5d) we have that $\eta = 0$ and $\mu \geq 0$ respectively. Hence equation (14) becomes:

$$\frac{\partial R_i(e_i, e_{-i})}{\partial e_i} - \theta_{j,i}(m_{-i})\frac{\partial s(e_i - \bar{e})}{\partial e_i} \geq \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(0, m_{-(i,j)})}{\partial m_i}[s(e_j - \bar{e}) - \gamma]. \tag{15}$$

Restricting our attention to symmetric equilibria, we can denote the Nash equilibrium extraction and monitoring effort levels by $e_i = e^8$ with $e^* > \bar{e}$ and $m_i = m^*$ with $m^* = 0$, for all players i. Thus, an equilibrium strategy given by the pair (e^*, m^*) must satisfy condition (14). **Q.E.D.**

Result 4 shows that an agent will violate the social norm and will not carry out monitoring effort whenever her expected net marginal revenue (net of extractive effort costs) from using a fishing effort level higher than the socially allowed level is higher or equals the expected net marginal revenue from monitoring and sanctioning other agents at zero monitoring level. Thus, if the marginal probability of detecting and sanctioning another agent at zero monitoring level and the monetary reward given to those who monitor and sanction are rather low, and at the same time the transaction costs associated with effectively sanctioning one agent and the marginal revenue from extraction are relatively high, it is likely that there will neither be norm compliance nor monitoring within the fishery.

Result 5: *Given* $e_i + m_i = 1$, *a necessary condition for violating the norm* $(e_i = e^* > \bar{e})$ *and still carrying out monitoring effort* $(m^* > 0)$ *is the following:*

$$\frac{\partial R_i(e^*, e^*_{-i})}{\partial e_i} - \theta_{j,i}(m_{-i})\frac{\partial w(e^* - \bar{e})}{\partial e_i} = \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i}[s(e^* - \bar{e}) - \gamma] - \frac{\partial \varphi(m^*)}{\partial m_i} \tag{16}$$

Proof of Result 5: Since we assume that $e_i + m_i = 1$ by (5e) we obtain $\lambda \geq 0$. Then, given an optimal choice of e_i and m_i combining equations (5a) and (5c) we get:

$$\frac{\partial R_i(e_i, e_{-i})}{\partial e_i} - \theta_{j,i}(m_{-i})\frac{\partial s(e_i - \bar{e})}{\partial e_i} + \eta = \qquad (17)$$

$$\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m_i, m_{-(i,j)})}{\partial m_i}[s(e_j - \bar{e}) - \gamma] - \frac{\partial \varphi(m_i)}{\partial m_i} + \mu$$

Suppose now that $e_i > \bar{e}$ and $m_i > 0$, then from (5b) and (5d) we have that $\eta = 0$ and $\mu = 0$ respectively. Hence equation (17) becomes:

$$\frac{\partial R_i(e_i, e_{-i})}{\partial e_i} - \theta_{j,i}(m_{-i})\frac{\partial s(e_i - \bar{e})}{\partial e_i} = \qquad (18)$$

$$\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m_i, m_{-(i,j)})}{\partial m_i}[s(e_j - \bar{e}) - \gamma] - \frac{\partial \varphi(m_i)}{\partial m_i}.$$

Restricting our attention to symmetric equilibria, we can denote the Nash equilibrium extraction and monitoring effort level by $e_i = e^*$ with $e^* > \bar{e}$ and $m_i = m^*$ with $m^* > 0$, for all players i. Thus, an equilibrium strategy given by the pair (e^*, m^*) must satisfy condition (16). **Q.E.D.**

Result 5 shows that an individual violates the social norm and carries out monitoring effort to the extent that her expected net marginal revenue from using a fishing effort level higher than the socially allowed level offsets the expected net marginal revenue from monitoring and sanctioning other agents. Comparing this result with Result 4, see equations (13) and (16), it can be noticed that the larger the marginal probability of detecting and sanction a violator the flatter the schedule associated with the marginal revenue from monitoring and sanctioning becomes and therefore the lower the extraction effort in the fishery. By contrast, increases in the expected marginal sanction also decrease the individual's fishing effort as the schedule associated with the marginal revenue from using extractive effort shifts down. Similarly, increases in the monitoring effort also affect the schedule associated with the marginal revenue from fishing as this schedule becomes steeper. This is so because in this setting more monitoring effort devoted in the fishery means less extractive effort.

Result 6: *Given* $e_i + m_i = 1$*, a necessary condition for complying with the norm, i.e.* $e_i = e^* = \bar{e}$*, and still carry out monitoring effort* $(m^* > 0)$*, is the following:*

$$\theta_{j,i}(m^*_{-i})\frac{\partial s(0)}{\partial e_i} - \frac{\partial R_i(e^*, e^*_{-i})}{\partial e_i} \geq \gamma \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*, m^*_{-(i,j)})}{\partial m_i} + \frac{\partial \varphi(m^*)}{\partial m_i} \tag{19}$$

Proof of Result 6: Since we assume that $e_i + m_i = 1$ by (5e) we obtain $\lambda \geq 0$. Then, given an optimal choice of e_i and m_i combining equations (5a) and (5c) we get:

$$\frac{\partial R_i(e_i, e_{-i})}{\partial e_i} - \theta_{j,i}(m_{-i})\frac{\partial s(e_i - \bar{e})}{\partial e_i} + \eta = \tag{20}$$

$$\sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m_i, m_{-(i,j)})}{\partial m_i}[s(e_j - \bar{e}) - \gamma] - \frac{\partial \varphi(m_i)}{\partial m_i} + \mu$$

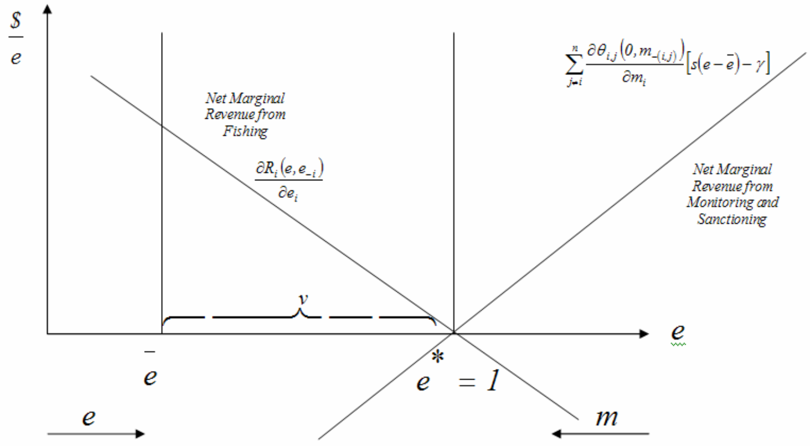
Suppose now that $e_i = \bar{e}$ and $m_i > 0$, then from (5b) and (5d) we have that $\eta \geq 0$ and $\mu = 0$ respectively. Hence equation (20) becomes:

$$\theta_{j,i}(m_{-i})\frac{\partial s(0)}{\partial e_i} - \frac{\partial R_i(e_i, e_{-i})}{\partial e_i} \geq \gamma \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m_i, m_{-(i,j)})}{\partial m_i} + \frac{\partial \varphi(m_i)}{\partial m_i}. \tag{21}$$

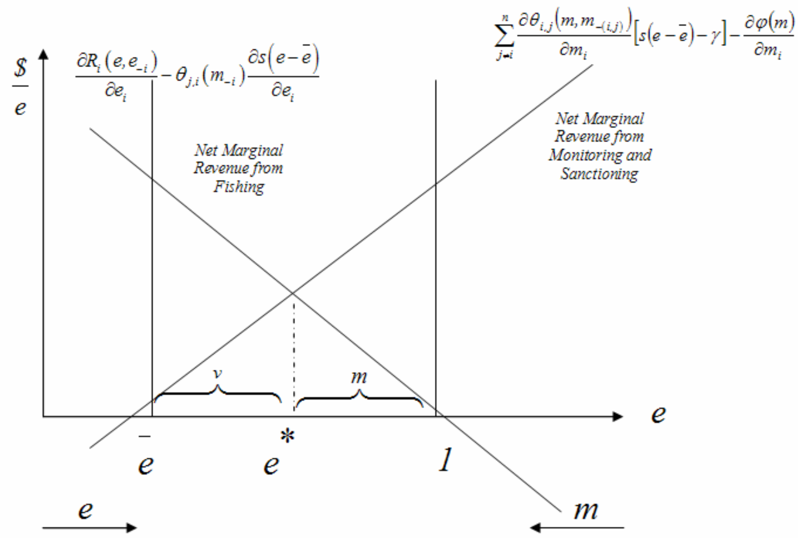
Restricting our attention to symmetric equilibria, we can denote the Nash equilibrium extraction and monitoring effort level by $e_i = e^*$ with $e^* = \bar{e}$ and $m_i = m^*$ with $m^* > 0$, for all players i. Thus, an equilibrium strategy given by the pair (e^*, m^*) must satisfy condition (19). **Q.E.D.**

Result 6 shows that an individual complies with the social norm and carries out monitoring effort to the extent that her expected net marginal revenue from using a fishing effort equivalent to the socially allowed level is lower or equals the expected net marginal revenue from monitoring and sanctioning other agents. Since in equilibrium all individuals use the same fishing effort, $e_i = e_{-i} = e^8$ with $e^* = \bar{e}$, and therefore nobody violates the social norm, there will be no reward possible for those individuals who monitor and sanction. As monitoring and sanctioning are costly activities the net marginal revenue from monitoring and sanctioning is negative. In this case the only possibility for this result to hold is that the individual faces an expected marginal penalty at the zero violation level *greater* than the marginal revenue from using a fishing effort level equivalent to the one established by the social norm. The same condition can be interpreted in terms of marginal costs. An agent will comply with the social norm and carry out monitoring effort if and only if the expected net marginal costs from using a fishing effort equivalent to the socially allowed level is greater or equal the expected net marginal costs associated with sanctioning and monitoring. Formally, $\theta_{j,i}(m^*_{-i})\frac{\partial s(0)}{\partial e_i} - \frac{\partial R_i(e^*,e^*_{-i})}{\partial e_i} \geq \gamma \sum_{j \neq i}^{n} \frac{\partial \theta_{i,j}(m^*,m^*_{-(i,j)})}{\partial m_i} + \frac{\partial \varphi(m^*)}{\partial m_i}$. In policy terms, this result implies that in order to ensure that there will be norm compliance and monitoring in the fishery, the costs of monitoring effort and the expected transaction costs associated with effectively sanctioning one agent must be low in comparison with the probability of being detected and the marginal sanction at zero violation level. At the same time the marginal revenue from using a fishing effort equivalent to the socially allowed level must be rather low in comparison with the expected marginal sanction at zero violation level.

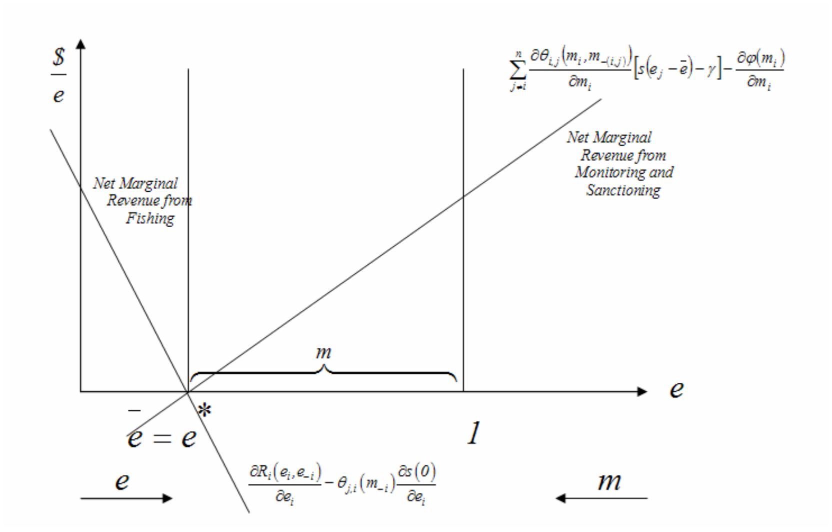
Comparing Result 6 with Results 4 and 5, we can also infer that an increase in the marginal probability of detecting and sanctioning a violator diminishes the agent's fishing effort level as the



(a) Non-Compliance without Monitoring



(b) Non-Compliance with Monitoring



(c) Compliance and Monitoring

Fig. 2. The Norm Compliance and Monitoring Decisions with Dependent Fishing and Monitoring Choices

schedule associated with the marginal revenue from monitoring and sanctioning becomes flatter. In this case the monitoring effort level is so high that there is no violation at all. This also implies that there is no actual monetary reward to those who monitor and sanction, since no one violates the norm in the fishery. Let us now provide an additional explanation of Results 4, 5 and 6 through a graphical analysis.

From Figure 2 we can infer that the individual will devote fishing effort to a level e^* in excess of the norm, $e^* > \bar{e}$, where the *expected net marginal revenue from fishing* equals the *expected net marginal revenue from monitoring and sanctioning* associated with the respective violation level. Unlike results 1 and 2, see figure 1, in this setting, the choices of fishing and monitoring efforts are dependent, so there is a trade-off between using fishing and monitoring efforts. This means that the more effort an agent devote to fishing the less she can allocate to monitoring and vice versa. Hence, the optimal compliance and monitoring decisions are made by comparing the marginal benefits of each activity. Panel (a) shows the case where in equilibrium there is non-compliance without monitoring, panel (b) shows the intermediate case where there is non-compliance with monitoring and panel (c) where there is compliance and monitoring. In general, from figure 2 it is easy to see that an individual will violate the norm whenever the schedule associated with the marginal revenue from fishing lies above the schedule of the marginal revenue from monitoring and sanctioning for all $e_i < 1$ or intersects the schedule of the marginal revenue from monitoring and sanctioning precisely at $e_i = 1$. By contrast, in order to have compliance and monitoring in the fishery, schedule of the marginal revenue from monitoring and sanctioning must lie above the schedule associated with the marginal revenue from fishing for all $e_i > \bar{e}$ or must intersect the schedule of marginal revenue from fishing precisely at $e_i = \bar{e}$. From Figure 2 it can also be inferred that increases in the marginal probability of detecting and sanction a violator will diminish the agent's fishing effort level as the marginal revenue from monitoring and sanctioning schedule becomes flatter. Nevertheless, it should be noted that these increases in the monitoring effort level will necessarily imply higher total monitoring costs and lower monetary rewards to those agents who monitor and sanction violators since in this setting more monitoring means less extractive effort. These effects are clearly reflected in the equilibrium conditions shown in Results 4, 5 and 6. On the other hand, an increase in the expected marginal sanction also diminishes the individual's fishing effort as the marginal revenue from using a fishing effort schedule shifts down. Likewise, increases in the monitoring effort level make the schedule of the marginal revenue from fishing becomes steeper, since these increases in monitoring imply that less extractive effort is devoted in the fishery as a whole.

4 Concluding Remarks

A first conclusion that can be inferred from our analysis is that in the absence of any *endogenous regulation* from the part of the fishing community, namely norms or rules aimed at restricting the use of the commonly owned resource, TURFs can not avoid the economic over-exploitation of the fishery. Indeed, even assuming that the access to the fishery is effectively enforced by the external regulatory authority, TURFs legislation only transform the open access problem in a common property resources problem, and therefore there will still be economic over-exploitation, where fishing firms will use more effort than that which is socially optimal. This implies that some form of internal regulation is required for TURFs to produce the desired changes in terms of aggregated effort used in the fishery.

Another implication from our work, specifically from the static game of norm compliance presented in section 3, is the importance of economic incentives (and disincentives) in the formulation of endogenous regulations aimed at ensuring compliance of the MEP. This is particularly important for fishing communities with no tradition in co-operative management. Indeed, from our analysis of the norm compliance and monitoring decisions when the choices of fishing and monitoring efforts are independent decisions, it becomes clear that if monitoring and sanctioning are costly activities, in the absence of economic incentives for those agents who detect and report a violator, monitoring will never be performed by rational fishermen (see Result 3 and Corollary 2). This in turn implies that even considering very large monetary sanctions to violators, compliance of the social norm will not necessarily be ensured, e.g. if the monitoring effort level of each individual within the fishery is actually zero this implies non-compliance of the norm (see Results 1 and 2 and Corollary

2).

These results on the importance of economic incentives and disincentives are also confirmed in the most restrictive setting analysed in section 3, that where the choices of fishing and monitoring efforts are considered to be dependent. In this case there is a trade-off between using fishing and monitoring efforts. This means that the more effort an agent devote to fishing the less she can allocate to monitoring and vice versa. Hence, the optimal compliance and monitoring decisions are made by comparing the marginal benefits of each activity. Clearly in this case, if the marginal benefits from fishing are very large in comparison with the marginal benefits from monitoring and sanctioning, the higher will be the extractive effort spent by each fishermen and consequently the lower will be her monitoring effort (see Results 4, 5 and 6). This implies that in order to ensure compliance and monitoring, it is necessary to formulate economic incentives to increase the marginal benefits from monitoring and sanctioning and economic disincentives to decrease the marginal benefits from using a fishing effort higher than the socially allowed level.

Our results on the relevance of economic incentives in the context of a TURF regulation can also be used to highlight the importance of less conventional enforcement tools. The implementation of TURF, especially in communities where previous experience with this type of property rights is absent, the regulation might require to be supported with enforcement strategies that substitutes traditional tools, like the monitoring activity to detect violations and the imposition of sanctions. For example, increasing the perception of legitimacy of the regulation as well as the sense of belonging to the community or organization among the regulated population, might help to induce compliance with the norm even in the absence of monetary rewards.

Furthermore, despite the importance of the enforcement of the

MEP to ensure an effective TURF regulation, currently all related regulation focus mainly on the biological and technical aspects of the fishery exploitation, leaving out of the analysis the economic considerations which are crucial to understand the strategic behaviour of the fishermen. The Chilean Fisheries and Aquaculture Law, for example, does not specifically ask for the detail of the norms and internal regulations to be used by the community to guarantee the compliance of the MEP. According to the results shown in this article, for the regulatory authority to know this information is vital to ensure that these fishing associations take into account the potential problems associated with self-regulation prior they are granted the rights of exploitation. This is especially relevant in cases where the fishery in question has been traditionally over-exploited in an open-access regime, and no previous form of community organisation has existed before the proposal for the use rights, which is precisely the case of some Chilean fisheries under TURFs.

Finally, in terms of future lines of research related to the topics addressed in this article, it can be mentioned the empirical testing of the models of norm compliance formulated here. This would require conducting interviews in fisheries regulated under TURFs to get data for the econometric study. This survey should include fisheries where co-operative management has worked and where it has not, so it can be empirically determined the determinants of compliance and non-compliance.[13] Once validated the theoretical results presented here, another topic of research consists in the design of specific regulations aimed at ensuring that fishing communities asking for fishing use rights do appropriately consider the problems associated with the issue of enforcement of the MEP.

[13] For a methodological guideline for this type of econometric study see for instance, Sutinen and Gauvin (1989).

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Appendix 1:

Proof of Proposition 1:[14] Denote the average product by $A(e_1 + \ldots + e_n) = \frac{H(e_1+\ldots+e_{i-1}+e_i+e_{i+1}+\ldots+e_n)}{(e_1+\ldots+e_{i-1}+e_i+e_{i+1}+\ldots+e_n)}$. It can be easily checked that $\frac{\partial A(e_1+\ldots+e_n)}{\partial e_i} < 0$ and $\frac{\partial^2 A(e_1+\ldots+e_n)}{\partial e_i^2} < 0$. Hence the optimisation problem presented in equation (1) becomes: (A1) $R_i(e_i, e_{-i}) = e_i A(e_1 + \ldots + e_{i-1} + e_i + e_{i+1} + \ldots + e_n) - ce_i$. The first-order condition for (A1) is: (A2) $A(e_i + \sum e^*_{-i}) + e_i \frac{\partial A(e_i + \sum e^*_{-i})}{\partial e_i} - c = 0$ where $\sum e^*_{-i} = e^*_1 + \ldots + e^*_{i-1} + e^*_{i+1} + \ldots + e^*_n$. Substituting e^*_i into (A2), summing over all n players' first-order conditions, and then dividing by n yields: (A3) $A(E^*) + \frac{1}{N} E^* \frac{\partial A(E^*)}{\partial e_i} - c = 0$ where $E^* = e^*_1 + \ldots + e^*_n$ denotes the Nash equilibrium fishing effort. In contrast, the social optimum denoted by $\bar{E} = \bar{e}_i + \ldots + \bar{e}_n$ solves: $\max_{0 \leq E \leq \infty} EA(E) - Ec$. The first-order condition for which is: (A4) $A(\bar{E}) + \bar{E} \frac{\partial A(\bar{E})}{\partial e_i} - c = 0$. Let us suppose that $E^* < \bar{E}$. Then $A(E^*) \geq A(\bar{E})$, since $\frac{\partial A(e_1+\ldots+e_n)}{\partial e_i} < 0$. Likewise, $0 > \frac{\partial A(E^*)}{\partial e_i} \geq \frac{\partial A(\bar{E})}{\partial e_i}$ since $\frac{\partial^2 A(e_1+\ldots+e_n)}{\partial e_i^2} < 0$. Finally, $\frac{E^*}{n} < \bar{E}$. As this implies that $A(E^*) + \frac{1}{N} E^* \frac{\partial A(E^*)}{\partial e_i} - c > A(\bar{E}) + \bar{E} \frac{\partial A(\bar{E})}{\partial e_i} - c$ the inequality $E^* < \bar{E}$ will never hold since by equation (A3) and (A4) we know that $A(E^*) + \frac{1}{N} E^* \frac{\partial A(E^*)}{\partial e_i} - c = A(\bar{E}) + \bar{E}) \frac{\partial A(\bar{E})}{\partial e_i} - c$. Therefore we have proved that $E^* > \bar{E}$. **Q.E.D.**

[14] This proof is based on Gibbons (1992: 27-29)