Social Norm Compliance in Territorial Use Rights Regulations: A Game Theoretic Approach*

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Abstract

One type of regulation 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 consist 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, there is, to our knowledge, 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 *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 addition, we also put forward a dynamic version of the norm compliance game based on the evolutionary game theoretic concept of replicator dynamics. In particular, here we explore the long run stability of the non-compliant and compliant equilibria, analysing the population dynamics.

***JEL Classification*:** Q22, K42, C72, B52
***Keywords*:** Social Norm Compliance, Territorial Use Rights, Common Property Resources, Game Theory and Evolutionary Game Theory.

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1. Introduction

Regulatory authorities have increasingly begun to implement decentralised management systems in fisheries. In particular, one type of regulation 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 consist 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 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). 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 a long-standing tradition of community management. This is, for instance, the case of Vanuatu (Johannes, 1998; 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, as the Japanese case referred above, some countries have started to evaluate the possibility of pushing this type of regulation forward and introducing territorial use rights even in coastal fisheries were *property rights have never been in place*[1]. This type of "de novo" implementation is not 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

[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 TURFs in the shellfish fisheries of Galicia (NW Spain)).

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 Fernandez, 1998; Orensanz et. al., 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.[3]

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-

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

[3] There are two main aims associated with the allocation of AMEBRs in the Chilean case (D.S. 355, 12 June 1995). First, the reduction of aggregate fishing effort in coastal fisheries, reverting thus the uncontrolled increment in effort seen in the past (see also, Barros and Aranguez, 1993; Castilla et al. 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). To this end, 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.).

exploitation). Can then fishing communities, with no tradition in co-operative management, be able to enforce the MEP, achieving adequate 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[4]. 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[5]. We assume that whenever a fisherman is detected violating the norm, a monetary fine is imposed upon him. While we assume that monitoring and 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

[4] 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 Fernandez (1998) and Orensanz et al. (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.

[5] See, for instance, Sethi and Somanathan (1996; 2001) and Ostrom et al. (1992; 1994).

community[6]. 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.

While this game of norm compliance does capture some of the main issues associated with the strategic decisions of norm compliance and monitoring, there is one additional aspect to consider in the analysis, which is related to the long-term adoption of the social norm within the community. If initially most of the people adhere to the social norm and monitor each other, it is more likely that the norm will be complied by the population in the long run. This can be so, among other reasons, because the probability of being detected and sanctioned obviously depends upon the number of other agents monitoring each other actions. Thus, if initially most people monitor and sanction violators, it would not be convenient to start violating the norm from the beginning and most of the people will stay compliant. By contrast, if initially most of the population violates the norm and do not monitor (for instance, because it is a costly activity) it is more likely that the norm will not be complied by the population in the long run. This can be so because if a small fraction of the population starts monitoring and sanctioning violators, they will be a minority and it will still be profitable to violate the norm (the probability of being caught and sanctioned will be rather small). Hence, an important aspect to consider regarding the successful implementation of the MEP is the *stability of the social norm over time*, which crucially depends upon the population adhering to the different strategies.

In order to formally address this issue, here we deviate from the traditional game theoretical framework, and using elements of evolutionary game theory present the population dynamics of the static game of norm compliance. In particular, here we follow the work of Sethi and Somanathan (1996) who using the concept of the replicator dynamics

[6] 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 properties…Individual 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.”

(RD) investigate how successful, in evolutionary terms, alternative strategies, associated with several groups within the population, are in a CPR game with costly sanctioning. We depart from Sethi and Somanathan's work, however, in the sense that we are no longer modelling the dynamics of the traditional CPR game with costly sanctioning[7], but the static model of norm compliance that we propose here.

The paper has been structured as follows. First, we analyse what would happen in the absence of endogenous regulation. Clearly, in the best scenario, assuming that access to the fishery is effectively enforced by the external regulatory authority, the TURFs legislation transform the open access problem in a common property problem, and therefore the economic over-exploitation 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 norm compliance in a regime of CPR exploitation. Specifically, here we present results addressing the norm compliance and monitoring decisions. Third, in section 4 we propose a dynamic version of the norm compliance game based on the concept of the replicator dynamics. Basically, here we explore the stability of the non-compliant and compliant equilibria, analysing the population dynamics. Finally, in section 5 some concluding remarks are offered. Based on the economic models proposed in sections 3 and 4, we offer here some specific policies recommendations regarding the enforcement 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 in accord with 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 at this point 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

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[7] See, for instance, Jankowski (1990), Ostrom *et al*.(1992) and Sethi and Somanathan (1996).

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, assumed identical, each of which has access to a common property resource. Each player can exploit the resource using a particular effort level (which includes labour and fishing equipment), which for individual i we denote by e_i, the aggregate extraction effort being $E = \sum_{i=1}^{n} e_i$. The total product is given by a differentiable real function H which, in this static version of the 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*. Finally, we suppose that, $0 < c < H'(0)$, which guarantees that an interior solution is obtained.

The individual profit of each fishing agent can be written as the revenue resulting from the sale of the amount of resource extracted by the individual (remember that we normalise the price of a unit of the resulting product as one) minus the cost of the individual's extractive effort. Thus agent *i*'s net benefit from resource extraction, denoted by R_i, is:

$$(1) \qquad R_i(e) = \frac{e_i}{E} H(E) - ce_i ,$$

where $R_i(0) = 0$. Alternatively, denoting by $E_{-i} = (n-1)e_{-i}$ the extractive effort of all other agents besides a single representative player *i*, such that $e_i + (n-1)e_{-i} = E$, then from (1) we have that the profit of individual *i* will be given by:

$$(2) \qquad R_i\left(e_i, (n-1)\, e_{-i}\right) = \frac{e_i}{e_i + (n-1)\, e_{-i}} H\left[e_i + (n-1)\, e_{-i}\right] - ce_i .$$

Consequently, the CPR game can be formally described as follows: $G \equiv \{e_i, R_i\}_{i \in I}$, which corresponds to an *n*-person normal form game where $I = \{1,...,n\}$ is the set of players, $e_i \geq 0$ denotes the action set of player *i*, given by the effort level, and $R_i : \times_j e_j \to R,\ i\ Î\ I,$ the *material* payoff functions, given by the profit associated with the exploitation of the common resource by each agent, that is equation (2). As proposition 1 formally shows below, the main result of this game is that if all players are payoff maximisers then 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.[8]

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

Proposition 1: *Let* $G \equiv \{e_i, R_i\}_{i \in I}$ *be a game satisfying the assumptions of the model discussed above, and let* $\overline{E} = n\,\overline{e}$ *denote the socially optimum, efficient, fishing effort, and* $E^* = n\,e^*$ *the Nash equilibrium fishing effort. We then have that the Nash equilibrium effort level introduced by each fisherman, i.e.* $e_i = e^*$ *for all* $i \in I$*, is larger than the Pareto efficient, socially optimum, level, i.e.* $e^* > \overline{e}$*. As this implies that* $E^* > \overline{E}$*, 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 not 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.

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 (without the presence of an external regulatory authority). 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, that is $\overline{e} > 0$, are sanctioned. Thus, in formal terms, an agent violates the social norm whenever her individual effort, e_i, is above the norm, $\overline{e}$, that is: $e_i - \overline{e} > 0$.

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. [9] In particular, in terms of monitoring, we suppose that each player can monitor other players using a particular effort level, which for individual i we denote by m_i, the aggregate monitoring effort being $M = \sum_{i=1}^{n} m_i$. We denote by $M_{-i} = (n-1)m_{-i}$ the monitoring effort of all other agents besides a single representative player *i*, such that $m_i + (n-1)m_{-i} = M$. Hence, we assume that there exists a probability of being detected and sanctioned, denoted by $q = q\left(e_i - \bar{e}, (n-1)m_{-i}\right)$, which depends on the violation level of the representative individual *i*, i.e. $e_i - \bar{e} > 0$, and on the level of the monitoring effort of all other individuals besides *i*, i.e. the population vigilance level $M_{-i} = (n-1)m_{-i}$. We further assume that $\frac{\partial q}{\partial e_i} > 0$, $\frac{\partial q}{\partial m_{-i}} > 0$, $\frac{\partial^2 q}{\partial e_i^2} \geq 0$ and $\frac{\partial^2 q}{\partial m_{-i}^2} \leq 0$. To simplify the analysis, we assume all agents face the same q.

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 $j(m_i)$, which accounts for the cost of monitoring one agent, similar to a unit cost function. Formally, we assume that this function is strictly increasing and convex in monitoring effort, i.e. $\frac{\partial j}{\partial m_i} > 0$, $\frac{\partial^2 j}{\partial m_i^2} \geq 0$. The latter is denoted by g, which is an exogenous variable, and represents the transaction costs associated with reporting one agent [10]. Since, we are

[9] For previous work on social norm compliance in CPR context, see, for instance, Sethi and Somanathan (1996; 2001) and Ostrom et al. (1992; 1994).

[10] 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

assuming imperfect monitoring here, sanctioning depends upon being able to detect a violator, in other words depends on probability q. Thus, we suppose that the expected cost for agent i of sanctioning another agent is given by $q\left(e_{-i}-\bar{e}, m_i\right)g$.

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. To simplify the analysis here we consider that sanctioning in the form of a fine always fits the crime and that every player can be convicted only once for the violation. 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, the penalty, if caught, is given by, $s=s\left(e_i-\bar{e}\right)$, with $\frac{\partial s}{\partial e_i}>0$, $\frac{\partial^2 s}{\partial e_i^2}\geq 0$, $\forall\, e_i>\bar{e}$ and $s\left(e_i-\bar{e}\right)=0,\ for\ e_i-\bar{e}\leq 0$. We also assume that this penalty is zero for zero 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:

(3)

$$p_i=R_i\left(e_i,(n-1)e_{-i}\right)-q\left(e_i-\bar{e},(n-1)m_{-i}\right)s\left(e_i-\bar{e}\right)+q\left(e_{-i}-\bar{e},m_i\right)\left[s\left(e_{-i}-\bar{e}\right)-g\right](n-1)-j\left(m_i\right)(n-1)$$

where $R_i\left(e_i,(n-1)e_{-i}\right)$ represents agent i's net payoff under the basic CPR setting presented in section 2, see equation (2). 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 he/she will have to pay a fine proportional to her violation, that is $s\left(e_i-\bar{e}\right)$. Since, monitoring is imperfect, the detection of her violation will depend upon probability $q\left(e_i-\bar{e},(n-1)m_{-i}\right)$, which is function of the

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only monitoring other agents is costly, but also reporting a violator, to be sanctioned, involves a cost. This amount of the violation and the monitoring effort put by the rest of the population. Thus, the expected cost for agent *i* of being caught violating the norm is given by $q\left(e_i - \bar{e}, (n-1)\, m_{-i}\right) s\left(e_i - \bar{e}\right)$.

Agent *i* also chooses her monitoring effort level, which can be positive or zero, i.e. $m_i \geq 0$.[11] Given this level of monitoring effort level, player *i* can be able to detect a violator and receive the associated payment, given by the fine levied to the offender. As the probability of being able to catch a violator not only depends upon the monitoring effort of agent *i*, but also upon the amount of the violation, we have that the expected reward to agent *i* for effectively detect and sanction a violator is given by $q\left(e_{-i} - \bar{e}, m_i\right) s\left(e_{-i} - \bar{e}\right)$. Similarly, the expected cost for agent *i* of sanctioning the offender is $q\left(e_{-i} - \bar{e}, m_i\right) g$. Since we assume that agent *i* can monitor and sanction all the rest of the population, that is *(n-1)* players, the expected payoff associated with sanctioning other agents who violate the norm is given by $q\left(e_{-i} - \bar{e}, m_i\right)\left[s\left(e_{-i} - \bar{e}\right) - g\right](n-1)$. Here we further assume that the reward awarded to those agents who detect and report a violator is always greater than the transaction costs associated with reporting one agent, i.e. $s > g$. Finally, in terms of the monitoring costs for agent *i* we have that they are given by the unit cost function $j\left(m_i\right)$ which is strictly increasing in monitoring effort. As agent *i* monitors all the rest of the population, total monitoring cost are given by $j\left(m_i\right)(n-1)$.[12]

The norm compliance game can be formally described by $G \equiv \left\{(e_i, m_i), p_i\right\}_{i \in I}$ which corresponds to an *n*-person normal form game where $I = \{1, \ldots, n\}$ is the set of players, (e_i, m_i), with $e_i \geq \bar{e}$ and $m_i \geq 0$, denotes the action set of player *i*, given by the extraction and monitoring effort levels, and $p_i : \times_j e_j \rightarrow R,\ i\ \hat{I}\ I$, the *material* payoff functions, given

idea has empirical support in local commons, for a particular example see Casari and Plott (2003).

[11] We assume that the choice of the effort to monitor peers is independent from the decision on fishing effort. That would be the case, for example, when an agent is able to monitor her peers while developing fishing activities.

[12] 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 devoted to produce monitoring effort.

by the expected profit associated with the exploitation of the common resource under the monitoring and sanctioning norm by each agent, that is equation (3).

Consequently, we have that the Symmetric Nash equilibrium (SNE) of this norm compliance game, given by the pair $\left(e^{*}, m^{*}\right)$, is found by solving the following optimisation problem.[13]

(4)

$$\max_{e_i, m_i} \quad p_i = R_i\left(e_i, (n-1)\, e_{-i}\right) - q\left(e_i - \bar{e}, (n-1)\, m_{-i}\right) s\left(e_i - \bar{e}\right) + q\left(e_{-i} - \bar{e}, m_i\right)\left[s\left(e_{-i} - \bar{e}\right) - g\right](n-1) - j\left(m_i\right)(n-1)$$

$$\text{s.t.} \quad e_i - \bar{e} \geq 0$$
$$m_i \geq 0$$

The Lagrange equation for (4) is:

(5)

$$L = R_i\left(e_i, (n-1)\, e_{-i}\right) - q\left(e_i - \bar{e}, (n-1)\, m_{-i}\right) s\left(e_i - \bar{e}\right) + q\left(e_{-i} - \bar{e}, m_i\right)\left[s\left(e_{-i} - \bar{e}\right) - g\right](n-1) - j\left(m_i\right)(n-1) + m m_i + b\left(e_i - \bar{e}\right)$$

and the Khun-Tucker conditions are:

(5a) $$\frac{\partial L}{\partial e_i} = \frac{\partial R_i\left(e_i, (n-1)\, e_{-i}\right)}{\partial e_i} - s\left(e_i - \bar{e}\right)\frac{\partial q\left(e_i - \bar{e}, (n-1)\, m_{-i}\right)}{\partial e_i} - q\left(e_i - \bar{e}, (n-1)\, m_{-i}\right)\frac{\partial s\left(e_i - \bar{e}\right)}{\partial e_i} + b = 0$$

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

(5c) $$\frac{\partial L}{\partial m_i} = \left[s\left(e_{-i} - \bar{e}\right) - g\right](n-1)\frac{\partial q\left(e_{-i} - \bar{e}, m_i\right)}{\partial m_i} - (n-1)\frac{\partial j\left(m_i\right)}{\partial m_i} + m = 0 \cdot$$

(5d) $$\frac{\partial L}{\partial m} = m_i \geq 0, \quad m \geq 0, \quad m\, m_i = 0$$

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

Given the assumptions about the profit function, the probability of being detected violating the norm, penalty schedule, and monitoring cost, (5a) -(5d) are necessary and sufficient to determine the agent optimal allocation of extraction and monitoring effort (for details, see Appendix 2). Before presenting the conditions for a SNE, we discuss some partials results regarding the compliance conditions, the optimal level of monitoring effort and the respective comparative static results.

Result 1: *An individual chooses to violate the social norm, i.e.* $e_i = e^* > \bar{e}$, *if and only if*

(6) $$\frac{\partial R_i\left(e^*, E_{-i}^*\right)}{\partial e_i} = s\left(e^* - \bar{e}\right)\frac{\partial q\left(e^* - \bar{e}, M_{-i}^*\right)}{\partial e_i} + q\left(e^* - \bar{e}, M_{-i}^*\right)\frac{\partial s\left(e^* - \bar{e}\right)}{\partial e_i}$$

Proof of Result 1: Suppose 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 $b = 0$, then (6) is clearly necessary for $e_i > \bar{e}$ to be an optimal choice.

To show that (6) is also sufficient, suppose to the contrary that (6) holds but $e_i = \bar{e}$. Given $e_i = \bar{e}$, equation (5b) implies that $b \geq 0$. This in turn implies by equation (5a) that $\frac{\partial R_i\left(e_i, (\mathrm{n}-1)e_{-i}\right)}{\partial e_i} - q\left(0, (\mathrm{n}-1)m_{-\mathrm{i}}\right)\frac{\partial s(0)}{\partial e_i} \leq 0$. Since this contradicts (6), we have established the sufficiency of (6) for an optimal choice of $e_i > \bar{e}$. Consequently, assuming that individuals are identical, we can denote the Nash equilibrium extraction effort level by a single element, i.e. $e_i = e_{-i} = e^*$. Thus, an equilibrium strategy e^* 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. $\frac{\partial R_i\left(e^*, E_{-i}\right)}{\partial e_i}$ with $e_i > \bar{e}$, offsets the expected marginal costs associated with her violation. In particular, the expected marginal cost from violating the norm depends on the sanction, s, the marginal sanction, $\frac{\partial s}{\partial e_i}$, the probability, q, and the marginal probability,

$\frac{\partial q}{\partial e_i}$, of detection and sanctioning. By definition all these variables are increasing in fishing effort, and therefore an increase in fishing effort 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.

Result 2: *Given an optimal choice of fishing effort, the following comparative static result holds*: $\frac{de^*}{d\bar{e}} > 0$, $\frac{de^*}{dn} < 0$ and $\frac{de^*}{dg} = 0$.

Proof of Result 2: See Appendix 3.

In terms of parameters, $\bar{e}$, the social norm, and, n, the number of agents exploiting the CPR from the comparative static result presented above we can infer the following. First, an increase in the social norm will trigger an increase in the illegal amount of fishing effort. Second, an increase in the number fishermen sharing the CPR, by contrast, will induce a reduction of the illegal fishing effort level. This is consistent with the fact mentioned above that an increase in the number of fishing firms exploiting the CPR reduces the marginal revenue from violating the norm. Finally, as expected, it can be noted that in terms of g, the transaction costs associated with effectively sanctioning one agent, an increase in this parameter has no effect on the individuals' optimal choice of fishing effort.

It should also be noted that from result 1 it is clear that in this static model, the individual's optimal choice of fishing effort is independent of her choice of monitoring effort, m_i. However, the individual decision does depends on the rest of the population vigilance level, that is the monitoring level of all other individuals, $M_{-i} = (n-1)\, m_{-i}$. 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 3: An agent chooses to comply with the social norm, i.e. $e_i = e^* = \bar{e}$, if and only if

(7) $\frac{\partial R_i\left(e^*, E_{-i}^*\right)}{\partial e_i} \leq q\left(0, M_{-i}^*\right)\frac{\partial s(0)}{\partial e_i}$

Proof of Result 3: Suppose 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 $b \geq 0$, then by equation (5a) the condition in (7) is clearly necessary for $e_i = \bar{e}$ to be an optimal choice.

To show sufficiency, suppose to the contrary that (7) holds but $e_i - \bar{e} > 0$. Given $e_i - \bar{e} > 0$, equation (5b) implies that $b = 0$. This in turn implies by equation (5a) that $\frac{\partial R_i\left(e_i, (n-1)\, e_{-i}\right)}{\partial e_i} = s\left(e_i - \bar{e}\right)\frac{\partial q\left(e_i - \bar{e}, (n-1)\, m_{-i}\right)}{\partial e_i} + q\left(e_i - \bar{e}, (n-1)\, m_{-i}\right)\frac{\partial s\left(e_i - \bar{e}\right)}{\partial e_i}$, from which follows that $\frac{\partial R_i\left(e_i, (n-1)\, e_{-i}\right)}{\partial e_i} > q\left(0, (n-1)\, m_{-i}\right)\frac{\partial s(0)}{\partial e_i}$. Since we have contradicted (7), we have established the sufficiency of it for an optimal choice of $e_i = \bar{e}$. Assuming that individuals are identical, we can denote the Nash equilibrium extraction effort level by a single element, i.e. $e_i = e_{-i} = e^*$. Thus, an equilibrium strategy e^* must condition (7). **Q.E.D.**

From result 3, an agent will be compliant if the marginal revenue from using a fishing effort level equivalent to the one established by the social norm, $\frac{\partial R_i\left(e^*=\bar{e}, E_{-i}\right)}{\partial e_i}$, is lower or equals the expected marginal penalty it would pay at the zero violation level, $q\left(0, M_{-i}\right)\frac{\partial s(0)}{\partial e_i}$. As in result 1, it is obvious that the compliance decision is independent of the agent's own monitoring effort, but it dependent of the population's enforcement strategy, $M_{-i} = (n-1)\, m_{-i}$.

Results 1 and 3 can be better explained through a graphical analysis. Figure 1 below shows the solution to equations (6) and (7) for particular forms of the penalty function, s, and probability function, q.

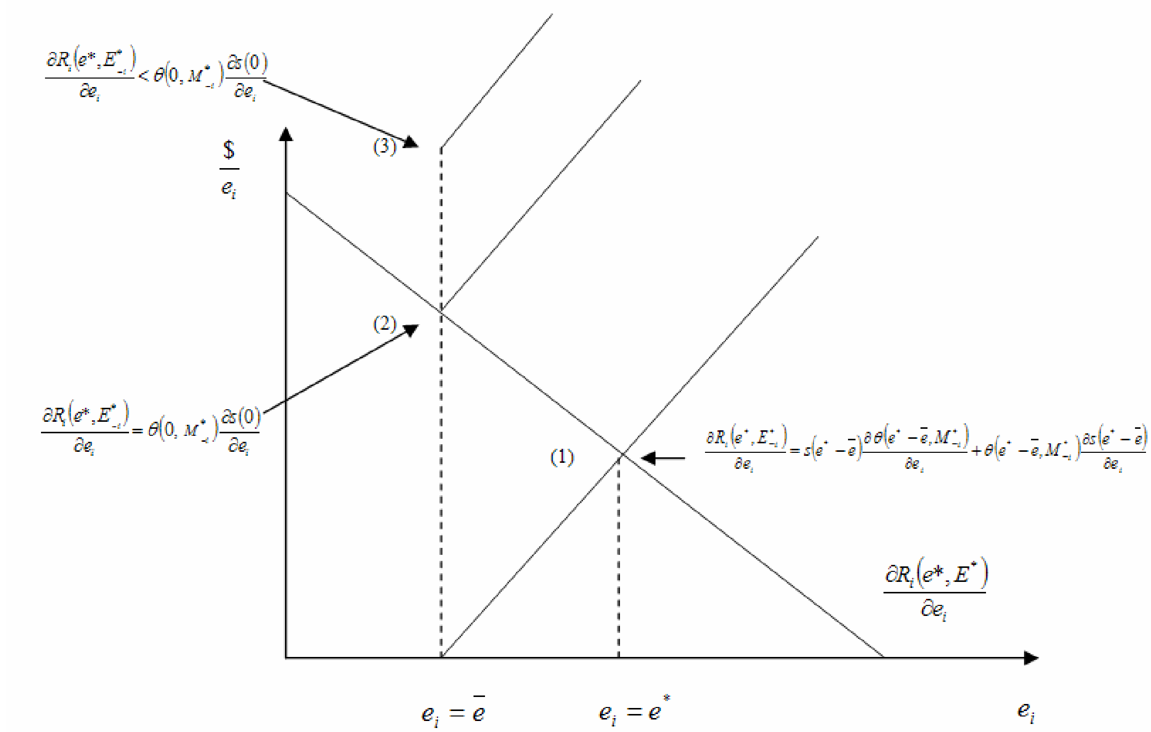

Figure 1: The Norm Compliance Decision

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.[14] In general, the individual will violate the norm whenever 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 sanction and 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 and the marginal probability of being detected and sanctioned also decrease the individual's fishing effort as the marginal cost schedule becomes steeper (see Figure 1). With respect to the marginal revenue schedule, increases in the number of fishing firms 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 4 provides a necessary and sufficient condition for ensuring that monitoring activity will be performed by agents.

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[14] 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 $q = 0$), 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 5.2, i.e. e^*. Here it should also be noted that as access is limited to just *n* fishermen (*n* not being infinite) 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 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)).

Result 4: *Monitoring will be carried out by an agent, i.e.* $m^* > 0$*, if and only if*

(8) $$s\left(e_{-i} - \bar{e}\right)\frac{\partial q\left(e_{-i} - \bar{e}, m^*\right)}{\partial m_i} = g\,\frac{\partial q\left(e_{-i} - \bar{e}, m^*\right)}{\partial m_i} + \frac{\partial j\left(m^*\right)}{\partial m_i}$$

Proof of Result 4: Suppose 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 $m = 0$, then (8) is clearly necessary for $m_i > 0$ to be an optimal choice.

To show that (8) is also sufficient, suppose to the contrary that (8) holds but $m_i = 0$. Given $m_i = 0$, equation (5d) implies that $m \geq 0$. This in turn implies by equation (5c) that $\left[s\left(e_{-i} - \bar{e}\right) - g\right]\frac{\partial q\left(e_{-i} - \bar{e}, m_i\right)}{\partial m_i} - \frac{\partial j\left(m_i\right)}{\partial m_i} \leq 0$. Since this contradicts (8), we have established the sufficiency of this condition for an optimal choice of $m_i > 0$. Assuming that individuals are identical, we can denote the Nash equilibrium monitoring effort level by a single element, i.e. $m_i = m_{-i} = m^*$. Thus, an equilibrium strategy m^* must satisfy condition (8). **Q.E.D.**

This result implies that monitoring will be carried out to the extent that the marginal benefits from monitoring and sanctioning, $s\left(e_{-i} - \bar{e}\right)\frac{\partial q\left(e_{-i} - \bar{e}, m^*\right)}{\partial m_i}$, equals the marginal costs associated with monitoring, $\frac{\partial j\left(m_i\right)}{\partial m_i}$, and sanctioning, $g\,\frac{\partial q\left(e_{-i} - \bar{e}, m^*\right)}{\partial m_i}$ activities. From result 4, it also becomes evident that 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 (i.e. $\frac{\partial j\left(m_i\right)}{\partial m_i} > 0$, and $g\,\frac{\partial q\left(e_{-i} - \bar{e}, m^*\right)}{\partial m_i} > 0$), and there is no reward awarded to those agents who detect and report a violator (i.e. $s\left(e_{-i} - \bar{e}\right)\frac{\partial q\left(e_{-i} - \bar{e}, m^*\right)}{\partial m_i} = 0$), monitoring will never be performed by rational fishermen.

Result 5: *Given an optimal choice of monitoring effort, where* $m_i = m^*\left(\bar{e}, n, g\right)$*. The following comparative static result holds:* $\frac{dm^*}{d\bar{e}} < 0$, $\frac{dm^*}{dn} > 0$ and $\frac{dm^*}{dg} < 0$.

Proof of Result 5: See Appendix 4.

From the comparative static result presented above, it can be noted that increases in parameter g , the transaction costs associated with effectively sanctioning one agent, implies a decrease in the marginal benefit from monitoring and sanctioning and therefore a decrease in the individual’s monitoring effort level. Similarly, an increase in the social norm reduces the marginal net benefit from monitoring and sanctioning and therefore implies a reduction of the monitoring effort level. By contrast, an increase in the number of agents sharing the CPR implies an increase in the individual’s monitoring effort.

Finally, from Results 1 and 4, the Symmetric Nash equilibrium (SNE) of the norm compliance game proposed here, given by the pair $\left(e^*, m^*\right)$, is presented in the following proposition.

Proposition 2: A pair $\left(e^*, m^*\right)$ corresponds to a SNE of the norm compliance game $G \equiv \left\{\left(e_i, m_i\right), R_i\right\}_{i \in I}$, whenever the following condition holds:

(9) $$\frac{\partial R_i\left(e^*, (n-1)e^*\right)}{\partial e_i} = \left[g\,\frac{\partial q\left(e^* - \bar{e}, m^*\right)}{\partial m_i} + \frac{\partial j\left(m^*\right)}{\partial m_i}\right]\left[\frac{\partial q\left(e^* - \bar{e}, (n-1)m^*\right)}{\partial e_i} \Big/ \frac{\partial q\left(e^* - \bar{e}, m^*\right)}{\partial m_i}\right] + q\left(e^* - \bar{e}, (n-1)m^*\right)\frac{\partial s\left(e^* - \bar{e}\right)}{\partial e_i}$$

Proof of Proposition 2: Follows directly from combining equations (6) and (8) **Q.E.D.**

From proposition 2, it becomes clear that the optimal, Symmetric Nash Equilibrium, choice of both extraction and monitoring efforts implies that an individual violates the social norm to the extent that her marginal revenue from using a extraction effort level higher than the socially allowed level offsets the expected marginal costs associated with her violation. Different from Result 1, however, here the expected marginal costs associated with the violation are expressed as a function of the marginal costs associated with monitoring and sanctioning activities. In other words, here the marginal costs associated with monitoring and sanctioning activities are considered as part of the expected marginal costs associated with the violation.

4. A Dynamic Evolutionary Game of Norm Compliance

In this section we propose a dynamic game of norm compliance. In particular, we use elements of evolutionary game theory to explore the population dynamics of the static model presented above.

4.1 The Norm Compliance Evolutionary Dynamics

In order to model the norm compliance evolutionary dynamics, instead of a continuum of possible extraction effort level, we assume that there are only two, e_c and e_v with $e_c < e_v$, which denote a low effort level that complies with the social norm and a high effort level that exceeds the social norm respectively. Here players adopting the high effort level, i.e. e_v, are referred to as *non-compliant players* or *violators*, since they violate the social norm, and those adopting the low effort level, i.e. e_c, are referred to as *compliant players*. It should be noted that unlike Sethi and Somanathan's (1996) contribution, here we are not concerned with the parameters of the payoff under the basic CPR setting presented in section 2, see equation (2). Instead we just assume that the basic payoff received for using a low fishing effort level, which we denote by R_c, and a high fishing effort level, which we denote by R_v, conform to the following relation: $R_v = b + R_c$ with $b > 0$. Here parameter b can be seen as a premium by being a violator in a population of compliant players. In other words, the basic payoff for *non-compliant players* is always higher than the basic payoff for *compliant players*.

In terms of the specific strategies pursued by different agents of the extracting community, we suppose that within the population there is a proportion of *compliant players*, other of *non-compliant players* and other of *compliant-sanctioning players*, which we denote p_1, p_2 and p_3 respectively. Given the population shares p_i at any point in time, it is assumed that each of the $p_1 n$ compliant players receives the payoff associated with the adoption of a low fishing effort level, namely R_c. By contrast, the $p_2 n$ non-compliant players receive the payoff associated with the adoption of a high fishing effort level, namely R_v. However, non-compliant players are monitored by the $p_3 n$ compliant-sanctioning players, and so they can be sanctioned if caught violating the norm. In particular, here we assume that there exists a probability of being detected and sanctioned, denoted by Θ, which is increasing in the proportion share of compliant-sanctioning players, p_3. A non-compliant player will meet a compliant-sanctioning player with probability p_3, and the latter will detect and sanction a violator with probability $Q(p_3)$, with $Q(0)=0$. Hence, assuming a monetary sanction of S, with $S>0$, each time an individual violates the norm, the expected sanction for a non-compliant player will be $(p_3)Q(p_3)S$[15]. Thus, the payoff associated with the non-comply strategy becomes $p_2 = R_v - (p_3)Q(p_3)S$. Finally, each of the $p_3 n$ compliant-sanctioning players receive the payoff associated with the adoption of a low fishing effort level, namely R_c. As in the norm compliance model presented in section 3, here individuals who monitor and sanction non-compliant players receive a monetary reward S, equivalent to the sanction imposed to a violator. The costs associated with sanctioning a violator are the transaction costs associated with sanctioning one agent, denoted by G, and the monitoring costs, denoted by, ϑ, which are function of the proportion of non-compliant players, p_2. Hence, as the probability of meeting a violator is p_2, the net expected gains for compliant-sanctioning players are: $p_3 = R_c + [S-G]p_2 - J(p_2)$. The payoffs to each strategy type, given the population composition, are therefore:

(10) $p_1 = R_c$

[15] As in section 3, in order to simplify the analysis here we consider that sanctioning in the form of a fine always fits the crime and that every player can be convicted only once for the violation.

(11) $\pi_2 = R_v - (p_3)Q(p_3)S$

(12) $\pi_3 = R_c + [S - G]p_2 - J(p_2)$

From equations (10), (11) and (12) it is clear that if there are no violators, compliant players will perform as well as compliant-sanctioning players. By contrast, if non-compliant players are present in the population, the dominance of the compliant-sanctioning strategy over the compliant strategy or vice versa, basically depends upon the expected net benefits from sanctioning, namely $[S - G]p_2$, and monitoring costs $J(p_2)$. Thus, if the expected net benefits of sanctioning a violator are greater than monitoring costs, i.e. $[S - G]p_2 > J(p_2)$, the compliant-sanctioning strategy will weakly dominate the compliant strategy, otherwise the opposite will happen, that is the compliant strategy will weakly dominate the compliant-sanctioning strategy. This clearly deviate from Sethi and Somanathan's paper, since in their work the enforcer strategy (the equivalent to the compliant-sanctioning strategy in this essay) is always weakly dominated by the co-operator strategy (Sethi and Somanathan, 1996: 773).

Let us now formalise the replicator equation as typically presented in the evolutionary game theoretical literature[16]. Consider an evolutionary game with n pure strategies and stage game pay-off π_{ij} to an i-player who meets a j-player. If $p = (p_1, ..., p_n)$ is the frequency of each type in the population, the expected payoff to an i-player is then $\pi_i(p) = \sum_{j=1}^{n} p_j \pi_{ij}$, and the average payoff in the game is $\bar{\pi}(p) = \sum_{i=1}^{n} p_j \pi_i(p)$. The replicator dynamic for this game is then given by:

(13) $\dot{p}_i = p_i\left(\pi_i(p) - \bar{\pi}(p)\right)$

[16] The mathematical formulation of the replicator dynamics is due to Taylor and Jonker (1978). For details see also, Weibull (1996), Vega-Redondo (1996) and Gintis (2000).

The replicator equation expresses the idea that strategies grow in the population if they do better than average, strategies that do best grow fastest. One immediately sees that a Nash equilibrium is a stationary point of the dynamical system. Conversely, each stable stationary point is a Nash equilibrium and an asymptotically stable fixed point is a perfect equilibrium (Bomze, 1986).

In the context of equations (10), (11) and (12), the replicator dynamics will be represented by the two differential equations presented below:

$$(14)\quad \frac{dp_1}{dt} = \dot{p}_1 = p_1(\pi_1 - \bar{\pi})$$

$$(15)\quad \frac{dp_2}{dt} = \dot{p}_2 = p_2(\pi_2 - \bar{\pi})$$

where $\bar{\pi} = p_1\pi_1 + p_2\pi_2 + (1 - p_1 - p_2)\pi_3$ is the average payoff in the population as a whole[17]. From (14) and (15) it is clear that the rate of growth of the share of the population using strategy 1 and strategy 2 are proportional to the amount by which those strategy's payoff exceed the average payoff of the strategies in the population.

Taken together, equations (14) and (15) constitute *a system of first order differential equations*[18]. In particular here we want to examine the stability of two equilibria, the case where the population consists only of violators, that is $(p_1 = 0, p_2 = 1)$, and the case where no violators are present, that is $(p_1 = a, p_2 = 0)$ with $a \in [0,1]$.[19] The stability of these two equilibria are examined in the following results.

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[17] It is easily verified that the population shares p_i always sum to one and remain nonnegative under the replicator dynamics (Somanathan, 1995).

[18] It is "first order" because no derivative higher than the first appear. It is "ordinary" as opposed to "partial" because we want to solve for a function of the single variable *t*, as opposed to solving for a function of several variables.

[19] The only remaining candidate for a stable equilibrium is $(p_1 = 0, p_2 > 0)$, consisting exclusively of violators and compliant/sanctioners. We do not address this case here.

Result 6: *The non-compliant equilibrium* $p_1 = 0$*, i.e. all the population violating the social norm, is local asymptotically stable if and only if:*

(16) $R_c + S < R_v + G + J(1)$

Proof of Result 6: From equations (14) and (15) we have that: $\frac{\partial \dot{p}_1}{\partial p_1} = p_1 - \overline{p} + p_1 \frac{\partial (p_1 - \overline{p})}{\partial p_1}$; $\frac{\partial \dot{p}_1}{\partial p_2} = p_1 \frac{\partial (p_1 - \overline{p})}{\partial p_2}$; $\frac{\partial \dot{p}_2}{\partial p_1} = p_2 \frac{\partial (p_2 - \overline{p})}{\partial p_1}$ and $\frac{\partial \dot{p}_2}{\partial p_2} = p_2 - \overline{p} + p_2 \frac{\partial (p_2 - \overline{p})}{\partial p_2}$. Hence, the *Jacobian* of $(\dot{p}_1, \dot{p}_2)$ at an arbitrary point (p_1^*, p_2^*) is:

$$(17)\quad J(\dot{p}_1, \dot{p}_2)(p_1^*, p_2^*) = \begin{pmatrix} \frac{\partial \dot{p}_1}{\partial p_1} & \frac{\partial \dot{p}_1}{\partial p_2} \\ \frac{\partial \dot{p}_2}{\partial p_1} & \frac{\partial \dot{p}_2}{\partial p_2} \end{pmatrix} = \begin{pmatrix} p_1 - \overline{p} + p_1 \frac{\partial (p_1 - \overline{p})}{\partial p_1} & p_1 \frac{\partial (p_1 - \overline{p})}{\partial p_2} \\ p_2 \frac{\partial (p_2 - \overline{p})}{\partial p_1} & p_2 - \overline{p} + p_2 \frac{\partial (p_2 - \overline{p})}{\partial p_2} \end{pmatrix}.$$

The steady stable equilibrium $(p_1 = 0, p_2 = 1)$, implies that $p_3 = 0$ and $\overline{p} = p_2$. In this case the *Jacobian* shown above becomes $J(\dot{p}_1, \dot{p}_2)(p_1^*, p_2^*) = \begin{pmatrix} p_1 - p_2 & 0 \\ Q(0)S + p_3 - p_1 & Q(0)S + p_3 - p_2 \end{pmatrix}$, and since we have assumed that $Q(0) = 0$, we get: $J(\dot{p}_1, \dot{p}_2)(p_1^*, p_2^*) = \begin{pmatrix} p_1 - p_2 & 0 \\ p_3 - p_1 & p_3 - p_2 \end{pmatrix}$. The conditions for the *Jacobian* matrix to have a positive determinant and a negative trace are: (i) $p_1 - p_2 < 0$ and (ii) $p_3 - p_2 < 0$. The former implies that $R_c < R_v - (p_3)Q(p_3)S$, as $p_3 = 0$ and since $Q(0) = 0$, we have that $R_c < R_v$ which by assumption of the model is always true. The latter implies that $R_c + [S - G]p_2 - J(p_2) < R_v - (p_3)Q(p_3)S$, as $p_2 = 1$, $p_3 = 0$ and since $Q(0) = 0$, we obtain $R_c + S < R_v + G + J(1)$. Hence, the condition in (16) is necessary and sufficient for local asymptotic stability. **Q.E.D.**

This result establishes that local asymptotical stability of the non-compliant equilibrium is possible only if the revenue from violating the social norm, R_v, is higher than the net benefits from complying with the norm and sanctioning a violator in a population which consists only of non-compliant players, $R_c + S - G - J(1)$. We can also interpret this result by considering the fact that $R_v - R_c = b$, with $b > 0$. Hence from (16) we get $S - G - J(1) < b$, which implies that the non-compliant equilibrium will be local asymptotically stable whenever the premium for being a violator in a population of compliant players is greater than the net benefits from sanctioning a violator. Thus, as expected, the stability of the non-compliant equilibrium is very related to the monetary benefits from sanctioning a violator, that is the reward established in the community, the monitoring costs which in this case are the higher possible having to monitor the whole population and the premium for using a high extraction level.

From (16) it can also be inferred that if there is no sanction S levied on violators and therefore no reward to agents that detect and report a violator, condition (16) becomes $-G - J(1) < b$, which since $b > 0$ is always satisfied. This in turn implies that if $S=0$, the non-compliant equilibrium will be always local asymptotically stable.

Let us now concentrate on the condition for local stability of the compliant equilibrium.

Result 7: *The compliant equilibrium* $(p_1 = a, p_2 = 0)$ *with* $a \in [0,1]$, *i.e. no violators are present, is local asymptotically stable if and only if:*

(18) $R_v - R_c < (p_3)Q(p_3)S$

Proof of Result 7: The steady stable equilibrium $(p_1 = a, p_2 = 0)$ with $a \in [0,1]$, implies that $\bar{p} = p_1 = p_3$. In this case the *Jacobian* shown in (17) becomes $J(\dot{p}_1, \dot{p}_2)(p_1^*, p_2^*) = \begin{pmatrix} -a(p_1 - p_3) & -a(p_2 - p_3) \\ 0 & p_2 - p_1 \end{pmatrix} = \begin{pmatrix} 0 & a(p_3 - p_2) \\ 0 & p_2 - p_1 \end{pmatrix}$. In this case the determinant of the *Jacobian* is zero, which implies that one eigenvalue is zero and the other equals the trace of the *Jacobian*. Thus, the inequality $p_2 < p_1$ is necessary and sufficient for local asymptotic stability, which in turn implies the condition in (18). **Q.E.D.**

Result 7 above shows that the compliant equilibrium will be local asymptotically stable whenever the premium from using a high extraction effort level in a population of compliant players, b, is lower than the expected sanction for violating the norm, $(p_3)Q(p_3)S$. It should be noted that if there is no sanction S levied on violators and therefore no reward to agents that detect and report a violator condition (18) would become $b < 0$, which by definition is never satisfied and therefore the compliant equilibrium would never be local asymptotically stable. Consequently, from results 6 and 7 we have that if $S=0$, the only possible local asymptotically stable equilibrium is the non-compliant one.

In addition, from the fact that the stability of the compliant equilibrium depends upon the *initial population share ascribing to the compliant-sanctioning strategy*, we can infer some interesting points relevant to our analysis on TURFs regulations. Given that in fishing communities with no tradition in co-operative management, e.g. the Chilean case, this initial population share will typically be rather small (or even zero), and therefore the expected sanction for violating the norm would be very low since the probability of being detected will be low as well. Hence, it can be argued that in order to ensure compliance in these fisheries a large monetary sanction will be required, so that despite having a small probability of being detected, the expected sanction for violating the norm would still be higher than the premium from using a high extraction effort level in a population of compliant players. By contrast, in fisheries with a long-standing tradition of co-operative management, e.g. the Japanese case, it is expected that the initial population share ascribing to the compliant-sanctioning strategy would be rather large, and so in spite of a low monetary sanction, the expected sanction to violators can still be higher than the premium from using a high extraction effort level.

5. Concluding Remarks

A first conclusion that can be inferred from our work is that TURFs 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, might 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 problem, and therefore there will still be economic over-exploitation, where fishermen 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 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 the static game of norm compliance presented in section 3, 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 fishermen (see Result 4). 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 aggregate monitoring effort is actually zero this implies non-compliance of the norm (see Results 1 and 3).

Moreover, from the dynamic game of norm compliance presented in section 4, it becomes clear that the initial population share complying with the social norm and performing monitoring activities is crucial to ensure compliance of the MEP in the long run. Assuming that in fisheries with no tradition in co-operative management this initial population share will typically be very small, the only possibility to ensure norm compliance in the long run is to set a large monetary sanction. By contrast, fisheries with a long-standing tradition of co-operative management can be thought as having a large initial population complying with the social norm and performing monitoring activities, and therefore the amount of the monetary sanction charged to violators can even be very low, and still norm compliance can be achieved. For instance, sanctioning could be in the form of social ostracism which can carry rather low economic consequences (no direct fine is charged), but since the monitoring/sanctioning population is very large, the probability of being sanctioned is still very high and so is the expected sanction for violating the norm.

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 paper, it is vital for the regulatory authority to know this information in order 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, the empirical testing of the models of norm compliance formulated here can be mentioned. 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 and has not been successful so that the determinants of compliance and non-compliance can be empirically determined[20]. 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.

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

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Appendices

Appendix 1: ***Proof of Proposition 1***

Necessary and sufficient conditions for an interior Nash equilibrium are given by the solution to the following maximisation problem: $\max_{e_i} \quad R_i = \dfrac{e_i}{e_i + (n-1)\,e_{-i}} H\left(e_i + (n-1)\,e_{-i}\right) - ce_i$. By differentiating with respect to e_i and setting the result equal to zero, we obtain the condition for profit maximisation: (A1)

$$\frac{e_i H'\{(n-1)e_{-i} + e_i\}}{(n-1)e_{-i} + e_i} + H\left((n-1)e_{-i} + e_i\right) \left[\frac{1}{(n-1)e_{-i} + e_i} - \frac{e_i}{\{(n-1)e_{-i} + e_i\}^2}\right] = c.$$

Since we assume here that individuals are identical, we restrict our analysis to symmetric equilibria, and denote an equilibrium by a single element of the set of strategies, i.e. $e_i = e_{-i} = e^*$. In order to be a Symmetric Nash equilibrium (SNE) strategy e^* must satisfy (A1). Hence, after simplifying and rearranging we obtain: (A2) $\dfrac{H(ne^*)}{ne^*} - \dfrac{1}{n}\left\{\dfrac{H(ne^*)}{ne^*} - H'(ne^*)\right\} = c$ (for all $i \in I$). Using $E^* = n\,e^*$ we can rewrite (A2) as follows: (A3) $\dfrac{H(E^*)}{E^*} - \dfrac{1}{n}\left\{\dfrac{H(E^*)}{E^*} - H'(E^*)\right\} = c$. Equation (A2) (or, equivalently, equation (A3)) is the well known result of the problem of the common[21]. Now, in order to find the symmetric Pareto-efficient allocation for the n fishing firms, we need to choose the total effort, E, which maximise the total net profit, and then divide this profit equally between them (this implies that the agents by their joint action internalise the externalities associated with the fact that the fishing ground is an unpaid factor in production). Thus, we have the following maximisation problem: (A4) $\max_{e} \quad H(ne) - cne$. The optimality condition then becomes: (A5) $H'(n\bar{e}) = c$, or equivalently, (A6) $H'(\bar{E}) = c$. Equation (A6) reflects the efficiency condition that the marginal product of fishing effort should equal their cost[22]. Now that we have obtained the conditions for both Nash and Pareto equilibria, we can compare them to see whether or not the effort introduced by each fishing firm at the Nash equilibrium is larger than the Pareto efficient, socially optimum, level, i.e. $e^* > \bar{e}$. To do that we subtract the term $H'(\bar{E})$ from both sides of equation (A3), which produces: (A7) $c - H'\left(E^*\right) = \left(\dfrac{n-1}{n}\right)\left\{\dfrac{H\left(E^*\right)}{E^*} - H'\left(E^*\right)\right\}$.

Since $\dfrac{H(E)}{E} > H'(E)$ we have that the RHS of (A7) is positive, therefore the following must hold: $c > H'\left(E^*\right)$. Using the efficiency condition given by equation (A6), we can replace c with $H'(\bar{E})$ to obtain: $H'\left(\bar{E}\right) > H'\left(E^*\right)$. Because, we have assumed diminishing marginal rates of

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[21] As anticipated, a positive value of E satisfying (A3) exists only if $0 < c < H'(0)$.

[22] It can be shown that the allocation implied by e^* is in the core for these n fishing firms. In other words no coalition of fishing firms can guarantee a profit level as high as that implied at the Pareto efficient outcome with symmetric division of the total profit. See Dasgupta and Heal (1979: 58).

extraction, that is, $H''(E) < 0$, $H'\left(E^*\right)$ can be less than $H'(\overline{E})$ if and only if $E^* > \overline{E}$, or equivalently, $e^* > \bar{e}$. **Q.E.D.**

Appendix 2: ***Second Order Conditions***

To check the second-order conditions, we make use of the Hessian matrix of the Lagrangian, equation (5). Since the problem we are analysing here is two-dimensional, i.e. it depends upon variables e_i and m_i, we have that:

(A8)

$$D^2L(e_i,m_i)=\begin{pmatrix}\frac{\partial^2 L}{\partial e_i^2} & \frac{\partial^2 L}{\partial e_i \partial m_i}\\ \frac{\partial^2 L}{\partial m_i \partial e_i} & \frac{\partial^2 L}{\partial m_i^2}\end{pmatrix}=\begin{pmatrix}\frac{\partial^2 R_i}{\partial e_i^2}-s\frac{\partial^2 q}{\partial e_i^2}-2\frac{\partial q}{\partial e_i}\frac{\partial s}{\partial e_i}-q\frac{\partial^2 s}{\partial e_i^2} & 0\\ 0 & [s-g](n-1)\frac{\partial^2 q}{\partial m_i^2}-(n-1)\frac{\partial^2 j}{\partial m_i^2}\end{pmatrix}$$

Calculus tells us that at the optimal choice of $\left(e^*,m^*\right)$, the Hessian matrix must be negative semidefinite. Since a negative semidefinite matrix must have diagonal terms that are less than or equal to zero, it follows that for sufficiency we need that: (a) $\frac{\partial^2 R_i}{\partial e_i^2} \le s\frac{\partial^2 q}{\partial e_i^2}+2\frac{\partial q}{\partial e_i}\frac{\partial s}{\partial e_i}+q\frac{\partial^2 s}{\partial e_i^2}$, to guarantee that the objective in (4) is strictly concave on *e*, and (b) $[s-g]\frac{\partial^2 q}{\partial m_i^2} \le \frac{\partial^2 j}{\partial m_i^2}$, to guarantee that the objective in (4) is strictly concave on *m*. Given the assumptions we have made in the model, namely $\frac{\partial q}{\partial e_i} > 0$, $\frac{\partial q}{\partial m_{-i}} > 0$, $\frac{\partial^2 q}{\partial e_i^2} \ge 0$, $\frac{\partial^2 q}{\partial m_{-i}^2} \le 0$, $\frac{\partial j}{\partial m_i} > 0$, $\frac{\partial^2 j}{\partial m_i^2} \ge 0$, $\frac{\partial s}{\partial e_i} > 0$, $\frac{\partial^2 s}{\partial e_i^2} \ge 0$, $s-g>0$, and the fact that $\frac{\partial^2 R_i}{\partial e_i^2} < 0$, it becomes clear that the sufficiency conditions (a) and (b) are always satisfied. **Q.E.D.**

Appendix 3: ***Proof of Result 2***

(a) Effect of a change in the norm: The effect of a change in the norm, $\bar{e}$, can be found by totally differentiating (5a) and (5c) with respect to $\bar{e}$. The result, after rearrangement, can be expressed by the following set of two simultaneous equations, where all derivatives are evaluated at the equilibrium point: $\begin{pmatrix}\frac{\partial^2 L}{\partial e_i^2} & \frac{\partial^2 L}{\partial e_i \partial m_i}\\ \frac{\partial^2 L}{\partial m_i \partial e_i} & \frac{\partial^2 L}{\partial m_i^2}\end{pmatrix}\begin{pmatrix}\frac{de^*}{d\bar{e}}\\ \frac{dm^*}{d\bar{e}}\end{pmatrix}=\begin{pmatrix}-\frac{\partial^2 L}{\partial e_i \partial \bar{e}}\\ -\frac{\partial^2 L}{\partial m \partial \bar{e}}\end{pmatrix}$. Using Cramer's rule, and knowing that we have assumed that the determinant of the Hessian is positive (a negative semidefinite matrix must have diagonal terms that are less than or equal to zero), we have that the effect of a change in

the norm, $\bar{e}$, over the equilibrium level of fishing effort is positive, that is: $\frac{de^*}{d\bar{e}} = \frac{\begin{pmatrix} <0 & 0 \\ >0 & <0 \end{pmatrix}}{\Delta} > 0$. *(b) Effect of a change in the number of fishing firms:* By totally differentiating (5a) and (5c) with respect to n, and after rearranging, and evaluating all derivatives at the equilibrium point, we obtain: $\begin{pmatrix} \frac{\partial^2 L}{\partial e_i^2} & \frac{\partial^2 L}{\partial e_i \partial m_i} \\ \frac{\partial^2 L}{\partial m_i \partial e_i} & \frac{\partial^2 L}{\partial m_i^2} \end{pmatrix} \begin{pmatrix} \frac{de^*}{dn} \\ \frac{dm^*}{dn} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 L}{\partial e_i \partial n} \\ -\frac{\partial^2 L}{\partial m \partial n} \end{pmatrix}$. Using Cramer's rule, and considering that the determinant of the Hessian is positive, we obtain: $\frac{de^*}{dn} = \frac{\begin{pmatrix} >0 & 0 \\ 0 & <0 \end{pmatrix}}{\Delta} < 0$.

(c) Effect of a change in the transaction costs associated with effectively sanctioning one agent: By totally differentiating (5a) and (5c) with respect to g, and after rearranging, and evaluating all derivatives at the equilibrium point, we obtain: $\begin{pmatrix} \frac{\partial^2 L}{\partial e_i^2} & \frac{\partial^2 L}{\partial e_i \partial m_i} \\ \frac{\partial^2 L}{\partial m_i \partial e_i} & \frac{\partial^2 L}{\partial m_i^2} \end{pmatrix} \begin{pmatrix} \frac{de^*}{dg} \\ \frac{dm^*}{dg} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 L}{\partial e_i \partial g} \\ -\frac{\partial^2 L}{\partial m \partial g} \end{pmatrix}$. Using Cramer's rule, and considering that the determinant of the Hessian is positive, we obtain: $\frac{de^*}{dg} = \frac{\begin{pmatrix} 0 & 0 \\ <0 & <0 \end{pmatrix}}{\Delta} = 0$ **Q.E.D.**

Appendix 4: ***Proof of Result 5***

(a) Effect of a change in the norm: The effect of a change in the norm, $\bar{e}$, can be found by totally differentiating (5a) and (5c) with respect to $\bar{e}$. The result, after rearrangement, can be expressed by the following set of two simultaneous equations, where all derivatives are evaluated at the equilibrium point: $\begin{pmatrix} \frac{\partial^2 L}{\partial e_i^2} & \frac{\partial^2 L}{\partial e_i \partial m_i} \\ \frac{\partial^2 L}{\partial m_i \partial e_i} & \frac{\partial^2 L}{\partial m_i^2} \end{pmatrix} \begin{pmatrix} \frac{de^*}{d\bar{e}} \\ \frac{dm^*}{d\bar{e}} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 L}{\partial e_i \partial \bar{e}} \\ -\frac{\partial^2 L}{\partial m \partial \bar{e}} \end{pmatrix}$. Using Cramer's rule, and knowing that we have assumed that the determinant of the Hessian is positive (a negative semidefinite matrix must have diagonal terms that are less than or equal to zero), we have that the effect of a change in the norm, $\bar{e}$, over the equilibrium level of fishing effort is positive, that is: $\frac{dm^*}{d\bar{e}} = \frac{\begin{pmatrix} <0 & <0 \\ 0 & >0 \end{pmatrix}}{\Delta} < 0$. *(b) Effect of a change in the number of fishing firms:* By totally differentiating (5a) and (5c) with respect to n, and after rearranging, and evaluating all derivatives at

the equilibrium point, we obtain: $\begin{pmatrix} \frac{\partial^2 L}{\partial e_i^2} & \frac{\partial^2 L}{\partial e_i \partial m_i} \\ \frac{\partial^2 L}{\partial m_i \partial e_i} & \frac{\partial^2 L}{\partial m_i^2} \end{pmatrix} \begin{pmatrix} \frac{de^*}{dn} \\ \frac{dm^*}{dn} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 L}{\partial e_i \partial n} \\ -\frac{\partial^2 L}{\partial m \partial n} \end{pmatrix}$. Using Cramer's rule, and considering that the determinant of the Hessian is positive, we obtain: $\frac{dm^*}{dn} = \frac{\begin{pmatrix} <0 & >0 \\ 0 & <0 \end{pmatrix}}{\Delta} > 0$. *(c) Effect of a change in the transaction costs associated with effectively sanctioning one agent:* By totally differentiating (5a) and (5c) with respect to g, and after rearranging, and evaluating all derivatives at the equilibrium point, we obtain: $\begin{pmatrix} \frac{\partial^2 L}{\partial e_i^2} & \frac{\partial^2 L}{\partial e_i \partial m_i} \\ \frac{\partial^2 L}{\partial m_i \partial e_i} & \frac{\partial^2 L}{\partial m_i^2} \end{pmatrix} \begin{pmatrix} \frac{de^*}{dg} \\ \frac{dm^*}{dg} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 L}{\partial e_i \partial g} \\ -\frac{\partial^2 L}{\partial m \partial g} \end{pmatrix}$. Using Cramer's rule, and considering that the determinant of the Hessian is positive, we obtain: $\frac{dm^*}{dg} = \frac{\begin{pmatrix} <0 & 0 \\ 0 & >0 \end{pmatrix}}{\Delta} < 0$ **Q.E.D.**