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**THE DESIGN PERSPECTIVE IN RESOURCE AND  
ENVIRONMENTAL ECONOMICS**

by

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**ABSTRACT**

Despite the fact that most regulatory problems in resource and environmental economics are design problems, rarely have resource economists explicitly adopted the design perspective in modeling such problems. In this note I argue that the design perspective should be adopted. I highlight the merits of the design approach by studying an old problem—the regulation of an open access fishery (OAF)—in a new way. I show that the design perspective has important implications for fisheries management.

*JEL* Classification: D82, L51, Q20

Key words: mechanism, design, resource, environment, fisheries

# THE DESIGN PERSPECTIVE IN RESOURCE AND ENVIRONMENTAL ECONOMICS

## 1. INTRODUCTION

Most, if not all, regulatory problems in resource and environmental economics are design problems characterized by, *inter alia*, asymmetrically held information. The typical such design problem involves an imperfectly informed regulator (the principal) who wishes to attain some pre-determined regulatory goal. The key problem is that the information that the principal typically needs to effectively discharge his regulatory responsibilities is private information possessed by the regulated firms (agents). As such, the principal's problem is to design an incentive scheme or a mechanism with which he will be able to attain his regulatory objectives and get the relevant agents to reveal their private information truthfully.<sup>1</sup>

The regulation of air and water pollution, the allocation of extractive rights to mining firms and the management of fisheries are all examples of problems which fit the rubric described above. Despite this, and the fact that adverse selection, i.e., hidden information, is an endemic part of all such regulatory problems, rarely have resource economists explicitly modeled the fact that information is held asymmetrically by the various parties. Given this, the purpose of this note is to demonstrate the power and appeal of the design perspective in a preliminary way by recasting an old problem—the regulation of an open access fishery (OAF)<sup>2</sup>—in the single principle/multi-agent schema. In doing so, I hope to encourage further research along these lines. I first briefly discuss the fishery problem and the impact of informational externalities on some popular regulatory instruments.

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<sup>1</sup>For a general description of the design perspective, see Kreps (1990, pp. 661-722) or Baron (1988).

<sup>2</sup>See Clark (1990, p. 24) for a general discussion of an open access resource.

## 2. THE OAF AND SOME CURRENT REGULATORY INSTRUMENTS

The inefficiency of the OAF equilibrium has been recognized by economists at least since Gordon (1954). There are two problems with this equilibrium. First, this equilibrium is inefficient owing to the lack of well defined property rights to the fishery. As a result, each fishing firm continues to fish until the *average* product of effort equals the marginal cost of effort. As contrasted to this, the equilibrium in a socially optimal fishery is characterized by the equality of the *marginal* product of effort with the marginal cost of effort. The second problem with the OAF equilibrium concerns bioeconomic efficiency. The OAF equilibrium can be bioeconomically inefficient if the equilibrium lies to the left of the maximum sustainable yield biomass. This is because such an equilibrium indicates that the same catch of fish could have been taken at a higher sustained biomass. Thus the OAF equilibrium can lead to the extinction of the fish species. However, whether or not an OAF equilibrium is bioeconomically inefficient, it is invariably inefficient from an economic standpoint.

Given this state of affairs, there is definitely a case for regulatory intervention. Indeed, for quite some time now, regulators have attempted to regulate the OAF by means of quotas, licenses and occasionally taxes. Unfortunately, at least in the USA and in Canada, the regulatory record with these instruments has been less than impeccable (see Hartwick and Olewiler, 1986, pp. 293-323). This stems from the myriad regulatory problems arising from the regulator's *lack of information* regarding the variables necessary to set the chosen regulatory instrument optimally. Despite the unsatisfactory experience with the above mentioned instruments, to the best of my knowledge no alternate scheme(s) have been proposed to regulate the OAF. In this note, I propose a tournament mechanism for regulating the OAF. I believe that tournaments provide a very interesting context in

which to structure certain kinds of regulatory problems such as the regulation of an OAF. I now discuss, in turn, the merits of taxes, quotas and licenses in the context of an OAF.

An optimal tax on either the catch or on fishing effort can convert an OAF equilibrium into a socially efficient one. A correctly set catch tax is a very appealing regulatory instrument. In practice however things can go wrong with a catch tax. How is the regulator to know at what level to set the tax? It is clear that a tax set too high can cause considerable unemployment in the OAF and a tax set too low can drive the fish species to extinction. The other kind of theoretically popular tax is a tax on effort. Effort taxes often fail in practice because regulators are unable and/or unwilling to regulate *all* kinds of effort. The piecemeal attempts of regulators result in the emergence of small top heavy boats when boat size is taxed, large numbers of boats in a limited time span when season length is taxed etc. On the other hand, if the regulator does in fact tax all kinds of effort then an extremely complex set of rules and regulations emerge with high enforcement costs.

In the USA and in Canada, quotas have proven to be the most popular regulatory instrument. An optimal catch quota can be set which will lead to the desired *industry* catch. However, the quota need not lead to an efficient amount of effort by *individual* fishermen. Individual effort will be optimal if and only if the total quota is distributed among fishermen in an efficient manner. Thus a quota on catch solves only half the problem and creates a new one: how to allocate individual quota rights among the fishermen. A correctly apportioned effort quota which is transferable and/or divisible accomplishes many of the objectives that a tournament mechanism - to be discussed below - does. For instance, not only will such a scheme generate the optimal industry effort but individual effort will also be optimal. With effort quotas, the obvious question concerns the allocation of quota rights. Irrespective of whether the rights are auctioned off or whether some kind of free distribution

system is adopted, the OAF is likely to be politicized.

Licenses have begun to be used by regulatory authorities relatively recently. The idea here is twofold. Efficiently apportioned licenses should limit entry into the fishery, and achieve an optimal level of effort by individual license holders. In practice however, things have often turned out differently. For instance, the Canadian government's licensing scheme in the halibut industry actually *increased* entry (Hartwick and Olewiler, 1986, p. 322). On another level, licensing regulations in one fishery have often exacerbated problems in another industry because licenses are restricted and hence they have a market value. As a result, fishermen who are unable to pay for the licenses in a specific fishery have moved to less regulated fisheries.

These problems with taxes, quotas, and licenses all arise - in large part - due to the asymmetric information in the regulatory problem. This basic asymmetry in the information available to the relevant parties suggests that the OAF regulation problem ought to be cast in a design framework. I now proceed to do so by discussing tournaments in the context of the OAF regulation problem.

### 3. THE OAF AND TOURNAMENTS

#### 3A. Preliminaries

The typical OAF is characterized by a large number of *heterogeneous* fishermen. Individual fishermen know the effort level employed by them but the regulator *does not*. Each individual fisherman knows his type (which is a proxy for effort) but this information is not available to anyone else. Information about fishermen is costly to acquire. The regulator can observe unit catch.<sup>3</sup> Hence,

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<sup>3</sup>This refers to the output/time ratio where the output is the catch or harvest.



any mechanism the regulator designs must be based on observable variables. In addition to this, the regulator has to account for the fact that there are common stochastic events in the fishery which affect fishermen similarly. Further, the risk associated with this common stochastic environmental variable can be large.<sup>4</sup> This represents some of the salient aspects of an OAF. A perusal of the tournament literature shows that these are also some of the key characteristics of environments in which tournaments do well.

In the design literature, a "...rank order tournament is a compensation scheme in which contestant rewards are based on their ordinal positions alone and not on the actual size of their output" (Nalebuff and Stiglitz, 1983, p. 26). The "...rules of the game specify a fixed prize...to the winner and a fixed prize...to the loser" (Lazear and Rosen, 1981, p. 844). The contest is rank order because "...payments are based solely on ordinal comparisons of output across agents" (Mookherjee, 1984, p. 439). This is the basic scheme which I now adapt to the OAF regulation problem in the simplest possible manner.

The following sequence of events take place in a single period, two stage noncooperative game between the regulator and the fishermen. In the first stage the regulator determines a fixed set of prizes which eventually will be the salaries of the fishermen. Observing this salary structure, in the second stage the fishermen choose their effort levels, catch fish in a tournament and bring their fish to the regulator for sale. The regulator sells the total catch in a competitive fish market and with the proceeds pays the salaries depending on the ordinal rank of each fisherman in the tournament. Rank is determined by the unit catch level. In equilibrium, each fisherman gets a prize, the

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<sup>4</sup>The El Nino and its disastrous effects readily come to mind.

regulator's budget balances<sup>5</sup> and the OAF regulation problem is - in principle - solved. I now formalize some of the concepts discussed above.

### 3B. A Simple Tournament Model

My model is a hybrid of the models presented in Lazear and Rosen (1981), Green and Stokey (1983) and Nalebuff and Stiglitz (1983). There are  $n(>1)$  types of fishermen. The  $j$ th fisherman,  $1 \leq j \leq n$ , produces unit catch/harvest<sup>6</sup>  $h_j = \mu_j + \epsilon$ , where  $\mu_j$  is his unit effort level and  $\epsilon$  is the environmental disturbance term<sup>7</sup> with distribution function  $G(\bullet)$  and density  $g(\bullet)$ ; these functions are the same for all types of fishermen. The  $j$ th fisherman is permitted to control the mean of the harvest distribution,  $F_j(\bullet)$ , by investing in costly equipment, training etc. The unit effort level  $\mu_j$  is chosen prior to the realization of  $\epsilon$ . At the time that the fishermen choose their unit effort levels (the respective means of the harvest distributions), they know  $G(\bullet)$  and  $g(\bullet)$ , but not the realization of  $\epsilon$ . Unit effort is produced at cost  $c(\mu_j)$  where  $c'(\bullet) > 0$  and  $c''(\bullet) > 0$ . Further, I assume that  $E(\epsilon) = 0$  and that  $Var(\epsilon) = \sigma^2$ . The regulator is risk neutral and he maximizes expected profits. He cannot observe  $\mu_j$  but he can observe  $h_j$ . He designs a salary scheme  $W = (w_1, \dots, w_p, \dots, w_n)$  where  $w_j$  is the salary (prize) paid to the  $j$ th ranking fisherman in the tournament. It is possible that  $w_i = w_j$  for some  $i$  and  $j$ . I am interested in the prize structure that emerges in the subgame perfect Nash equilibrium (SPNE) of the game between

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<sup>5</sup>The budget balance criterion is important. Although I shall not impose budget balance in my formal analysis in section 3B, budget balance means that the regulator collects no rents in equilibrium and all rents are transferred to the relatively more efficient fishermen through the prize structure. Allowing the regulator to collect rents invariably politicizes the OAF; this problem is avoided by imposing budget balance. For more on budget balance, see Fudenberg and Tirole (1991, Chapter 7).

<sup>6</sup>By the word unit I mean per unit time. One can think of harvest per hour etc.

<sup>7</sup>To better understand the disturbance term think of a natural disaster such as an oil spill.

the regulator and the fishermen. The respective payoffs are profit for the regulator and utility (wealth) for the fishermen. My approach to the modeling problem will be as follows. I will raise a particular issue, discuss how it can or cannot be resolved for the  $n=2$  case and then I shall proceed to discuss the general case.

The first modeling issue concerns risk attitudes. Are heterogeneous fishermen risk averse or risk neutral? The existing literature on homogeneous agents has considered both cases. To keep the exposition simple, I consider the risk neutral case. The case of risk averse fishermen would appear to strengthen the case for tournaments because a tournament can reduce the risk imposed on any one fisherman from shocks that are common to all fishermen.

The second question concerns fishermen self sorting. The salience of this stems from the adverse selection problem. With heterogeneous fishermen, every fisherman knows his type but no one else does. If fishermen self sorted into their respective types then the regulator's problem would become considerably simpler. Consider the two type case. If fishermen self sorted, then just by observing the different harvests the regulator would be able to determine a fisherman's type. What this means is that a separating equilibrium (see Kreps, 1990, p. 633) can be constructed in which fishermen of type 1 choose a particular harvest and fishermen of type 2 choose another harvest. For a separating equilibrium to exist, it is essential that fishermen self sort. Do they? For the two type case, Lazear and Rosen (1981) have shown that they do not. Since there is no self sorting when there are only two types, it is difficult to see how self sorting can occur when there are  $n(>2)$  types. Given that there is no self sorting, one can still ask whether "mixed" tournaments are efficient? This is the third and fundamental modeling issue that I shall now address.

To show that a mixed tournament is efficient in my tournament setting, I have to show that

in the SPNE of such a tournament in which there are two types of fishermen (more efficient and less efficient), the more efficient fishermen exert greater effort and hence do most of the fishing and the less efficient fishermen exert less effort and hence do relatively little fishing. I now demonstrate this using the methodology of Lazear and Rosen (1981).

Let the two types of fishermen be denoted by  $p$  and  $q$  where  $c'_p(\mu) < c'_q(\mu)$ ,  $\forall \mu$ . That is, the  $p$  type fisherman is more efficient than the  $q$  type fisherman. Assume that the fraction of  $p$  types in the fisherman population equals  $\beta < 1/2$  and that the fraction of  $q$  types equals  $(1-\beta) < 1/2$ . In other words, the OAF is populated by more relatively efficient fishermen. Let  $W \equiv (w_1^m, w_2^m)$  be the prize vector where  $m$  denotes the fact that the tournament is mixed. Let  $p_l^k$  denote the probability that a type  $k$  fisherman beats a type  $l$  fisherman,  $k, l = p, q$ . The decision problem of a type  $p$  fisherman is

$$\max_{\mu_p > 0} [1 - \beta p_p^p - (1 - \beta) p_q^p] w_2^m + [\beta p_p^p + (1 - \beta) p_q^p] w_1^m - c_p(\mu_p) \quad (1)$$

and that of a type  $q$  fisherman is

$$\max_{\mu_q > 0} [1 - \beta p_p^q - (1 - \beta) p_q^q] w_2^m + [\beta p_p^q + (1 - \beta) p_q^q] w_1^m - c_q(\mu_q). \quad (2)$$

The relevant first order necessary conditions are

$$[\beta(\partial p_p^p / \partial \mu_p) + (1 - \beta)(\partial p_q^p / \partial \mu_p)][w_1^m - w_2^m] - c'_p(\mu_p^m) = 0 \quad (3)$$

and

$$[\beta(\partial p_p^q / \partial \mu_q) + (1 - \beta)(\partial p_q^q / \partial \mu_q)][w_1^m - w_2^m] - c'_q(\mu_q^m) = 0. \quad (4)$$

Now efficiency requires that  $c'_p(\mu_p^m) = c'_q(\mu_q^m) = K$ , where  $K$  is the price of fish in a competitive output

market. Using this efficiency condition, I get

$$[\beta(\partial p_p^p/\partial \mu_p) + (1 - \beta)(\partial p_q^p/\partial \mu_p)] = [\beta(\partial p_p^q/\partial \mu_q) + (1 - \beta)(\partial p_q^q/\partial \mu_q)]. \quad (5)$$

Assuming that the density corresponding to  $p_i^k$  is symmetric and nonuniform, after some algebra - using  $\beta > 1/2$  - it can be shown that in equilibrium  $\mu_p^m > \mu_q^m$ . That is, a mixed contest is efficient *even if* fishermen do not self sort. What happens if  $\beta \leq 1/2$  ? Keeping (5) in mind and using the fact that the density corresponding to  $p_i^k$  is symmetric and nonuniform, I conclude that  $\mu_p^m = \mu_q^m$  when  $\beta = 1/2$ , and that  $\mu_p^m < \mu_q^m$  when  $\beta < 1/2$ . That is, in both these cases mixed contests are not directly efficient. In these cases the regulator will have to use historical information to sort fishermen and then a tournament mechanism can be used. It is clear that the  $\beta \leq 1/2$  cases increase the regulator's informational requirements. While it is still possible to design tournaments in such settings, the resulting tournaments are less attractive as externality correcting devices.

Thus far I have provided the basic building blocks of a tournament mechanism. I have discussed the important issues of risk attitude, self sorting, the role of adverse selection and the efficiency of the tournament mechanism in the two type case. The task ahead of me is to show how the above discussion might be generalized to the case of  $n(>2)$  heterogeneous fishermen.

To the best of my knowledge, this problem has not been studied to date. I propose to examine whether the two type case can be generalized in the following manner. First, determine the probability that fisherman  $j$  finishes in a specific rank between 1 and  $n$ . In other words, I am interested in the density function of the, say,  $j$ th order statistic in a sample of size  $n$  which is drawn from the harvest distribution. One has to be careful here since  $F_j(\bullet)$  is fisherman specific. This is the first difference between my proposed scheme and the cases analyzed in the literature. I then

compute the expected utility (or wealth) for a specific fisherman (see Nalebuff and Stiglitz, 1983).

The next issue concerns the nature of the desired equilibrium. Since fishermen are heterogeneous, I must now focus on asymmetric Nash equilibria. This raises an existence question and is the second point of departure from the standard  $n$  identical agents case. Green and Stokey (1983) get around the existence problem by studying tournaments which are designed so that they have a symmetric Nash equilibrium. For my case, following Nalebuff and Stiglitz (1983), I conjecture that a sufficient condition for the existence of asymmetric Nash equilibria is that each effort level be a continuous and decreasing function of all other  $(n-1)$  effort levels at all feasible effort levels.<sup>8</sup> A related issue concerns the existence of pure strategy equilibria. Once again, I conjecture that pure strategy equilibria will exist if the above sufficiency condition regarding effort levels holds. Even if a particular effort level happens to be a discontinuous function of the remaining  $(n-1)$  effort levels, asymmetric equilibria may still exist; however, pure strategy equilibria are unlikely to exist. A way around the existence problem is to restrict the set of tournaments and study those for which asymmetric Nash equilibria exist.

Assuming that the existence question can be resolved, one would then proceed to maximize each fisherman's expected utility (wealth) subject to budget balance, and then use the resulting first order conditions to compute all the reaction functions. These reaction functions can then be used to solve for the underlying - possibly nonunique - equilibrium. This is a scheme for determining the efficacy of the tournament approach in the most general case.

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<sup>8</sup>While I am unable to prove this conjecture, some intuition might help. Continuity prevents jumps in effort responses which would prevent the existence of any kind of equilibria. The second part of the conjecture says that at all feasible effort levels, when fisherman  $p$  "works hard," fisherman  $q$  "slacks off."

#### 4. CONCLUSIONS

In this note I have made a preliminary case for adopting the design perspective in resource economics by casting an old problem in a tournament setting. I discussed taxes, quotas, and licenses and focused on the reasons for the limited practical success of these instruments.

Noting the similarity in the characteristics of the OAF regulation problem and the tournament design problem, I argued that the tournament approach has sufficient merit to warrant further research. I then discussed the tournament approach in the two heterogeneous fisherman case and argued that the question as to whether this approach can solve the OAF regulation problem in the most general case is an interesting question which awaits further study. I am pursuing some of the issues mentioned in this note in my current research. Undoubtedly, I have not solved all problems that might arise in the implementation of the tournament approach. However, I do hope to have demonstrated how insights from the design perspective can be used to address regulatory questions in resource and environmental economics.

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Most, if not all, regulatory problems in resource and environmental economics are design problems characterized by, *inter alia*, asymmetrically held information. The typical such design problem involves an imperfectly informed regulator (the principal) who wishes to attain some pre-determined regulatory goal. The key problem is that the information that the principal typically needs to effectively discharge his regulatory responsibilities is private information possessed by the regulated firms (agents). As such, the principal's problem is to design an incentive scheme or a mechanism with which he will be able to attain his regulatory objectives and get the relevant agents to reveal their private information truthfully.<sup>1</sup>

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