Conservation for Sale: A Dynamic Common Agency Model of Natural Resource Regulation*

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ABSTRACT: This paper considers the regulation of a natural resource within a dynamic common agency framework. In setting harvest quotas, the regulator responds to lobbying pressure (contributions) from harvesters and conservationists. The truthful Markov perfect equilibrium stock is then an increasing function of the effective political weight for conservationists. Since the contributions to the regulator are independent of the no-regulation equilibrium, both individual and aggregate welfare may decline by adopting regulation. Indeed, harvesters operating under private property will always oppose regulation, and harvesters operating under common property will oppose regulation if their welfare is not valued highly enough by the regulator. Since conservationists' gross welfare is always improved by regulation, and since the regulator cannot fully capture their rents, conservationists will support regulation. For regulation to be supported by harvesters and conservationists, it is more important that the welfare of harvesters be taken into account by the regulator. This is because harvesters, like conservationists, value the stock, but conservationists, unlike harvesters, place no value on the harvests.

KEY WORDS: Common agency; natural resources; conservation; truthful Markov perfect.
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I. Introduction

For many natural resources, regulatory agencies have been established to determine the total harvest quota and to allocate harvest quotas across user groups. For example, the Magnuson Fishery Conservation and Management Act (1976) created regional fishery management councils in the United States with these powers.[i] In many instances, the user groups considered by these agencies include harvesters—fishermen, whalers, oil producers, land- and resource-owners, etc.—and non-consumptive users such as conservationists. Indeed, many of the fisheries management councils in the U. S. have among their voting members representatives of both harvesting and conservation groups.[ii] Conservationists even dominate some regulatory agencies (the International Whaling Commission, the Convention on Trade in Endangered Species), and are very influential in others (the Montreal Protocol and the Kyoto Agreement).

This paper considers a dynamic common agency model of natural resource regulation in which harvester and conservation groups compete to influence a regulator who chooses and allocates harvest quotas. The model is dynamic, because the main issue in most natural resource problems is the rate at which the stock is exploited over time. In the model, each harvester's welfare is increasing and concave in his own harvest quota, and each conservationist's welfare is increasing and concave in the size of the stock remaining after harvesting. The regulator cares about the gross welfare of both harvesters and conservationists, since their gross welfare translates positively into electoral support for the regulator or the regulator's overseers. However, since the regulator can affect their utility, harvesters and conservationists also expend resources lobbying the regulator (via campaign contributions). The regulator benefits from the contributions, since these may be either consumed directly or used to influence uninformed voters.[iii] The contributions paid by each interest group are in the form of contingency contracts specifying a payment that depends upon the harvest quotas chosen by the regulator. A key assumption is that neither the regulator nor the interest groups are able to commit to future actions. This assumption not only drives the

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solution technique (Markov perfect), but it also focuses attention on the "constitutional" restrictions one might expect to see in successful treaties, laws, and agreements.[iv]

The common agency model was first developed by Bernheim and Whinston (1986), adapted to political economy by Grossman and Helpman (1994), and extended to a dynamic framework by Bergemann and Valimaki (1998).[v] The harvesters and conservationists act as principals who each attempt to influence the common agent, the regulator, in the regulator's choice of the harvest quotas. As in Bergemann and Valimaki (1998), the strategy space of each agent is restricted to Markov decision rules, implying that the history of the game is reduced to the current state—here, the size of the resource stock. Following Bernheim and Whinston, the strategies employed by the principals are also required to be "truthful." Bernheim and Whinston show that restricting players to truthful strategies in common agency games involves no cost, since if other players behave truthfully, then a truthful strategy is always a best-response. Bergemann and Valimaki show that this holds in dynamic games as well.

The first objective of this paper is to derive and characterize the truthful Markov perfect equilibrium (TMPE) harvest quotas in a dynamic common agency model of the regulation of a natural resource that generates consumptive and non-consumptive use values to different groups.[vi] Since the functional forms utilized are those that are known to produce tractable results (e.g., Levhari and Mirman 1980, Eswaran and Lewis 1985, Renganim and Stokey 1985), it is possible to characterize the equilibrium behavior of the model for any initial stock size. Dixit, Grossman and Helpman (1997) and Persson (1998) showed in static additive utility models that the equilibrium policy is equivalent to the policy that would be chosen by a benevolent social planner who assigns particular weights to the welfare of the interest groups.[vii] This result also holds in the dynamic game considered here. The effective political weights assigned to each group in the common agency equilibrium are increasing in the group's electoral importance to the regulator, decreasing in the transaction costs faced by the group in raising the contributions, and increasing in the intensity of the group's preferences. Thus, the share of the stock harvested in each period decreases as the effective political weight for the conservationists increases or as the effective political weight of the harvesters decreases.

The second objective of the paper is to address the question of when and in what form regulation is likely to occur.[viii] It is well known that the common agency equilibrium is Pareto efficient, *given* that regulation is in place (e.g., Dixit, Grossman and Helpman 1997, Persson 1998, Bergemann and Valimaki 1998). However, this says little about the efficiency of the institution of regulation or about the conditions under which regulation will be voluntarily adopted.[ix] The question then is, what is the welfare effect to each group, and to society as a whole, of moving from the unregulated non-cooperative Markov perfect equilibrium, in which each harvester determines his own harvest level, to the regulated equilibrium?

There are two main ways in which regulation may fail to be socially optimal. The first is where the non-transfer rent-seeking expenditures by the principals outweigh the gross benefits of regulation. While this conclusion is perhaps obvious, it turns out to have important implications. Absent constitutional restrictions on the regulator, once regulation is in place, the dissipation of rents is independent of the unregulated equilibrium. This is because the amount each principal is willing to expend in lobbying depends only on the difference between the equilibrium policy and the policy the regulator would choose if that principal abstained from lobbying. Second, if the effective political weights are sufficiently skewed, it is possible that the (un-weighted) gross welfare of society will decrease relative to the unregulated case by adopting regulation. Since successful regulations are presumably ones that have overcome these problems, one can then predict the form of constraints observed in successful regulations.

Since the lobbying contribution transferred to the regulator is not a social cost, welfare-improving regulation may not be voluntarily supported by both harvesters and conservationists. In particular, in the event that property rights for the stock are well defined (but transactions costs prevent conservationists from participating in that market), the harvesters will always oppose regulation. This is because regulation will force them to internalize the externality they impose on conservationists. Harvesters are more likely to support regulation when property rights to the stock are not well defined, but even in this case they will support regulation only if their interests are given sufficient weight in the regulatory equilibrium. Conservationists, on the other hand, are much more likely to support regulation, since even if their interests are not given positive weight in the regulatory equilibrium, they benefit from the resolution of the common property problem.

The remainder of the paper is organized as follows. Section II characterizes the truthful Markov perfect equilibrium of a simple dynamic common agency model. Section III derives the Markov perfect equilibrium for the unregulated case, and shows how this is affected by different property rights regimes. Section IV examines the welfare effects, both on the individual interest groups, and for society as a whole, of adopting regulation. Section V concludes the paper with a brief discussion of the results.

II. The Renewable Resource Markov Common Agency Equilibrium.

A. Assumptions.

Let the set of principals (the interest groups) be denoted as $\Gamma = \Gamma_H \cup \Gamma_C$, where $\Gamma_H \equiv \{1,2,...,N\}$ is the set of harvesters and $\Gamma_C \equiv \{1,2,\ldots,M\}$ the set of conservationists. Throughout, the notation $\Gamma_{H\backslash i}$ or $\Gamma_{C\backslash c}$ will be used to denote the set excluding harvester i or conservationist c. The instance where there is one harvesting group ($N = 1$) is taken to imply that private property rights exist for the stock, since with private property rights the harvesters will maximize the joint returns of the harvesting sector (Scott 1955).[x]

Harvester i exploits the resource, harvesting $h_{i,t}$ units in period t. The aggregate harvest in period t is $y_t = \Sigma_{i\in\Gamma_H} h_{i,t}$. Let $z_t \equiv x_t - y_t$, denote the stock remaining at the end of each harvest period, where x_t is the stock beginning at period t.[xi] The utility in period t is $u_i = \nu_i \log(h_i)$ for harvester i and $u_c = \nu_c \log(z_t)$ for conservationist c. Thus, both types have concave utility functions in the relevant arguments.[xii] The preference intensity parameters $\nu_j \geq 0$, $j \in \Gamma$, measures the relative *preference intensity* of group j. Both total and marginal utility are increasing in ν_j, implying that the ν_j act as demand shifters.

The regulator R chooses the harvest quota for each harvester in each period. In making this choice, the regulator considers how the harvest quotas affect the welfare of the harvester and conservation groups, and how the harvest quotas affects the contributions each group pays to the regulator (Bernheim and Whinston 1986, Grossman and Helpman 1994). The regulator cares about the welfare of the groups because the group's support for the regulator (e.g., votes, demonstrations, letter-writing campaigns, etc.) depends upon their utility level.[xiii] The regulator cares about the contributions because she can use the funds either for herself or to convince uninformed voters to vote for her. The contributions the regulator receives are incentive contracts that specify the contribution as a function of the current harvest quotas.

The model is dynamic, because the future stock is affected by the harvest decisions in the current period. Following Levhari and Mirman (1980), assume the equation of motion of the stock is given by

$$x_{t+1} = (x_t - y_t)^{\alpha}, \qquad t = 0, 1, 2, \ldots, \tag{1}$$

for some $\alpha \in [0,1]$, with $x(0) = x_0$ fixed. This function has the property that the un-exploited ($y_t = 0$ for all t) steady state stock is $\bar{x} = 1$. As the parameter α increases, the value of x_{t+1} decreases for any $z_t = x_t - y_t < 1$. Thus, lower levels of α correspond to *faster* growing biological populations. Indeed, as $\alpha \to 1$, the rate of growth approaches zero, so harvesting exhausts the resource (e.g., oil, minerals, or old growth forest). As $\alpha \to 0$, the resource renews itself to the same level ($x_{t+1} = \bar{x}$) each year, independent of the size of the remaining stock. This occurs for resources such as ground and surface water and, to some extent, herring, which are harvested after they spawn.

The objective of harvesters and conservationists is to maximize the present value of the stream of utility net of the costs of influencing the regulator. In each period, each principal observes the stock x_t, and then the principals simultaneously and non-cooperatively offer the regulator payment $b_j(\boldsymbol{h}_t)$, $j \in \Gamma$, contingent upon the vector of harvest quotas $\boldsymbol{h}_t \equiv \{h_1, h_2, \ldots, h_N\}$ chosen by the regulator. The regulator, after observing the stock x_t and the incentive contracts $b_j^*(\boldsymbol{h}_t)$, chooses the harvest quotas $\boldsymbol{h}_t$ to maximize her own utility. Thus, there exists a Stackelberg relationship between the interest groups and the regulator, with the interest groups moving first, but simultaneously with one another.

Following Bergemann and Valimaki (1998) and Boyce (1999), the strategy space of the harvesters and conservationists is restricted to Markov strategies.[xiv] In addition, I use a methodology first developed by Levhari and Mirman (1980) to solve dynamic Markov games, that Boyce showed to be useful in dynamic common agency games. Levhari and Mirman assume that the harvest quotas are endogenously chosen only up to period T. After period T, the actions are fixed. This allows one to utilize backwards induction methods to solve the game beginning at some arbitrary period $T\!-\!t$.[xv] The steady-state is found by taking the limit as $t \to \infty$. This methodology is not as general as that used by Bergemann and Valimaki, but what is given up by generality is gained in both tractability and transparency of the results.

B. The Game at Period T.

In the game considered by Levhari and Mirman (1980) and Boyce (1999), there are no conservation groups. Thus, they assume that the stock is fully consumed in period T, with each harvester getting an arbitrary but fixed share. However, since the conservationist's utility depends upon the stock remaining after harvesting, I modify the final period problem so that that in all periods beyond T, the aggregate harvest quota is a constant proportion of the stock, with each harvester receiving a fixed share.[xvi] Thus, the period T+1 aggregate harvest is $y_{T+1} = \phi x_{T+1}$; the period T+2 aggregate harvest is $y_{T+2} = \phi x_{T+2} = \phi[(1-\phi)x_{T+1}]^{\alpha}$, and so on, where $\phi \in [0,1)$ is the proportion of the stock harvested in each period. Harvester i's harvest quota is assumed to be $\theta_i y_{T+t}$, where $\Sigma_{i\in\Gamma_H}\theta_i = 1$. Under these assumptions, after period T the stock evolves according to:

$$x_{T+1+t} = (1-\phi)^{\alpha\Sigma_{\tau=0}^{t-1}\alpha^{\tau}} x_{T+1}{}^{\alpha t}. \tag{2}$$

Thus, the present value of the utility to harvesters and conservationists, respectively, at time T+1 is

$$U_i(x_{T+1}) = \sum_{t=0}^{\infty} \beta^t \nu_i \log\left(\theta_i \phi (1-\phi)^{\alpha\Sigma_{\tau=0}^{t-1}\alpha^{\tau}} x_{T+1}{}^{\alpha^t}\right) \equiv \frac{\alpha\nu_i \log(x_T - y_T)}{1-\alpha\beta} + A_i, \qquad i \in \Gamma_H,$$

$$U_c(x_{T+1}) = \sum_{t=0}^{\infty} \beta^t \nu_c \log\left((1-\phi)^{\alpha\Sigma_{\tau=0}^{t-1}\alpha^\tau} x_{T+1}^{\alpha^t} \right) \equiv \frac{\alpha\nu_c \log(x_T - y_T)}{1-\alpha\beta} + A_c, \qquad c \in \Gamma_C,$$

where $A_i = \nu_i \log(\theta_i\phi)/(1-\beta) + \alpha\beta\nu_i \log(1-\phi)/(1-\beta)(1-\alpha\beta)$ and $A_c = \nu_c \log(1-\phi)/(1-\beta)(1-\alpha\beta)$ are constants. The parameter $\beta \in (0,1)$ is the (common) discounted value of one period future returns. Thus, the period T utility functions for the harvesters and conservationists, respectively, are:

$$\text{(3)} \qquad U_i(x_T, \boldsymbol{h}_T) = \nu_i \log(h_i) - \frac{b_i(\boldsymbol{h}_T)}{\kappa_i} + \frac{\alpha\beta\nu_i \log(x_T - y_T)}{1-\alpha\beta} + \beta A_i, \qquad i \in \Gamma_H,$$

$$\text{(4)} \qquad U_c(x_T, \boldsymbol{h}_T) = \nu_c \log(x_T - y_T) - \frac{b_c(\boldsymbol{h}_T)}{\kappa_c} + \frac{\alpha\beta\nu_c \log(x_T - y_T)}{1-\alpha\beta} + \beta A_c, \qquad c \in \Gamma_C.$$

The first two terms on the right-hand-side are the gross utility less the payment to the regulator in period T, and the third and fourth terms are the present value of the period T+1 forward actions, using (2). The parameter $1/\kappa_j$, $\kappa_j \in (0,1]$, $j \in \Gamma$, measures the transactions costs to group j of raising the payment $b_j(\boldsymbol{h}_T)$ (e.g., Olson 1965, Aidt 1998). To better understand the parameter κ_j, note that the *non-transfer* cost associated with payment $b_j(\boldsymbol{h}_T)$ is

$$\text{(5)} \qquad \frac{b_j(\boldsymbol{h}_T)}{\kappa_j} - b_j(\boldsymbol{h}_T) = \left(\frac{1-\kappa_j}{\kappa_j}\right) b_j(\boldsymbol{h}_T), \qquad j \in \Gamma.$$

Thus, as $\kappa_j \to 1$, the transaction costs to group j of making payment $b_j(\boldsymbol{h}_T)$ approaches zero. However, as $\kappa_j \to 0$, the transaction costs become prohibitively large. Thus, κ_j serves as a parametric measure of the lobbying ability of principal j to influence policy via bribes. As κ_j increases, group j costs of raising $b_j(\boldsymbol{h}_T)$ decreases, so I refer to κ_j as the *lobbying ability weight* for group j.

Let us now turn to the regulator. Following Grossman and Helpman (1994), let the regulator's utility be a linear function of the utility and contributions of the harvesters and conservationists:

$$\text{(6)} \qquad U_R(x_T, \boldsymbol{h}_T) = \sum_{i\in\Gamma_H} \gamma_i \nu_i \log(h_i) + \sum_{c\in\Gamma_C} \gamma_c \nu_c \log(x_T - y_T) + \sum_{i\in\Gamma} b_i(\boldsymbol{h}_T)$$

$$+ \left(\frac{\alpha\beta}{1-\alpha\beta}\right)\left(\sum_{j\in\Gamma} \gamma_j \nu_j\right) \log(x_T - y_T) + \beta A_R,$$

where $A_R \equiv \Sigma_{j\in\Gamma}\gamma_j A_j$, and the γ_j parameters ($\gamma_j \geq 0$, $j \in \Gamma$) measure the value to the regulator of the welfare of the interest groups. Since groups with larger voting populations may receive a larger γ_j (*cf.*, Denzau and Munger 1986), γ_j is denoted as the *electoral weight* the regulator places on the gross welfare of group j.

The Markov common agency game in period T proceeds as follows. From Proposition 1 of Grossman and Helpman (Lemma 2 of Bernheim and Whinston 1986), the regulator chooses the harvest quotas $\boldsymbol{h}_T^*$ to maximize $U_R(x_T, \boldsymbol{h}_T)$, taking the optimal incentive contracts $b_j^*(\boldsymbol{h}_T)$ of the interest groups as given. Thus:

$$\text{(7)} \qquad \frac{\gamma_i \nu_i}{h_i^*} - \frac{\gamma_c \nu_c}{x_T - y_T^*} + \sum_{j\in\Gamma}\left(\frac{\partial b_j^*(\boldsymbol{h}_T^*)}{\partial h_i}\right) - \frac{\alpha\beta\Sigma_{j\in\Gamma}\gamma_j\nu_j}{(x_T - y_T^*)(1-\alpha\beta)} = 0, \qquad i \in \Gamma_H.$$

Therefore, the regulator takes into account how an increase in h_i^* affects both present and future utilities of each of the groups as well as how it affects the contingency payments from each group.

Similarly, Grossman and Helpman's Proposition 1, which Bergemann and Valimaki (1998) show holds in general dynamic games, implies that the harvest quota must also maximize the joint welfare of the regulator and each interest group individually, i.e., $\boldsymbol{h}_T^*$ maximizes U_R+U_j, $j \in \Gamma$. However, since (7) implies $\partial U_R/\partial h_i = 0$, maximization of U_R+U_j implies $\partial U_j/\partial h_i = 0$, for each $i \in \Gamma_H$, and each $j \in \Gamma$. Thus

$$\frac{\partial b_i^*(\boldsymbol{h}_T^*)}{\partial h_i} = \frac{\kappa_i \nu_i}{h_i^*} - \frac{\alpha\beta\kappa_i\nu_i}{(x_T - y_T^*)(1-\alpha\beta)}, \qquad i \in \Gamma_H,$$

$$\text{(8)} \qquad \frac{\partial b_j^*(\boldsymbol{h}_T^*)}{\partial h_i} = -\frac{\alpha\beta\kappa_j\nu_j}{(x_T - y_T^*)(1-\alpha\beta)}, \qquad j \neq i;\ i, j \in \Gamma_H,$$

$$\frac{\partial b_c^*(\boldsymbol{h}_T^*)}{\partial h_i} = -\frac{\kappa_c\nu_c}{x_T - y_T^*} - \frac{\alpha\beta\kappa_c\nu_c}{(x_T - y_T^*)(1-\alpha\beta)}, \qquad i \in \Gamma_H,\ c \in \Gamma_C.$$

These conditions imply that the contributions are *locally truthful*: At the margin, the change in the contribution from group j as h_i increases equals the change in value to group j of a unit of additional harvest quota given to harvester i. In general, an increase in the harvest quota to harvester i reduces the payment from other harvesters and conservationists, reflecting the externality the group imposes on these other groups. For a self-replenishing resource such as ground or surface water, where $\alpha = 0$, it follows that $\partial b_j^*/h_i = 0$, for $i \neq j$, $i, j \in \Gamma_H$. Thus, other harvesters are unaffected by an increase in i's harvest quota.[xvii] However, conservationists are affected even when $\alpha = 0$, since their utility depends upon the quantity of water left in the reservoir at the end of each period. For any resource for which tomorrow's stock depends upon today's harvest quotas (i.e., $\alpha > 0$), both the other harvesters and the conservationists will oppose an increase in harvester i's quota. Finally, note that a decrease in the lobbying ability of group j (an increase in j's transaction costs) will diminish the ability of group j to offer an effective incentive contract. Indeed, in the limit as $\kappa_j \to 0$, the marginal contribution vanishes, and the group has no influence over the regulator other than through the electoral weight γ_j the regulator places on the group's utility.

Let us now characterize the common agency equilibrium in period T. Combining (7) and (8) yields:

$$\text{(9)} \qquad \frac{\omega_i}{h_i^*} = \frac{\omega_C + \alpha\beta\omega_H}{(x_T - y_T^*)(1-\alpha\beta)}, \qquad i \in \Gamma_H.$$

where $\omega_j \equiv (\gamma_j + \kappa_j)\nu_j$, $j \in \Gamma$, are the *effective political weights* assigned to the harvesters and the conservationists in the political equilibrium, and $\omega_H \equiv \Sigma_{i\in\Gamma_H}\omega_i$ and $\omega_C \equiv \Sigma_{c\in\Gamma_C}\omega_c$ are the aggregate effective political weights placed on harvesters and conservationists. The effective political weight for group j is increasing in group j's electoral weight γ_j, transactions costs weight κ_j, and preference intensity weight ν_j.

Solving the system of equations in (9) for the h_i^* yields the TMPE harvest quotas, given the stock x_T:

$$\text{(10)} \qquad h_i^*(x_T) = \left(\frac{(1-\alpha\beta)\omega_i}{\omega_H + \omega_C}\right)x_T, \qquad i \in \Gamma_H,$$

where $s_i^* = (1-\alpha\beta)\omega_i/(\omega_C + \omega_H)$ is the share of the stock harvested by harvester i. The aggregate period harvest in period T is thus:

$$\text{(11)} \qquad y_T^*(x_T) \equiv \sum_{i\in\Gamma_H} h_i^*(x_T) = \left(\frac{(1-\alpha\beta)\omega_H}{\omega_H + \omega_C}\right)x_T,$$

where the aggregate share of the stock harvested is $s^* \equiv \Sigma_{i\in\Gamma_H} s_i^* = (1-\alpha\beta)\omega_H/(\omega_C + \omega_H)$. The stock remaining at the end of period T is thus $(1 - s^*)x_T$:

$$\text{(12)} \qquad z_T^*(x_T) \equiv x_T - y_T^*(x_T) = \left(\frac{\omega_C + \alpha\beta\omega_H}{\omega_H + \omega_C}\right)x_T.$$

I will discuss the properties of these solutions shortly. However, first let us consider the properties of the contribution functions when each principal is *globally truthful*, since a very important conclusion immediately follows. The necessary conditions (8) tie down only the marginal properties of the contribution functions, so there are any number of contribution functions that satisfy (8). However, Bernheim and Whinston (1986) show that if we restrict ourselves to contribution functions that are globally truthful, denoted as $b_j^{\mathrm{T}}(\boldsymbol{h}_T)$, so the superscripted 'T' implies 'truthful', then unique contribution functions exist. These are also a best-response when the other players behave truthfully, and are coalition proof, implying no individual principal nor any group of principals can improve their lot by deviating.

C. Truthful Contributions.

A truthful contribution by principal $j \in \Gamma$ is one such that j pays exactly the difference between his gross utility in equilibrium and his gross utility to he contributes zero. Let $\boldsymbol{h}_T^{-j}$ be the policy chosen when $b_j^{\mathrm{T}}(\boldsymbol{h}_T^{-j}) = 0$. In order for the regulator to choose policy $\boldsymbol{h}_T^*$, she must be indifferent between choosing policy $(\boldsymbol{h}_T^*, \{b_k^{\mathrm{T}}(\boldsymbol{h}_T^*)_{k\in\Gamma}\})$ and policy $(\boldsymbol{h}_T^{-j}, \{0, b_k^{\mathrm{T}}(\boldsymbol{h}_T^{-j})_{k\in\Gamma\backslash j}\})$, where the j^{th} contribution has been replaced with zero. No principal wishes to contribute more than $b_j^{\mathrm{T}}(\boldsymbol{h}_T^*)$, since his net utility is decreasing in $b_j^{\mathrm{T}}(\boldsymbol{h}_T^*)$.

By way of illustration, for the i^{th} harvester the regulator's indifference implies

$$b_i^{\mathrm{T}}(\boldsymbol{h}_T^*) \;=\; \sum_{j\in\Gamma_H}\gamma_j\nu_j\log\left(\frac{h_j^{-i}}{h_j^*}\right) \;+\; \sum_{c\in\Gamma_C}\gamma_c\nu_c\log\left(\frac{x_T-y_T^{-i}}{x_T-y_T^*}\right) \;+\; \left(\frac{\alpha\beta}{1-\alpha\beta}\right)\left(\sum_{j\in\Gamma_H}\gamma_j\nu_j+\sum_{c\in\Gamma_C}\gamma_c\nu_c\right)\log\left(\frac{x_T-y_T^{-i}}{x_T-y_T^*}\right)+\sum_{j\in\Gamma_{H/i}\cup\Gamma_C}[b_j^{\mathrm{T}}(\boldsymbol{h}_T^{-i})-b_j^{\mathrm{T}}(\boldsymbol{h}_T^*)]$$

If the other contributions are globally truthful, then

$$b_j^{\mathrm{T}}(\boldsymbol{h}_T^{-i})-b_j^{\mathrm{T}}(\boldsymbol{h}_T^*) \;\equiv\; \kappa_j\nu_j\log\left(\frac{h_j^{-i}}{h_j^*}\right) \;+\; \left(\frac{\alpha\beta\kappa_j\nu_j}{1-\alpha\beta}\right)\log\left(\frac{x_T-y_T^{-i}}{x_T-y_T^*}\right), \qquad j\in\Gamma_{H\backslash i}$$

$$b_c^{\mathrm{T}}(\boldsymbol{h}_T^{-i})-b_c^{\mathrm{T}}(\boldsymbol{h}_T^*) \;\equiv\; \left(\frac{\kappa_c\nu_c}{1-\alpha\beta}\right)\log\left(\frac{x_T-y_T^{-i}}{x_T-y_T^*}\right), \qquad c\in\Gamma_C.$$

Solving the regulator's indifference condition for $b_i^{\mathrm{T}}(\boldsymbol{h}_T^*)$ yields:

$$(13)\qquad b_i^{\mathrm{T}}(\boldsymbol{h}_T^*) \;=\; \gamma_i\nu_i\log\left(\frac{h_i^{-i}}{h_i^*}\right) \;+\; \left(\frac{\omega_C+\alpha\beta(\omega_{H/i}+\gamma_i\nu_i)}{1-\alpha\beta}\right)\log\left(\frac{x_T-y_T^{-i}}{x_T-y_T^*}\right) \;+\; \sum_{j\in\Gamma_{H/i}}\omega_j\log\left(\frac{h_j^{-i}}{h_j^*}\right), \quad i\in\Gamma_H,$$

where $\omega_{H\backslash i}\equiv\Sigma_{j\in\Gamma_{H\backslash i}}\,\omega_j$, and the harvest quotas when harvester i does not contribute are $h_i^{-i}\equiv s_i^{-i}x_T$ and $h_j^{-i}\equiv s_j^{-i}x_T$, with aggregate harvest $y_T^{-i}\equiv s^{-i}x_T$, where $s_i^{-i}\equiv(1-\alpha\beta)\gamma_i\nu_i/(\omega_C+\omega_{H\backslash i}+\gamma_i\nu_i)$, $s_j^{-i}\equiv(1-\alpha\beta)\omega_j/(\omega_C+\omega_{H\backslash i}+\gamma_i\nu_i)$ for $i\neq j\in\Gamma_H$, and $s^{-i}\equiv(1-\alpha\beta)(\omega_{H\backslash i}+\gamma_i\nu_i)/(\omega_C+\omega_{H\backslash i}+\gamma_i\nu_i)$. By a similar process, the equilibrium contribution for conservationist c can be shown to be:

$$(14)\qquad b_c^{\mathrm{T}}(\boldsymbol{h}_T^*) \;=\; \left(\frac{\omega_{C/c}+\gamma_c\nu_c+\alpha\beta\omega_H}{1-\alpha\beta}\right)\log\left(\frac{x_T-y_T^{-c}}{x_T-y_T^*}\right) \;+\; \sum_{j\in\Gamma_H}\omega_i\log\left(\frac{h_i^{-c}}{h_j^*}\right), \qquad c\in\Gamma_C.$$

where $\omega_{C\backslash c}\equiv\Sigma_{k\in\Gamma_{C\backslash c}}\omega_k$, and the harvest quota shares when conservationist c does not contribute are $h_i^{-c}\equiv s_i^{-c}x_T$, with aggregate harvest $y_T^{-c}\equiv s^{-c}x_T$, where $s_i^{-c}\equiv(1-\alpha\beta)\omega_i/(\omega_{C\backslash c}+\gamma_c\nu_c+\omega_H)$ and $s^{-c}\equiv(1-\alpha\beta)\omega_H/(\omega_{C\backslash c}+\gamma_c\nu_c+\omega_H)$. Thus, when principal j does not contribute, it is as though their effective political weight becomes $\gamma_j\nu_j$, which, as Grossman and Helpman (1994) observe, is the weight j would receive if it were unorganized, i.e., if $\kappa_j=0$.

The interesting thing about the truthful contributions in (13) and (14) is that they do not depend upon the stock x_T. This is because the ratio $h_j^{-k}/h_j^*=s_j^{-k}/s_j^*$, and $(x_T-y_T^{-k})/(x_T-y_T^*)=(1-s^{-k})/(1-s^*)$, for all $j\in\Gamma_H$, and $k\in\Gamma$. Thus, the x_T terms cancel out in each part of (13), and all that is left are terms involving the equilibrium share of the harvest. Therefore, define the equilibrium contributions as:

$$(15)\qquad b_i^{\mathrm{T}}(\boldsymbol{s}^*) \;=\; \gamma_i\nu_i\log\left(\frac{s_i^{-i}}{s_i^*}\right) \;+\; \left(\frac{\omega_C+\alpha\beta(\omega_{H/i}+\gamma_i\nu_i)}{1-\alpha\beta}\right)\log\left(\frac{1-s^{-i}}{1-s^*}\right) \;+\; \sum_{j\in\Gamma_{H/i}}\omega_j\log\left(\frac{s_j^{-i}}{s_j^*}\right), \quad i\in\Gamma_H,$$

$$(16)\qquad b_c^{\mathrm{T}}(\boldsymbol{s}^*) \;=\; \left(\frac{\omega_{C/c}+\gamma_c\nu_c+\alpha\beta\omega_H}{1-\alpha\beta}\right)\log\left(\frac{1-s^{-c}}{1-s^*}\right) \;+\; \sum_{i\in\Gamma_H}\omega_i\log\left(\frac{s_i^{-c}}{s_i^*}\right), \qquad c\in\Gamma_C,$$

where $\boldsymbol{s}^*\equiv(\{s_i^*,\ s_i^{-i},\ s_j^{-i}\}_{i,j\in\Gamma_H},\ \{s_i^{-c}\}_{i\in\Gamma_H,\ c\in\Gamma_C})$ are the equilibrium harvest quota shares. Notice that this implies that the equilibrium contributions are a constant, independent of the stock.

Since the equilibrium contributions do not depend upon the stock, the optimized value of harvester i's objective function can be written as

$$U_i^*(x_T) \;=\; \frac{\nu_i\log(x_T)}{1-\alpha\beta} \;+\; \nu_i\log(s_i^*) \;+\; \frac{\alpha\beta\nu_i\log(1-s^*)}{1-\alpha\beta} \;-\; \frac{b_i^{\mathrm{T}}(\boldsymbol{s}^*)}{\kappa_i} \;+\; \beta A_i, \qquad i\in\Gamma_H,$$

where this expression uses (10)-(12). Thus, the period $T-1$ objective function for this harvester is:

$$U_i(x_{T-1},\boldsymbol{h}_{T-1}) \;=\; \nu_i\log(h_i) \;-\; \frac{b_i(\boldsymbol{h}_{T-1})}{\kappa_i} \;+\; \frac{\alpha\beta\nu_i\log(x_{T-1}-y_{T-1})}{1-\alpha\beta}$$

$$+\;\beta\nu_i\log(s_i^*) \;+\; \frac{\alpha\beta^2\nu_i\log(1-s^*)}{1-\alpha\beta} \;-\; \frac{\beta b_i^{\mathrm{T}}(\boldsymbol{s}^*)}{\kappa_i} \;+\; \beta^2A_i,\ \ i\in\Gamma_H.$$

Except for the constants (the terms on the second line), this expression is identical in form to that in (3). Similar expressions can be derived for the conservationists and the regulator. Thus, the harvest quota shares $\boldsymbol{s}^*$ are valid for any stock x. In each period, the regulated equilibrium involves a *constant* proportion of the stock being harvested.[xviii] This was assumed for periods T+1 forward, but it is true for each period.

Since an identical proportion of the stock is consumed in each period, it means that the steady-state for renewable resources will only be approached asymptotically, and that an exhaustible resource will never be completely consumed. Thus, is possible to talk about the utility at any point along the steady-state approach path. In the limit as $t\to\infty$, the values of the objective functions become:

$$(17)\qquad U_i^*(x) = \frac{\nu_i \log(x)}{1-\alpha\beta} + \frac{\nu_i \log(s_i^*)}{1-\beta} + \frac{\alpha\beta\nu_i \log(1-s^*)}{(1-\beta)(1-\alpha\beta)} - \frac{b_i^{\mathrm{T}}(\boldsymbol{s}^*)}{(1-\beta)\kappa_i}, \qquad i \in \Gamma_H,$$

$$(18)\qquad U_c^*(x) = \frac{\nu_c \log(x)}{1-\alpha\beta} + \frac{\nu_c \log(1-s^*)}{(1-\beta)(1-\alpha\beta)} - \frac{b_c^{\mathrm{T}}(\boldsymbol{s}^*)}{(1-\beta)\kappa_c}, \qquad c \in \Gamma_C.$$

These objective functions do not depend upon the arbitrary actions in periods T+1 forward, since the outcome of these actions has been discounted to zero.

Thus, in the Markov common agency equilibrium, each harvester removes a constant portion of the stock $s_i^* = (1-\alpha\beta)\omega_i/(\omega_H + \omega_C)$, $i \in \Gamma_H$. The proportion of the stock harvested by harvester i is an increasing function of the effective welfare weight given to harvester i, and a decreasing function of the effective welfare weight to other harvesters and conservationists. In addition, harvester i's harvest quota share is increasing in the rate of growth of the stock (i.e., as α decreases), and decreasing in the discount rate β. The share of the stock harvested in aggregate, $s^* \equiv (1-\alpha\beta)\omega_H/(\omega_H + \omega_C)$, is an increasing function of the harvester's effective welfare weights, a decreasing function of the conservationist's effective welfare weight, and a decreasing function of both α and β. Thus, the increase in i's aggregate harvest due to an increase in ω_i is greater than the decrease to the other N–1 harvester's aggregate harvest due to an increase in ω_i. The proportion of the stock remaining at the end of each period, $1-s^* = (\omega_C + \alpha\beta\omega_H)/(\omega_H + \omega_C)$, is an increasing function in ω_C, a decreasing function in ω_H, and an increasing function in both α and β.

The other shares of interest appear in the $b_c^{\mathrm{T}}(\boldsymbol{s}^*)$ and $b_i^{\mathrm{T}}(\boldsymbol{s}^*)$ functions. Harvester i's share when he does not contribute is $s_i^{-i} = (1-\alpha\beta)\gamma_i\nu_i/(\omega_C + \omega_{H\backslash i} + \gamma_i\nu_i)$, $i \in \Gamma_H$. Since s_i^* is increasing in ω_i, harvester i's share decreases when harvester i does not contribute to the regulator: $s_i^{-i} < s_i^*$. However, when harvester i does not contribute, each other harvester's share, $s_j^{-i} = (1-\alpha\beta)\omega_j/(\omega_{H\backslash i} + \gamma_i\nu_i + \omega_C)$, $i \neq j$, $i, j \in \Gamma_H$, increases: $s_j^{-i} > s_j^*$. When harvester i does not contribute, the aggregate harvest quota share $s^{-i} = (1-\alpha\beta)(\omega_{H\backslash i} + \gamma_i\nu_i)/(\omega_C + \omega_{H\backslash i} + \gamma_i\nu_i)$, $i \in \Gamma_H$, is smaller than when i does contribute: $s^{-i} < s^*$. Therefore, the reduction in harvester i's quota share is greater than the increase in all other harvester's quota shares. This also implies that $1-s^{-i} > 1-s^*$, or that the proportion of the stock remaining at the end of each period when i does not contribute is smaller than when i does contribute, which implies conservationists are made worse off if i contributes. Similarly, if conservationist c does not contribute, then $s_j^{-c} = (1-\alpha\beta)\omega_j/(\omega_{C\backslash c} + \gamma_c\nu_c + \omega_H)$, and $s_j^{-c} > s_j^*$, since s_j^* is decreasing in ω_C. If conservationist c does not contribute, the aggregate harvest quota share, $s^{-c} = (1-\alpha\beta)\omega_H/(\omega_{C\backslash c} + \gamma_c\nu_c + \omega_H)$, is greater than s^*, since s^* is decreasing in ω_C. Since $s^{-c} > s^*$, it follows that $1-s^{-c} < 1-s^*$, or that each conservationist is worse off when conservationist c does not contribute.

For harvester i, the second and third terms in $b_i^{\mathrm{T}}(\boldsymbol{s}^*)$ (see (15)) represent the payments to the regulator for the costs harvester i imposes on the other harvesters (since $s_j^{-i} > s_j^*$) and conservationists (since $1-s^{-i} > 1-s^*$), less the reduction (since $s_i^{-i} < s_i^*$) in the payment to the regulator, because the regulator values the benefits accruing to harvester i. The equilibrium contribution for conservationist c (see (16)) includes the costs conservationist c imposes on each harvester i (since $s_i^{-c} > s_i^*$) in the political equilibrium less the reduction in the payment to the regulator since increased conservation benefits both other conservation groups and the harvesters in the future (since $1-s^{-c} < 1-s^*$). Both the harvesters and conservationists impose net costs on the other groups.

Finally, for cases where the resource is renewable (i.e., whenever $\alpha < 1$), the steady-state stock equals

$$(19)\qquad x^* = \left(\frac{\omega_C + \alpha\beta\omega_H}{\omega_H + \omega_C}\right)^{\alpha/(1-\alpha)}.$$

Thus, the steady-state stock shares the same qualitative properties as the stock remaining at the end of each harvest period: It is increasing in the aggregate effective political weight of conservationists and decreasing in the effective political weight of harvesters. When $\omega_H = 0$, the welfare of conservationists is maximized, and the individual and aggregate harvest quota shares equal zero. In this case the stock reverts to its natural steady-state value $\bar{x}$. We shall see in a moment that when $\omega_C = 0$, the harvest quota share equals $1 - \alpha\beta$, which maximizes the joint welfare of harvesters.

III. The Unregulated Common Property Equilibrium.

In this section, I solve for the equilibrium payoffs when there is no regulation. These results are used in the next section both to assess the conditions under which regulation will be voluntarily adopted and to determine when regulation is welfare-improving, relative to the unregulated equilibrium. The assumption maintained throughout is that the public good nature of the conservation benefits prevents conservation groups from purchasing the stock. Thus, even if harvesters enjoy private property rights to the stock, they will still impose an externality on the conservationists. In addition, the structure of the harvesting sector, here taken to be the number of harvesting groups N, is exogenous.

In period T, given (2), harvester i chooses h_i to maximize

$$U_i(x_T, \boldsymbol{h}_T) = \nu_i \log(h_i) + \frac{\alpha\beta\nu_i \log(x_T - y_T)}{1 - \alpha\beta} + \beta A_i, \qquad i \in \Gamma_H,$$

taking the harvest choice of the other groups as fixed. The Nash equilibrium in period T thus satisfies

$$\frac{\nu_i}{h_i^{\#}} - \frac{\alpha\beta\nu_i}{(x_T - y_T^{\#})(1 - \alpha\beta)} = 0, \qquad i \in \Gamma_H.$$

This has solutions

$$h_i^{\#}(x_T) = \left(\frac{1 - \alpha\beta}{N(1 - \alpha\beta) + \alpha\beta}\right) x_T, \qquad i \in \Gamma_H, \tag{20}$$

where the share of the stock harvested by harvester i, $s_i^{\#} = (1 - \alpha\beta)/[N(1 - \alpha\beta) + \alpha\beta]$, is decreasing in the number of harvesters N, and decreasing in $\alpha\beta$. The aggregate harvest is thus

$$y_T^{\#}(x_T) = \left(\frac{N(1 - \alpha\beta)}{N(1 - \alpha\beta) + \alpha\beta}\right) x_T, \tag{21}$$

where the aggregate share of the stock harvested, $s^{\#} = N(1 - \alpha\beta)/[N(1 - \alpha\beta) + \alpha\beta]$, is increasing in N and decreasing in $\alpha\beta$. Thus, the stock remaining at the end of period T is

$$z_T^{\#}(x_T) = \left(\frac{\alpha\beta}{N(1 - \alpha\beta) + \alpha\beta}\right) x_T, \tag{22}$$

where the share of the stock remaining at the end of each period under the non-cooperative equilibrium, $1 - s^{\#} = \alpha\beta/[N(1 - \alpha\beta) + \alpha\beta]$, is decreasing in N and increasing in $\alpha\beta$.

The equilibrium period T utility for harvester i in the non-cooperative harvesting game is given by

$$U_i^{\#}(x_T) = \frac{\nu_i \log(x_T)}{1 - \alpha\beta} + \nu_i \log(s_i^{\#}) + \frac{\alpha\beta\nu_i \log(1 - s^{\#})}{1 - \alpha\beta} + \beta A_i, \qquad i \in \Gamma_H.$$

Thus, the period T–1 utility function for harvester i can be written as

$$U_i(x_{T-1}, \boldsymbol{h}_{T-1}) = \nu_i \log(h_i) + \frac{\alpha\beta\nu_i \log(x_{T-1} - y_{T-1})}{1 - \alpha\beta} + \beta\nu_i \log(s_i^{\#}) + \frac{\alpha\beta^2\nu_i \log(1 - s^{\#})}{1 - \alpha\beta} + \beta^2 A_i, \quad i \in \Gamma_H.$$

This is identical to the period T objective function, except for the constant term. Therefore, as in the dynamic common agency case, the non-cooperative equilibrium involves a constant proportion of the stock being harvested in every period.[xix] For an arbitrary stock, the welfare of each harvester is thus:

$$U_i^{\#}(x) = \frac{\nu_i \log(x)}{1 - \alpha\beta} + \frac{\nu_i \log(s_i^{\#})}{1 - \beta} + \frac{\alpha\beta\nu_i \log(1 - s^{\#})}{(1 - \beta)(1 - \alpha\beta)}, \qquad i \in \Gamma_H. \tag{23}$$

Similarly, for an arbitrary initial stock x, each conservationist's utility can be shown to equal

$$U_c^{\#}(x) = \frac{\nu_c \log(x)}{1 - \alpha\beta} + \frac{\nu_c \log(1 - s^{\#})}{(1 - \beta)(1 - \alpha\beta)}, \qquad c \in \Gamma_C. \tag{24}$$

As the number of harvesting groups grows, the aggregate share of the stock that is harvested approaches unity. Thus, in the limit as $N \to \infty$, the stock is completely consumed in the first period. Conversely, when there is only one harvesting group, the share of the stock harvested in each period equals $s_H^{\#} = 1 - \alpha\beta$, where the subscript '$H$' is taken to imply that private property rights exist to the stock, so the harvest quota share maximizes the welfare of fishermen.[xx] This is what occurs if private property rights are well defined for the stock.

In the event that the resource is renewable (i.e., $\alpha < 1$), the unregulated steady-state stock equals

$$(25) \qquad x^{\#} = \left(\frac{\alpha\beta}{N(1-\alpha\beta)+\alpha\beta}\right)^{\alpha/(1-\alpha)}, \qquad \text{for } \alpha < 1.$$

Taking the limit as $N \to \infty$, we see that the stock is completely consumed instantaneously, so $x^{\#} \to 0$. In contrast, in the private property case, the steady-state stock equals $x^{\#}_H = (\alpha\beta)^{\alpha/(1-\alpha)}$, which is greater than $x^{\#}$, since $x^{\#}$ is decreasing in N.

It is now possible to show the effect regulation has on the share of the stock that is harvested, and, for the case where $\alpha < 1$, on the steady-state stock. With regulation, the aggregate share of the stock harvested is unambiguously smaller, and the aggregate share of the stock that remains after each harvest period is unambiguously larger, than that which occurs absent regulation, i.e.,

$$(26) \qquad s^{\#} - s^{*} = (1-s^{*}) - (1-s^{\#}) = \frac{\omega_C N(1-\alpha\beta) + (N-1)(1-\alpha\beta)\alpha\beta\omega_H}{(\omega_C+\omega_H)[N(1-\alpha\beta)+\alpha\beta]} > 0.$$

In the event that $\omega_C = 0$, the regulated aggregate harvest quota share is $s^{*} = 1 - \alpha\beta$, which corresponds to the aggregate harvest quota share that maximizes harvesters' joint welfare. In the event that $\omega_H = 0$, the regulated aggregate harvest quota share is $s^{*} = 0$, which corresponds to the aggregate harvest quota share that maximizes conservationists' joint welfare. These suggest that when ω_C and ω_H are each greater than zero, the regulated harvest quota share maximizes the joint welfare of harvesters and conservationists. However, this is not the case. The equilibrium harvest quota share that maximizes the joint welfare of harvesters and conservationists equals $(1-\alpha\beta)(\Sigma_{j\in\Gamma_H}\nu_i)/(\Sigma_{j\in\Gamma_H}\nu_i + \Sigma_{c\in\Gamma_C}\nu_c)$. Thus, the regulated harvest quota share s^{*} maximizes the joint welfare of harvesters and conservationists if and only if the effective political weights are all in the same relative proportions as the harvest intensity parameters, i.e., when $\omega_j \equiv k\nu_j$ for all $j \in \Gamma$. This difference occurs because the regulator, in effect, is weighting each group's preference intensity by the sum of its electoral plus lobbying ability weights. In the event that the electoral plus lobbying ability weight is equal across groups, the regulator maximizes aggregate welfare because that maximizes the possible contributions she can extract. However, in general, there is no reason for these weights to be equal across interest groups.

IV. Net Welfare Effects of Regulation.

This section examines two issues: When is regulation is likely to be voluntarily supported? And When is regulation socially beneficial, relative to the un-regulated case? The first question is important for understanding the "constitutions" under which regulation is adopted.[xxi] An important conclusion from this analysis is that harvesters are in general less likely to voluntarily support regulation. Thus, the model predicts that harvester's welfare will be given greater weight than that of conservationists in successful regulations.[xxii] The second question raises the issue that socially beneficial regulation might not be adopted if the regulator takes too large of a proportion of the surplus.

A. Voluntary Support of Regulation by Conservationists.

Let $\Delta U_c \equiv U^{*}_c(x) - U^{\#}_c(x)$ be the *net* change in welfare to conservationist c of adopting regulation. From (16) and (24), the necessary condition for conservationist c to support regulation is that

$$(27) \qquad \Delta U_c(x) = \left(\frac{\nu_c}{(1-\beta)(1-\alpha\beta)}\right)\log\left(\frac{1-s^{*}}{1-s^{\#}}\right) - \frac{b^{\mathrm{T}}_c(\boldsymbol{s}^{*})}{(1-\beta)\kappa_c} > 0, \qquad c \in \Gamma_C.$$

The first term in $\Delta U_c(x)$ is the gross increase in the present value of welfare to conservationists from the adoption of regulation and the second term is the present value of the cost of raising contributions $b^{\mathrm{T}}_c(\boldsymbol{s}^{*})$. This condition is not affected by the starting stock x, since neither the contributions $b^{\mathrm{T}}_c(\boldsymbol{s}^{*})$ nor the harvest quota shares s^{*} or $s^{\#}$ depend on x.

Since the contributions are non-negative, it is necessary that the gross welfare change be positive in order that conservationists to support regulation. However, this condition always holds, since $s^{*} < s^{\#}$ (see (26)). Thus, the question is when will the gross benefits outweigh the costs to conservationists? Suppose that conservationist group c is completely unorganized in the sense that $\kappa_c \to 0$. Since group c's cost of contributing even a penny becomes prohibitive, c's contributions vanish.[xxiii] But if this is so, then c will be willing to support regulation no matter what the current state of the property rights, since its gross welfare change from the adoption of regulation is positive whenever $\omega_C = \Sigma_{c\in\Gamma_C}\gamma_c\nu_c > 0$. Indeed, this point can be extended to the case where $\omega_c = 0$ for *all* $c \in \Gamma_C$.[xxiv] In this event, every conservationist's contributions vanish. However, by (27), $\Delta U_c(x)$ is determined entirely by the change in group c's gross welfare, which is non-negative (and strictly positive for $N > 1$). Thus, even if their own interests are not explicitly accounted for, conservationists will support regulation.

In contrast, suppose harvesters are given zero weight in the equilibrium, i.e., let $\omega_H = 0$, so that $\gamma_i = \kappa_i = 0$, for all $i \in \Gamma_H$. Then no harvest is allowed even if conservationist c does not contribute (indeed, even if none of the conservationists contribute), so long as the regulator places positive electoral weight on the welfare of at least one conservationist group (i.e., so long as $\omega_c > 0$ for some $c \in \Gamma_C$). Then, each conservationist contributes zero, since no conservationist affects the outcome (i.e., $s^* = s^{-c} = 0$). Therefore, conservationists support regulation when the regulator cares only about their interests. This suggests that conservationists support a regulator such as the International Whaling Commission, which has placed a permanent moratorium on whaling, not just because the regulator cares more about their interests than those of the harvesters, but also because the regulator can not credibly extract rents from the conservationists groups.

Finally, suppose that the weight the regulator places on the welfare of harvesters is independent of the number of harvesters, so that ω_H is fixed, but N may vary. Then, as N increases, the change in the gross welfare to conservationist c is

$$\frac{\partial}{\partial N}\left(\log\left(\frac{1-s^*}{1-s^\#}\right)\right) = \frac{1-\alpha\beta}{(1-s^*)\alpha\beta} > 0.$$

Thus, the change in gross welfare to conservationists as regulation is adopted is increasing in N. Furthermore, since ω_H is independent of N, there is no corresponding increase in $b_c^{\mathrm{T}}(\boldsymbol{s}^*)$. This implies that conservationists are more likely to prefer regulation as the common property problem worsens. Since the gross welfare change to conservationists is increasing in N, consider the case where private property rights exist, so $N = 1$. Expanding (27) by explicitly considering the contributions yields:

$$\Delta U_c(x) = \left(\frac{\nu_c}{(1-\beta)(1-\alpha\beta)}\right)\log\left(\frac{1-s^*}{1-s^\#}\right) + \left(\frac{\omega_{C/c}+\gamma_c\nu_c}{(1-\alpha\beta)(1-\beta)\kappa_c}\right)\log\left(\frac{1-s^*}{1-s^{-c}}\right)$$

$$-\frac{\omega_H}{(1-\beta)\kappa_c}\left(\log\left(\frac{s^{-c}}{s^*}\right) + \left(\frac{\alpha\beta\omega_H}{1-\alpha\beta}\right)\log\left(\frac{1-s^{-c}}{1-s^*}\right)\right).$$

The terms on the first line are positive in total, and represent the gross increase in welfare to conservationist c plus the increase in welfare to conservationists as a group of the incremental increase in the remaining share of the stock due to conservationist c's contribution ($1 - s^* > 1 - s^{-c}$), given that regulation is in place. The terms on the second line represent the present value of the costs each conservationist c imposes on the (sole) harvester due to c's contribution, given that regulation is in place. Since $s^{-c} > s^*$, the first expression on the second line is positive, but the second is negative. Thus, so long as the cost to harvester is not too great, the net change in welfare to conservationists is positive, even when there is no common property problem with the use of the stock. This occurs because in the regulated equilibrium the share of the stock harvested decreases (see (26)). Furthermore, since the contributions by each conservationist are reduced by the amount of benefit they create for other conservationists, there is no free-rider effect among conservationists in the dynamic common agency equilibrium.[xxv]

B. Voluntary Support of Regulation by Harvesters.

Now consider the condition under which harvesters support regulation. Let $\Delta U_i \equiv U_i^*(x) - U_i^\#(x)$ be the *net* change in welfare to harvester $i \in \Gamma_H$ of adopting regulation. From (15) and (23), the necessary condition harvester i to support regulation is that

$$\text{(28)} \qquad \Delta U_i(x) = \left(\frac{\nu_i}{1-\beta}\right)\log\left(\frac{s_i^*}{s_i^\#}\right) + \left(\frac{\alpha\beta\nu_i}{(1-\beta)(1-\alpha\beta)}\right)\log\left(\frac{1-s^*}{1-s^\#}\right) - \frac{b_i^{\mathrm{T}}(\boldsymbol{s}^*)}{(1-\beta)\kappa_i} > 0, \qquad i \in \Gamma_H.$$

The first two terms are the present-value of the gross welfare change to harvester i of adopting regulation, and the third term is the present value of the cost of contributing $b_i^{\mathrm{T}}(\boldsymbol{s}^*)$ into perpetuity. As with the conservationists, whether harvester i will prefer regulation is independent of x.

First, suppose that private property rights exist to the stock. Thus, let $N = 1$. Since the share of the stock harvested in each period absent regulation maximizes the harvester's gross utility, and since the equilibrium regulated share s^* declines as ω_C increases, the harvester's gross utility of adopting regulation is unaffected when $\omega_C = 0$ and reduced when $\omega_C > 0$. Furthermore, since the regulator captures part of the rents in the form of the equilibrium payment $b_i^{\mathrm{T}}(\boldsymbol{s}^*)$, which is strictly positive when $\omega_C > 0$ for $N = 1$, the (sole) harvester's welfare is unambiguously reduced by the adoption of regulation when $\omega_C > 0$, and is unaffected when $\omega_C = 0$. Thus, with well-defined private property rights for the resource, regulation will not be supported by the harvesters, and will be actively opposed whenever the harvesters view the regulator as being responsive to conservationists.[xxvi]

When the resource is owned in common among N harvesters it is possible that the harvesters will benefit from regulation, since regulation will resolve the common property problem. Suppose that $\omega_C = 0$, so that conservationists are given zero weight in the effective political welfare function, and assume that each harvester is identical in the sense that ω_i

= $(1 - \alpha\beta)/N$, for all $i \in \Gamma_H$, so each harvester gets share $1/N$ of the optimal harvest quota in the regulated equilibrium. Then the change in the *gross* utility of to the *i*th harvester of adopting regulation is

$$\left(\frac{\nu_i}{1-\beta}\right)\log\left(\frac{N(1-\alpha\beta)+\alpha\beta}{N}\right) + \left(\frac{\alpha\beta\nu_i}{(1-\beta)(1-\alpha\beta)}\right)\log\big(N(1-\alpha\beta)+\alpha\beta\big), \qquad i \in \Gamma_H.$$

This expression vanishes for $N = 1$. However, this expression is increasing in N, i.e.,

$$\frac{\partial(\cdot)}{\partial N} = \left(\frac{\nu_i}{1-\beta}\right)\left(\frac{(N-1)\alpha\beta}{N(1-\alpha\beta)+\alpha\beta}\right) > 0.$$

Thus, the change in gross utility to harvesters is positive for $N > 1$. Furthermore, under these conditions, $s^{-i} = s^*$, since conservationists are ignored, and $s_i^{-i}/s_i^* = N/[N(1 - \alpha\beta) + \alpha\beta]$. Thus, $b_i^{\mathrm{T}}(\boldsymbol{s}^*) = \nu_i\log\{N/[N(1 - \alpha\beta) + \alpha\beta]\}$, which is decreasing in N. Thus, when fishermen in a common property fishery are homogeneous and the regulator places zero weight on conservationists, fishermen will support regulation. However, violation of either the homogeneity or zero weight on conservationists' assumptions may cause fishermen to oppose regulation, since the contributions will be positive and the gross change in welfare may be negative under these circumstances.[xxvii]

Finally, note that in the limit as the share to harvester *i* approaches zero, the harvester will clearly oppose regulation (i.e., the limit of $\log(s_i^{-i}/s_i^*)$ approaches negative infinity). Thus, a necessary condition for harvesters to support regulation is that the regulator values their welfare in equilibrium with significant enough weight. This could explain why whaling countries such as Norway and Japan have considered withdrawing from the International Whaling Commission.

C. Social Welfare and Regulation.

Next, consider the conditions under which *social* welfare is improved by regulation. The key assumption here is that when regulation exists, the regulator cares about the gross welfare of the groups *only* because their welfare translates positively into electoral support. Thus, absent regulation, the regulator does not care about the group's welfare in any meaningful way. Thus, the regulator's valuation of the gross utility of the harvesters and conservationists is ignored in what follows. However, the contributions are counted, since they are transfers from the pie of actual wealth.

Let $\Delta\hat{U}_j(x)$ be the change in gross utility *less* the transactions costs associated with the contributions:

$$\text{(29)} \qquad \Delta\hat{U}_c(x) = \left(\frac{\nu_c}{(1-\beta)(1-\alpha\beta)}\right)\log\left(\frac{1-s^*}{1-s^\#}\right) - \left(\frac{1-\kappa_c}{\kappa_c}\right)\left(\frac{b_c^{\mathrm{T}}(\boldsymbol{s}^*)}{1-\beta}\right), \qquad c \in \Gamma_C,$$

$$\text{(30)} \qquad \Delta\hat{U}_i(x) = \left(\frac{\nu_i}{1-\beta}\right)\log\left(\frac{s_i^*}{s_i^\#}\right) + \left(\frac{\alpha\beta\nu_i}{(1-\beta)(1-\alpha\beta)}\right)\log\left(\frac{1-s^*}{1-s^\#}\right) - \left(\frac{1-\kappa_i}{\kappa_i}\right)\left(\frac{b_i^{\mathrm{T}}(\boldsymbol{s}^*)}{1-\beta}\right), \quad i \in \Gamma_H.$$

Since $\Delta U_j(x) - \Delta\hat{U}_j(x) = b_i^{\mathrm{T}}(\boldsymbol{s}^*)/(1 - \beta) > 0$, if both harvesters and conservationists support regulation, then regulation is clearly welfare-improving. However, since both harvesters and conservationists perceive the contributions as a cost, when they are not social costs, it is possible that regulation that improves welfare is not voluntarily adopted.

The net welfare change to society is

$$\text{(31)} \qquad \Delta W_S(x) = \sum_{i\in\Gamma_H}\left(\frac{\nu_i}{1-\beta}\right)\log\left(\frac{s_i^*}{s_i^\#}\right) + \left(\frac{\Sigma_{c\in\Gamma_C}\nu_c + \alpha\beta\Sigma_{i\in\Gamma_H}\nu_i}{(1-\beta)(1-\alpha\beta)}\right)\log\left(\frac{1-s^*}{1-s^\#}\right) - \sum_{j\in\Gamma}\left(\frac{1-\kappa_j}{\kappa_j}\right)\left(\frac{b_j^{\mathrm{T}}(\boldsymbol{s}^*)}{1-\beta}\right).$$

We have already seen that as $\kappa_j \to 0$, the cost of the contributions vanish for both conservationists and harvesters. The same thing occurs here. Indeed, if all groups are unorganized in the sense that $\kappa_j = 0$ for all $j \in \Gamma$, then no group contributes in equilibrium. Similarly, the transactions costs also vanish if $\kappa_j = 1$ for all $j \in \Gamma$. Thus, the transactions costs associated with the contributions vanish in either case. Then if the regulator is "benevolent" in the sense that $\gamma_j = \gamma$, for some $\gamma > 0$, for all $j \in \Gamma$, then regulation will be welfare-improving. Furthermore, since by (26) we know that the aggregate share of the harvest declines under regulation (i.e., $s^* < s^\#$), so the second term in (31) is always positive. However, this means that the first term, on average, has to be negative. Thus regulation is socially beneficial whenever conservationists' aggregate preference intensity is sufficiently large.

Two other special cases are interest. First, we saw above that as $\omega_i \to 0$ for $i \in \Gamma_H$, the welfare loss to harvesters grew extremely large. Thus, for ω_i small enough, social welfare is clearly made worse off by the adoption of regulation. Therefore, for regulation to be socially beneficial, as well as for it to get the support of harvesters, it is necessary that the regulator place sufficient weight on the welfare of the harvesters. In contrast, suppose that $\omega_c = 0$ for all $c \in \Gamma_C$, and that each harvester is identical, so that $\gamma_i = \gamma_j$, $\kappa_i = \kappa_j$, and $\nu_i = \nu_j$, for all $i, j \in \Gamma_H$. We saw above that this resulted in support for regulation both from harvesters and conservationists. Thus, when $\omega_C = 0$, social welfare is improved, except in the instance where there exists private property, in which case regulation has no effect.

Combining these results suggests that harvesters are more important than conservationists in determining whether the regulated equilibrium is a welfare improvement over the common property equilibrium. This occurs because harvesters, like conservationists, value the stock, but conservationists, unlike harvesters, place no value on the harvests.

Finally, there exists an interesting parallel between common agency and bidding (Bernheim and Whinston 1986, Bergemann and Valimaki 1998). Suppose the regulator places zero electoral weight on each interest group. In this case, each harvester earns zero net utility in equilibrium, since failure by harvester *i* to pay results in *i* receiving zero harvest quota. By (15), each harvester pays the regulator for the cost harvester *i* imposes on the other $N-1$ harvesters for the reduction in their harvest quota, and the cost imposed on conservationists and harvesters of the increase in the total harvest. In contrast, conservationist *c* receives positive utility in equilibrium, since he only has to pay for the net reduction in the harvest quota from s^{-c} to s^*. From (16), the equilibrium contribution is the sum of the costs imposed on each harvester for the reduction in their harvest quota less the value of the increase in the stock due to the overall reduction in the harvest quota. If both harvesters and conservationists face zero transactions costs ($\kappa_j = 1$ for all $j \in \Gamma$), then the allocation maximizes social welfare in the standard sense. However, if as is more likely the conservationists face positive transactions costs, then the allocation will be skewed towards harvesters. Since harvesters earn zero net rents under an auction, one would not expect to see auctions very often. Indeed, the most common form of auctions occurs with resources not currently available, such as the newly exploited parts of the radio spectrum and new oil and gas leases.

IV. Discussion and Conclusions.

This paper has examined a dynamic common agency model in which harvester and conservation groups compete over the exploitation of a natural resource, where the rate of that exploitation is regulated by a public agency. The equilibrium concept employed is that of a truthful Markov perfect equilibrium (Bernheim and Whinston 1986, Grossman and Helpman 1994, Bergemann and Valimaki 1998). Simple logarithmic utility functions are assumed for both the harvesters and conservationists, and the regulator's utility is assumed to be additively linear in the utility and contributions of the interest groups. These assumptions give sufficient concavity to make the results relatively general, and they ensure that the results are tractable and transparent.

The following results are obtained:

1. The share of the stock harvested in each period is increasing in the relative aggregate political strength of harvesters and decreasing in the relative aggregate political strength of conservationists.
2. For regulation to be supported by harvesters, it is necessary that the no-regulation status quo involve common-property rent dissipation among the harvesters and that the effective political weight for harvesters under regulation be sufficiently high.
3. Since the gross change in conservationists' welfare is always non-negative and the regulator generally does not fully capture the rents earned by them, conservationists support regulation.
4. As the transactions costs associated with rent-seeking approach zero or become arbitrarily large, the equilibrium contributions vanish, and regulation is more likely to be socially beneficial and to be supported by each group.
5. Regulation is socially beneficial if the weight given to harvesters is sufficiently large relative to that given to conservationists. This occurs because harvesters, like conservationists, value the stock, but conservationists, unlike harvesters, place no value on the harvest.

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Endnotes

[i] Other renewable resource examples include the Migratory Waterfowl Treaty, signed by Canada, the United States and Mexico in 1916 to allocates harvests of waterfowl across the three countries; the Colorado River Compact, signed by Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming in 1921 to allocate water rights among the western states; the International Pacific Halibut Commission, formed in 1923 by the United States and Canada to allocate halibut harvests both across countries and fishery harvest gear types; the International Whaling Commission, formed in 1946 by forty whaling nations to allocate harvest quotas (it now has banned all harvests); the Convention on International Trade in Endangered Species, formed in 1973 and now signed by 150 countries to prohibit or control trade in many endangered species; and the Common Fishery Policy, enacted by the European Union in 1980 to allocate commercial harvests of fish. Examples dealing with exhaustible resources include unitized oilfields, where the regulator allocates extraction shares in commonly owned oil pools, and the Organization of the Petroleum Exporting Countries, which allocates production quotas across its members. In addition, many major environmental treaties such as the Montreal Protocol on ozone depleting substances and the Kyoto Agreement on greenhouse gases (if ratified) grant regulators with the power of determining the total quota and allocating that quota across various users. In almost all of these examples, quota regulations are used in lieu of price regulations.

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ii The 1995 House amendment to the Magnuson Act explicitly allowed for voting members "selected for their fisheries expertise as demonstrated by their academic training, marine conservation advocacy, consumer advocacy, or other affiliation with nonuser groups." However, the Senate version, which became law, only required that voting members "must be individuals who, by reason of their occupational or other expertise, scientific expertise, or training are knowledgeable regarding the conservation and management, or the commercial or recreational harvest, of the fishery resources" (Section 302(b) 16 U. S. C. 1852).

iii The assumption that the regulator can use the contributions to influence uniformed groups is a key, but controversial, assumption in the common agency literature. See Coate and Morris (1995) for a criticism of the view that uninformed voters can be influenced by politicians. Ironically, even with the assumption that politicians are able to deceive uninformed voters, it is possible to obtain results that appear remarkably efficient (Dixit, Grossman and Helpman (1997).

iv Constitutional restrictions include boilerplate statements about conservation being the primary goal (included in most agreements), explicit statements about which members have which particular voting rights (e.g., the United Nations), and, in some instances, specific allocations of the resource (e.g., the Colorado River Compact). In addition, there is often (although not always) some sort of super-majority requirement for the adoption the regulation.

v Other applications of the common agency model include regulation of multinational firms (Bond and Gresik 1996), government tax policy (Dixit, Grossman and Helpman 1997), lobbying by capital and labor over labor policies (Rama and Tabellini 1998), supply of public goods (Persson 1998), the internalization of environmental externalities (Aidt 1998), and common property resource games (Boyce 1999).

vi Freeman (1992) reviews the literature on non-consumptive use values.

vii Both models consider tax policy rather than quota policy. However, regulators of natural resources tend to use quota regulations more than price regulations, so the present paper focuses on these.

viii Boyce (1999) considers a similar question. However, he was only able to solve for the steady-state equilibria, so his comparisons ignore the costs along the transition. Here, I derive analytical solutions for an arbitrary initial stock. The analysis here also focuses on the properties of the constitution one might expect in treaties, laws, and agreements, given the conditions necessary for each principal to agree to adopt regulation. See Eggertsson (1990) for review of the transactions cost literature on these issues.

ix Both Dixit, Grossman and Helpman (1997) and Bergemann and Valimaki (1998) are interested in the efficiency of regulation, but only in so far as regulation exists. Dixit, Grossman and Helpman examine the efficiency of regulation when the marginal utility of income is not constant. Bergemann and Valimaki show that when an additional principal is added to a coalition, the net return to the coalition of adding that principal equals the marginal contribution of the principal to the coalition. The present paper follows Persson (1998) in focusing on the idea that some groups are less adept than others are at influencing policy. However, the model departs from the literature in its evaluation of regulation from the perspective of no regulation, rather than from the perspective of alternative instruments of regulation.

x So long as there are no price effects—as is assumed—this will maximize the joint welfare of harvesters.

xi For simplicity, the time subscripts are written only for the aggregate variables, x_t, y_t, and z_t.

xii It is possible to make this model more general by allowing harvesters utility to be of the form $u_i = \nu_i \log(h_i) + \eta_i \log(x_t - y_t)$. In this case, the equilibrium involving only harvesters will maintain a larger stock than when the utility of harvesters involves only the $\nu_i \log(h_i)$ term (e.g., Clark and Munro 1975), assuming second order conditions hold. However, the additional insights appear to be few relative to the notational costs.

xiii However, I do not explicitly model the process by which the regulator is selected. See Persson (1998).

xiv This rules out punishment strategies such as the "trigger strategies" used by Cave (1987) and Hannesson (1996).

xv This assumption does not affect the steady-state equilibrium. For example, I show below that the equilibrium is equivalent, in effect, to the regulator choosing harvest quotas to maximize weighted joint welfare of the principals. If one simply assumes Markov behavior and begins with Bellman's difference equation,

$$W(x_t) = \omega_H \log(h_t) + \omega_C \log(x_t - h_t) + \beta W[(x_t - h_t)^{\alpha}],$$

(only one harvester is assumed for the sake of simplicity), then the principle of optimality implies

$\omega_H/h_t - \omega_C/(x_t - h_t) = \alpha\beta(x_t - h_t)^{\alpha-1}W_X(x_{t+1})$.

Differentiating the difference equation with respect to x_t using the Envelope Theorem yields

$W_X(x_t) = \omega_C/(x_t - h_t) + \alpha\beta(x_t - h_t)^{\alpha-1}W_X(x_{t+1})$.

These, together with (1) may be combined to show that the steady-state stock and the harvest quota shares are identical to those derived below, using the assumption in the text.

[xvi] The behavior of this system away from the steady-state will be different from that using Levhari and Mirman's assumption, but the steady-state is not affected.

[xvii] This assumes that the pumping costs are unrelated to the stock size. In a more general model (see note 9, *supra*), where the utility of harvesters also depends upon the stock remaining, this would not be true.

[xviii] Boyce (1999) finds that under the assumption that all of the stock is consumed in period T+1, the share of the stock harvested does change as one moves away from T. However, it is possible to show that even in this case, the contributions are constant in each period, and that the steady-state share of the stock harvested equals that in the text.

[xix] See note 15, *supra*.

[xx] With N harvesters, the harvest quota shares that maximize the joint utility of the harvesters satisfies

$$\frac{\nu_i}{h_i^\#} - \frac{\alpha\beta\Sigma_{j\in\Gamma_H}\nu_i}{(x_T - y_T^\#)(1-\alpha\beta)} = 0, \qquad i\in\Gamma_H.$$

Thus, the optimal harvest quota shares are $s_i^\# = (1 - \alpha\beta)\nu_i/(\Sigma_{j\in\Gamma_H}\nu_j)$, implying that the aggregate harvest quota share is $s^\# = 1 - \alpha\beta$.

[xxi] See note 2, *supra*.

[xxii] This is similar to the argument by Libecap and Wiggins (1985) regarding oil field unitization, that says smaller firms will hold out for larger relative shares since regulation benefits them less than larger firms. Here, this result occurs because harvesters are unwilling to agree to regulation that does not give them sufficient weight. Thus, both models are based in part on the implied bargaining strength of the participants, although, here, it also turns out that harvesters must get large relative share for regulation to be welfare-improving.

[xxiii] The limit of the first term in the contributions as $\kappa_c\rightarrow 0$ is $-\omega_H/(\omega_H + \omega_{C/c} + \gamma_c\nu_c)$, and the limit of the second term is $\omega_H/(\omega_H + \omega_{C/c} + \gamma_c\nu_c)$, so the limit as $\kappa_c\rightarrow 0$ of $b_c^{\mathrm{T}}(\boldsymbol{s}^*)/[(1-\beta)\kappa_c] = 0$.

[xxiv] Conservation groups often complain that regulator's are skewed towards the interests of harvesters. The Audubon Society complained that the regulatory panel for the Atlantic States Marine Fisheries Commission "is composed of 19 individuals. Of these, 15 are associated with the fishing industry" (quoted in *Horseshoe Crab Plan*, November 1998, National Audubon Society, Washington, D. C.).

[xxv] Aidt (1998) makes a similar point regarding the internalization of externalities.

[xxvi] This will also occur in model where harvesters care about the stock (see note 9, supra), since the adoption of regulation will increase the stock.

[xxvii] See Johnson and Libecap (1982), Libecap and Wiggins (1985), and Karpoff (1987) for discussions of the effect of heterogeneity on common property resource regulations.