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# Crop Sharing in the Fishery and Industry Equilibrium

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**Abstract** *This article presents a model of commercial fishing in a stochastic environment that focuses on the labor-employment contract. In a partial equilibrium context, the authors show that when boat owners and crew members are risk-averse, crop sharing is the optimal contract, and the resultant labor employment level will be greater than with a (suboptimal) wage contract. Industry effects and steady-state resource growth limitations are introduced into a market equilibrium model. In this extended model, market equilibria will also involve sharing contracts. These will result in greater employment, which comes at the expense of reduced resource stocks and higher-than-necessary harvesting costs. The article also examines how industry regulation such as licensing, quotas, and subsidies will differ if the prevailing contract is cropsharing as compared with a wage. Despite the fact that cropsharing contracts are privately optimal in a regulated setting, they may not be socially optimal.*

**Keywords** Wage contracts, crop-sharing contracts, equilibrium, fisheries.

## Introduction

In economics literature, increasing attention is being paid to the structure, efficiency, and implementation of contracts whereby agents agree to share the costs and benefits of an activity. Although most analyses focus on contracts arising in the industrial organization, labor, and agriculture literatures, such agreements are also very important for natural resource markets. In most instances, formal sharing contracts define the responsibilities and payoffs of parties to the contracts. The terms of these contracts as well as their ultimate efficiency and stability properties usually depend on the relative bargaining strengths of the agents (which may be related to resource ownership), the existence of pure market alternatives and the extent to which the agents have (possibly different) information about each other and the often uncertain economic environment.

In this article we consider the structure, efficiency, and stability of wage and crop-sharing contracts that arise between boat owners and crew members in fisheries. Typically, these crop sharing contracts are defined by two parameters: an internal wage rate for crew, which may differ from the market wage, and a sharing rate for distributing realized revenue. These parameters vary from fishery to fishery, and the extreme cases of pure sharing and pure wage contracts, although less frequent, are sometimes observed.[1] In part, our work draws on the initial studies of Sutinen (1975, 1979, 1983), in which, for a stochastic environment, it was argued that crop-sharing contracts always dominate wage contracts. The long-held *deterministic* counterpart of this result is that resource allocation is independent of the form of contract (see Cheung 1970; Anderson 1982). In fact, Anderson (1982, 448) concluded that "the existence of a share system will have no effect on the economically efficient level of output," and "if the share rate is market determined, optimal regulation policy drawn from the traditional model is appropriate." Sutinen's work has important implications for the design and implementation of fisheries management policies given that the traditional approach to policy has been to assume that pure wage contracts hold in the fishery. This policy approach has been guided by the assumption of wage contracts present in most theoretical research in replenishable resource economics.

One feature of Sutinen's work is that it considers only the private optimum of boat owners and crew. Neither the output market equilibrium nor the biological (steady-state) equilibrium of the resource is considered. As well, distortions arising from regulatory policy are not considered. When these features are introduced into the analysis, several important results emerge. In the case where there is no regulation, the equilibrium return to firms is independent of the choice of contract. By way of contrast, in regulated markets, there are realistic situations in which wage contracts may be dominant to the extent that they lead to higher returns to firms in the fishery. In both the regulated and unregulated cases, however, we show that decentralized contracting on the part of agents may lead to only sharing contracts being implemented. In a situation where n-1 firms offer wage contracts, it is always optimal (as Sutinen's approach suggested) in an unregulated environment for the $n^{th}$ firm to offer a sharing contract, implying that wage contracts do not lead to a Nash equilibrium. Important implications for output, employment, and the role of regulation in the fishery arise when the crop-sharing Nash equilibrium in a regulated setting is not optimal.[2]

This article has the following structure. Throughout the study we work with a mean-variance model.[3] In the next section we introduce the model and point out Sutinen's results, which serve as benchmarks for what follows. An interesting result concerning the separability of contract selection and factor employment decisions is demonstrated. In the following section we consider the contracting problem in a full stochastic bioeconomic industry equilibrium setting. The last two sections consider issues related to contracting in a regulated environment and offer brief conclusions.

Before turning to the analysis contained in this study, it is useful to contrast briefly the share-contracting fisheries literature with the other contracting literature noted above. Although fisheries contract models exhibit some similarities to those arising in the principal/agent, implicit contract and agricultural crop-sharing literature, significant differences exist that make these models inappropriate for analyzing equilibrium contract formation in fisheries. One immediate difference is the need to introduce the notion of biological equilibrium into fisheries models. The results that we present depend on the characteristics of the biological equilibrium that arises. Other differences among the literature arise from standard assumptions about the relationships between contracting agents and the observability of economic variables in fisheries models. It is useful to examine them briefly.

Beginning with contrasts to the standard principal/agent models, in the fishery it is typically assumed that the information sets of all agents are identical and that behavior is perfectly observable (cf. Holmström 1979; Hart 1983). A point of similarity, however, is that in the fishery the decisions of one agent (the boat owner) are constrained by guarantees to other agents (the crew). In contrast to assumptions in the implicit contract literature, in the fishery it is standard to assume that all parties to the contract are risk-averse. In both kinds of literature, however, it is assumed that the agent offering the contract (the boat owner) has complete information about the preferences of the workers (see Grossman and Hart 1981).

Turning finally to the case of agricultural crop sharing (see, for example, Cheung 1969; Stiglitz 1974; Reid 1976), it is helpful to begin by briefly stating some of the important results that have arisen in that literature. First, in a riskless environment with complete markets (perfect information) and without transaction costs, it is generally accepted that agents in an agricultural setting should be indifferent between pure wage and pure sharing contracts. Similar deterministic results are known to hold for some fisheries models (see, for example, Cheung 1978; Anderson 1982; Ferris and Plourde 1982).

In a stochastic environment with complete markets and perfect information but with no transactions costs, Reid (1976) has argued that risk is not a fundamental determinant of sharecropping: "One could argue that share cropping is observed because the tenancy choice has no effect on the distribution of risk among factor owners, not because it shares risk" (p. 565). However, risk sharing also motivates contract formation in the fishery under uncertainty. Unlike in the agricultural model of Reid, fisheries contracts involve an *internal* wage rate that may differ (be less than) from the (exogenous) market determined wage rate relevant for the alternate employment of crew members. As well, there are important differences in production processes between agricultural and fisheries models. For example, in typical agricultural models land can be subdivided according to tenancy, and the productivity of labor in a given subdivision is independent of the quantity and quality of labor in any other subdivision. In a fishery, however, a boat cannot be similarly subdivided. As well, geographic considerations of the harvesting process make it less likely that a given worker will be a crew member on two different boats. In summary, the intuition and results arising in agricultural crop-sharing models are not directly applicable to fisheries models.

## The Model

Our basic model of agent behavior incorporates several features presented in Sutinen (1979). We consider two contracting parties: the boat owner (with relevant variables identified by subscript $B$), and the crew member (identified by subscript $C$). Incomes ($I_B$, $I_C$) under a sharing agreement are given by

$$I_B = r\mu p(nf)f(L, x) - \theta L \tag{1}$$

$$I_C = (1 - r)\mu p(nf)f(L, x) + \theta L + w(T - L) \tag{2}$$

In the above equations, $r$ and $\theta$ are the contract variables where $r \in (0,1]$ is the share of gross realized revenue of the boat owner and $\theta$ is an internal wage rate. When $0 < r < 1$, a sharing contract arises. Alternatively, if $r = 1$, there is a wage contract. We do not consider the case $r = 0$, where the roles of the boat owner and crew member are reversed. Market price depends on industry output ($nf$), where $n$ is the number of boats and $f(L, x)$ is the harvesting function dependent on the labor input of the crew member ($L$) and the aggregate resource stock ($x$). The crew member is assumed to work $L$ hours at fishing and $T - L$ ($\geq 0$) hours at an alternative employment. The alternative employment pays a wage rate $w$. Uncertainty enters through the multiplicative random term $\mu$ where $E[\mu] = 1$ and $\mathrm{Var}[\mu] = \sigma_{\mu}^{2}$. In the model, then, either demand or production or both can be considered random.

In contrast to Sutinen's approach, we assume that boats are identical and of fixed size and thus we do not consider optimal capital choices. This leads to no important loss in generality for our purposes. Furthermore, we consider only two contracting parties and thereby eliminate choice of the optimal number of crew members. Again, this is not an important restriction on the model. The parameter $\theta$ plays an important role in these contracts. The sign of $\theta$ is in general ambiguous except in the case where $r = 1$ and $\theta = w$ because a wage contract arises. In some actual fishing situations, fuel and other similar expenses are deducted from revenue before the shares are computed, and this could lead to a negative value for $\theta$. As well, sometimes owners guarantee a minimum wage (see Zoeteweij 1956).

The preferences of the boat owner and crew member ($U_B$, $U_C$) are given by the mean-variance utility functions:

$$U_B = \mathrm{E}[I_B] - \alpha_B \,\mathrm{Var}[I_B] \tag{3}$$

$$U_C = \mathrm{E}[I_C] - \alpha_C \,\mathrm{Var}[I_C] \tag{4}$$

where ($\alpha_B$, $\alpha_C$) are parameters describing the respective distastes for income variability. It is useful to note that Sutinen's general results regarding the optimality of sharing contracts are independent of types and degrees of risk aversion. The preferences specified in Eqs. (3) and (4), although therefore consistent with Sutinen's general framework, provide an analytically more tractable way of introducing risk aversion into our analysis.

Following Sutinen, we assume that the boat owner guarantees a fixed level of utility to the worker. This assumption implies that the boat owner has an advantage over the crew member. Given the high unemployment rate in many fishing regions, this does not seem unreasonable. Because the riskless income level $wT$ (guaranteed in part, perhaps, by unemployment insurance and other social assistance programs) is always available to the worker, we assume that the boat owner with a full knowledge of Eq. (4) guarantees the utility level $\bar{U}_C = wT$. The problem of the boat owner is thus to choose levels of the internal wage rate ($\theta$), contract parameter ($r$), and labor ($L$) so as to maximize his own welfare subject to that of the crew member.

Formally, the problem faced by the boat owner is written:

$$\max_{\{r,\, \theta,\, L\}} U_B = \mathrm{E}[I_B] - \alpha_{\mathrm{B}} \,\mathrm{Var}[I_R] \qquad \text{s.t.} \quad U_C = wT \tag{5}$$

Denoting a solution to Eq. (5) by [$r^*$, $\theta^*$, $L^*$], we first consider possible solutions for the contract variable $r$. In particular, if $r^* = 1$, then the only way to meet the crew constraint is for $\theta^* = w$. This is the pure wage contract case. If $0 < r^* < 1$ then the risk is shared by the boat owner and crew members.

In order to examine solutions to Eq. (5) where ($0 < r \leq 1$) and ($0 \leq L \leq T$), the crew member's utility constraint is substituted into the objective function. Using Eqs. (2) and (4), the crew member's constraint ($U_C = wT$) can be expressed:

$$(1 - r)pf = (w - \theta)L + p^2 f^2 \alpha_C \sigma_{\mu}^2 (1 - r)^2 \tag{6}$$

Equation (6) has the straightforward interpretation that the expected value of the crew member's share (the left-hand side of Eq. (6)) must be sufficient to compensate him for any wage differential (market versus internal) on hours worked fishing $(w - \theta)L$ plus the risk associated with his share of the uncertain output.

Solving Eq. (6) for $\theta$ and substituting into Eq. (5), the optimization problem takes the form:

$$\max_{\{r,\, L\}} \; \tilde{U}_B = pf(L, x) - wL - \sigma_\mu^2 p^2 f^2(L, x)[\alpha_B r^2 + \alpha_C(1 - r)^2] \tag{7}$$

Several points about Eq. (7) are noteworthy. First, the dependence of price on market output is not stressed because firms are assumed to be price takers. (An industry analysis is presented below.) Second, if $r = 1$ (and, hence, $\theta = w$), then (as discussed earlier) the problem in Eq. (7) is seen to be identical to that of a competitive boat owner maximizing expected utility by hiring labor, which is assumed to be in perfectly elastic supply at the wage $w$. Third, no consideration is given to the effects of resource dynamics.

An interesting feature of the optimization problem in Eq. (7) is that $r$ can be chosen independently of $L$. Because of the structure of the objective function, the value of $r$ ($r^*$) that maximizes Eq. (7) will be given as a solution to the problem:

$$D = \min_{\{r\}} \; \alpha_B r^2 + \alpha_C(1 - r)^2 \tag{8}$$

where $D$ is derived by essentially minimizing the term in square brackets in Eq. (7). Equating the derivative in Eq. (8) to zero, the unique solution ($r^*$) for the share of the boat owner is given by:

$$r^* = \frac{\alpha_C}{\alpha_B + \alpha_C} \tag{9}$$

It is useful to note that $r^*$ is always between 0 and 1 that in the optimal value of the problem in Eq. (8), $D^*$ is equal to $\alpha_B(r^*)^2 + \alpha_C(1 - r^*)^2$, which further simplifies to $\alpha_B r^*$. Note that $D^*$ is always less than min $[\alpha_B, \alpha_C]$. Thus, whenever production is feasible, a share contract is optimal, because the boat owner's utility is always greater with a sharing contract for any labor choice. Finally, the optimal share parameter $r^*$ will be independent of market variables such as wage, price, and employment.[4]

When Eq. (9) is introduced into Eq. (7), the boat owner's optimizing problem reduces to

$$\max_{L} \quad V = pf(L, x) - wL - kp^2 f^2(L, x) \tag{10}$$

where we introduce the parameter $k = \sigma_\mu^2 D^* = \sigma_\mu^2 \alpha_B r^*$. Indeed, as Eq. (10) suggests, the only effective difference between the crop-sharing and wage contract employment problems is the size of the parameter $k$. In particular, because $k$ is an increasing function of $r^*$ and takes on a value of $\sigma_\mu^2 \alpha_B$ in the limiting case $r^* = 1$, $k$ will always be larger under a wage contract. Note that the wage contract case corresponds to a limiting situation in which the crew is infinitely risk-averse.

The condition for an interior solution to Eq. (10) is

$$V_L = pf_L - w - 2kp^2 f f_L = 0 \tag{11}$$

The second order condition is $V_{LL} < 0$. Using Eq. (11) and the second order condition, it is straightforward to show by implicit differentiation that

$$\frac{\partial L^*}{\partial k} = \frac{2p^2 f f_L}{V_{LL}} < 0 \tag{12}$$

Because (as noted above) $k$ is an increasing function of $r^*$, the optimal employment[5] and output levels *for a firm* facing a given stock size will be greater under a sharing as opposed to a wage contract. This result has been demonstrated by Sutinen.

## Crop Sharing and Industry Equilibrium

### *An Extended Model*

In this section we extend the model of the previous section to incorporate simultaneous resource and industry (bioeconomic) equilibrium. In contrast to the conclusion of the last section, it is shown that crop-sharing contracts do not strictly dominate wage contracts in terms of the boat owner's payoff. Nonetheless, they will always be chosen. As well, the comparative statics results, which now incorporate industry and resource effects, may differ.

We begin by examining the properties of the following system of three equations that describe a steady-state industry equilibrium:

$$p(nf)f_L - w - 2kp^2(nf)ff_L = 0 \tag{13}$$

$$p(nf)f - wL - kp^2(nf)f^2 - \bar{U} = 0 \tag{14}$$

$$g(x) - nf = 0 \tag{15}$$

The variables to be determined are $x$, $L$, and $n$, because $r^*$ in our specification is defined solely by preference parameters as given in Eq. (9). Equation (13) provides the condition for an interior optimum for a representative boat owner where (as noted above) the magnitude of the parameter $k$ distinguishes crop sharing from wage contracts. Equation (13) differs from Eq. (11) to the extent that the dependence of market price on industry output is emphasized by replacing $p$ (the parametric price faced by the firm) by the demand function $p(nf)$, where $n$ is the number of (assumed identical) firms in the industry and $f$ is the production function. Equation (14) expresses the requirement that, in equilibrium, the representative firm owner will obtain the normal utility level $\bar{U}$. This might be interpreted as each boat owner receiving a normal return on his risky investment in the boat. Finally, Eq. (15) presents the condition that industry output be consistent with a resource steady state. The function $g(x)$ gives the amount of resource growth consistent with stock of size $x$. Typically (see Clark 1976), $g(x)$ is assumed to be strictly concave and differentiable over the interval $[0, \bar{x}]$ with $g(o) = g(\bar{x}) = 0$ and $g(s) > 0$ for $s \in (0, \bar{x})$. As such, $x_{\text{msy}} = \arg\max g(s)$ is the maximum sustainable yield stock size and $g(x_{\text{msy}})$ is the maximum sustainable yield. Equation (15) requires that a resource steady-state exist with resource growth just equal to industry extraction. From the assumed properties of $g(x)$ it follows that whenever industry output is less than maximum sustainable yield, there will be two values of $x$ that satisfy Eq. (15). The term *bioeconomic equilibrium* corresponds to values of the variables $[L^*, n^*, x^*]$ satisfying the system of Eqs. (13), (14), and (15) and the second order condition:

$$p(nf)f_{LL} - 2kp^2(nf)[f_L^2 p + f f_{LL}] < 0 \tag{16}$$

### *Properties of Bioeconomic Equilibrium*

An important observation concerning Eqs. (13)-(16) is that firms will, in principle, be indifferent between wage and crop-sharing contracts. This result is suggested by Eq. (14), which requires the output, price, stock, and the number of firms have adjusted so that each firm achieves the same level of utility $\bar{U}$. In practice, however, only sharing contracts will be observed. To see this, assume to the contrary that Eqs. (13)-(15) hold with all firms adopting a wage contract with $k_w = \lim_{r^* \to 1} k = \sigma_\mu^2 \alpha_B$. However, any firm is free to adopt a sharing contract with $k_s = \sigma_\mu^2 \alpha_B r^* < k_w$. Clearly, there is an incentive for a firm to do this because, for this firm, the left-hand side of Eq. (13) is now positive, indicating that there are private gains to be made by increasing employment and hence output. Of course, all firms will adopt this strategy, and $L$, $n$, and $x$ will adjust until marginal benefits are zero at a sharing equilibrium. Another way of stating this result is that a pure wage contract equilibrium is *not* a stable Nash equilibrium.

In order to examine further the properties of the bioeconomic contract equilibrium, it is helpful to reparameterize the model using familiar cost functions and duality results and to introduce new aggregate functions $G$, $H$, and $V$ below. An equivalent representation of Eqs. (12)-(15) is:

$$p - \partial c/\partial q - 2kp^2 q = \frac{\partial H}{\partial q} \equiv V(q, p, x) = 0 \tag{17}$$

$$pq - c(q, x) - kp^2q^2 - \bar{U} \equiv H(q, p, x) = 0 \tag{18}$$

$$g(x) - z(p) \equiv G(q, p, x) = 0 \tag{19}$$

$$\partial V/\partial q = \partial^2 H/\partial q^2 < 0 \tag{20}$$

In this system a bioeconomic equilibrium is given by the three variables $[q^*, p^*, x^*]$ satisfying Eqs. (17)-(19) and the second order condition, Eq. (20). The demand and production functions $p(nf)$, $f(L, x)$ in Eqs. (13)-(16) have been replaced by the parameters $p$ and $q$ respectively. Total factor costs for each output level are given by the cost function $c(q, x)$, which comes from solving the problem: $\min_L wL$ subject to $f(L, x) = q$. Note that marginal cost $(\partial c/\partial q)$ is equal to $w/f_L$. Finally, in Eq. (19) industry output $(nf)$ is defined by inverting the demand function to obtain $nf = p^{-1}(p) \equiv z(p)$ where $z'(p) < 0$ whenever the demand curve is negatively sloped.

For the comparative static analysis that follows, we assume that the equilibrium of Eqs. (17)–(20) is locally stable. The adjustment dynamics are given by:

$$\dot{q} = V(q, p, x) \tag{21}$$

$$\dot{p} = -H(q, p, x) \tag{22}$$

$$\dot{x} = G(q, p, x) \tag{23}$$

The system of total differential Eqs. (21)–(23) has a straightforward interpretation. The equations describe the respective adjustments in ($q$, $p$, and $x$) if the equilibrium is disturbed. Equation (21) is the behavioral assumption that whenever it is profitable to do so, firms will raise (or reduce) output. Equation (22) states that industry price will fall (or rise) whenever existing firms make greater (or less) than the normal return. This is just the standard entry condition for competitive markets.[6] Finally, Eq. (23) is a biological requirement that the stock size $x$ will increase (decrease) whenever net growth is positive (negative).

By the Routh-Hurwitz theorem,[7] the conditions for local stability can be expressed in terms of the Jacobian ($|J|$) of Eqs. (21)–(23) defined as

$$J = \det \begin{bmatrix} \dfrac{\partial V}{\partial q} & \dfrac{\partial V}{\partial p} & \dfrac{\partial V}{\partial x} \\ -\dfrac{\partial H}{\partial q} & -\dfrac{\partial H}{\partial p} & -\dfrac{\partial H}{\partial x} \\ \dfrac{\partial G}{\partial q} & \dfrac{\partial G}{\partial p} & \dfrac{\partial G}{\partial x} \end{bmatrix} = \det \begin{bmatrix} \dfrac{\partial V}{\partial q} & 1 - 4kpq & -c_{qx} \\ 0 & -q + 2kpq^2 & c_x \\ 0 & -z' & g' \end{bmatrix} \tag{24}$$

In Eq. (24), $\partial V/\partial q$ is less than zero by virtue of the second order condition given in Eq. (20) and $-\partial H/\partial q = 0$ by the first order condition. As well, $c_{q/x}$ and $c_x$ are both negative because at an equilibrium (by assumption), it cannot be more costly to harvest (in a marginal or total sense) the more abundant is the stock. The slope of the resource growth curve at an equilibrium ($g'$) can, in principle, be positive, negative, or zero. If $g' > 0$, then the prevailing equilibrium is inefficient in that total costs could be lower (less $L$ employed) and the same output produced at a stock size greater than the maximum sustainable yield. It is nonetheless stable for small $k$.[8] If $g' < 0$ and $k$ is sufficiently small, then if $\partial V/\partial q < 0$ is satisfied, all of the Routh-Hurwitz conditions will hold, including the restriction that the Jacobian is negative ($|J| < 0$). Recall that $k$ is an increasing function of the variance $\sigma_\mu^2$ (for fixed $r$), and thus the smaller is the variability in $\mu$, the more likely the industry will be (locally) stable.

Differentiating Eqs. (17)–(19) with respect to $k$, we obtain:

$$J \begin{bmatrix} \dfrac{\partial q}{\partial k} \\ \dfrac{\partial p}{\partial k} \\ \dfrac{\partial x}{\partial k} \end{bmatrix} = \begin{bmatrix} 2p^2 q \\ -p^2 q^2 \\ 0 \end{bmatrix} \tag{25}$$

Repeated application of Cramer's Rule yields:

$$\frac{\partial q}{\partial k} = p^2 q^2 \left( z' \left\{ \frac{c_x}{q} - c_{qx} \right\} - g' \right) \Big/ |J| \tag{26}$$

$$\frac{\partial p}{\partial k} = -\left( \frac{\partial V^*}{\partial q} \right) (p^2 q^2) g' \Big/ |J| \tag{27}$$

$$\frac{\partial x}{\partial k} = -\left( \frac{\partial V^*}{\partial q} \right) (p^2 q^2) z' \Big/ |J| \tag{28}$$

From Eq. (28) it is unambiguously the case that equilibrium stock size will be greater the greater is $k$. Thus, a crop-sharing equilibrium will be associated with a smaller stock size than a wage contract equilibrium, were it to arise. Moreover, because $k$ increases ceteris paribus as the variance $\sigma_\mu^2$ increases, stock size will be larger the greater the variability in the random parameter (demand and/or harvesting) under either a wage or a crop-sharing contract.

The dependence of firm output and market price on contract structure (or variability in demand/harvesting) is ambiguous. At the market equilibrium in which $q' < 0$, from Eq. (27) it follows that market price will increase with increasing uncertainty. As Eq. (26) indicates, there is more ambiguity regarding the effect of increasing $k$ on firm output. Because the stock increases, it lowers average costs ($c_x/q$) and marginal costs $c_{qx}$, and the combined effect depends on the elasticity of the cost function with respect to $x$, the stock. The effect on the number of firms in the industry is also ambiguous. However, aggregate output will decline (because market price increases). Finally, individual firms will hire less labor as uncertainty increases.

### *A Comment on Subsidies*

Subsidies are common in the fishing industry. One form of subsidization is for governments to provide forgivable loans and subsidized borrowing rates for boat construction. The effect of these subsidies can be studied in the context of the model of this section by examining the dependence of the equilibrium ($q^*$, $p^*$, $x^*$) on the normal return parameter $\bar{U}$. In particular, the greater is the subsidy, the smaller is the required return $\bar{U}$.

Differentiating Eqs. (17)–(19) with respect to $\bar{U}$, we obtain:

$$J \begin{bmatrix} \frac{\partial q}{\partial \bar{U}} \\ \frac{\partial p}{\partial \bar{U}} \\ \frac{\partial x}{\partial \bar{U}} \end{bmatrix} = \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \tag{29}$$

Cramer's Rule yields:

$$\frac{\partial q}{\partial \bar{U}} = [(1 - 4kpq)g' - z'c_{qx}]/\,|J| \tag{30}$$

$$\frac{\partial p}{\partial \bar{U}} = -\left(\frac{\partial V^*}{\partial q}\right) g'/\,|J| \tag{31}$$

$$\frac{\partial x}{\partial \bar{U}} = -\left(\frac{\partial V^*}{\partial q}\right) z'/\,|J| \tag{32}$$

From Eq. (32), an increase in $\bar{U}$ unambiguously increases the stock size and therefore industry subsidies, which implies that a reduction in $\bar{U}$ tends to reduce the equilibrium stock size. This result is consistent with the argument that industry subsidies to boat owners cause overfishing. Similarly, output price increases with increasing $\bar{U}$ whenever there is no biological inefficiency. Price thus decreases with increasing subsidies.[9] Finally, the effect of subsidies on firm output is difficult to determine. Some insight is gained by noting that $1\text{-}4kpq > 0$ is just the condition that the supply curve of a representative firm is upward sloping. Thus, whenever there is no biological inefficiency ($q' < 0$), output per firm increases with increasing $\bar{U}$ and thus decreases with increasing subsidies, although industry output expands through increased entry.

Subsidies to labor also arise in fishing industries. In parts of Canada, for example, individuals who work as crew members in fishing are entitled to more (longer duration) unemployment benefits. Suppose that these extra benefits have a monetary value of $\delta$. Then, in terms of our model, the boat owner no longer has to guarantee a utility level of $wT\,(= \bar{U}_c)$ to crew members. Rather, the boat owner guarantees $wT - \delta$ and the government makes up the difference. Note, then, that the boat owner effectively appropriates some or all of these benefits. In terms of our model, it is straightforward to show that the zero profit constraint Eq. (17) now becomes

$$pq - c(q, x) - kp^2q^2 = \bar{U} - \delta \tag{18'}$$

Thus, because of the contract power of the boat owner, he is able to appropriate effectively the supplementary benefits of the workers. This is then operationally equivalent to a policy whereby the boat owner is subsidized. As such, the foregoing analysis regarding boat owner subsidies is also appropriate for labor subsidies.

In summary, the results suggest that extending the analysis of crop sharing to the case of full bioeconomic industry equilibrium leads to several new insights into the structure and stability of fisheries sharing contracts and market equilibrium. In particular, the choice of contract is not a matter of indifference to the contracting parties. Higher employment sharing contracts will always be adopted despite the fact that, ultimately, they do not improve profitability. The employment increases come, however, at the expense of a reduced resource population and resulting higher average costs of harvesting that accompany lower resource stock levels.[10]

## Contracts Within Regulated Industries

Most fisheries are subject to regulation, often in the form of quotas and/or licenses provided to a fixed number of firms. Regulation, in general, leads to economic rents for firms remaining in the industry. In this section we show that the benefits associated with these rents depend on the choice of contract and that the contract scheme that generates the greater utility for boat owners may be either a share contract or a wage contract. Like the results discussed previously, however, even if the wage contract dominates, it may not be adopted. Factors that influence which contract is preferred by boat owners include the elasticity of market demand, the sensitivity of extraction costs to the size of the available resource stock, and properties of the resource growth dynamics.

### *Licenses*

With this type of regulation, a fixed number of boats ($n$) is allowed to remain in the industry. These boats are unrestricted with respect to output decisions. The utility of a representative boat owner is given by:

$$V = p(nq)q - c(q, x) - p^2(nq)q^2\sigma_u^2\alpha_B r^* \tag{33}$$

Equation (33) is similar to Eq. (10) but is expressed in terms of a cost function and output. Individual firms maximize profits treating price as fixed, thereby leading to the following first- and second-order conditions:

$$p(nq) - c_q - 2p^2(nq)q\sigma_u^2\alpha_B r^* = 0 \tag{34}$$

$$- C_{qq} - 2p^2(nq)\sigma_u^2\alpha_b r^* < 0 \tag{35}$$

Finally, industry equilibrium will depend on the growth constraint

$$g(x) - nq = 0 \tag{36}$$

In this situation a bioeconomic equilibrium is defined by the values $[q^*, x^*]$ satisfying Eqs. (34), (35), and (36). In general, $[q^*, x^*]$ will depend on $r^*$, which, it will be recalled, takes the value 1 for wage contracts and $\alpha_c/(\alpha_c + \alpha_B)$ for crop-sharing contracts. Furthermore, the maximized utility of the boat owner, $V^*(r^*)$, is obtained by evaluating the right-hand side of Eq. (33) at $(q^*, x^*)$. The socially optimal contract structure when industry effects are incorporated is determined by comparing the wage-contract with crop-sharing utility levels, respectively given by $V(r = 1)$ and $V^*(r = \alpha_B/(\alpha_B + \alpha_C))$. It is useful to begin this comparison by examining the effect on the boat owner's equilibrium utility of increasing $r$ relative to the crop-sharing equilibrium $r^*$. Making use of Eq. (34), this can be written

$$\frac{dV^*(r^*)}{dr^*} = \frac{1}{\eta}\frac{\partial c}{\partial q^*}\frac{\partial q^*}{\partial r^*} - \frac{\partial c}{\partial x^*}\frac{\partial x^*}{\partial r^*} - \sigma_\mu^2 p^2(nq^*)q^{*2}\alpha_B \tag{37}$$

where $\eta$ is the market elasticity of demand and is negative. Thus, the change in utility can be decomposed into three effects: an output effect, a resource effect, and a risk effect. Assuming that the equilibrium is stable, the resource effect ($-\ \partial c/\partial x^*\ \partial x^*/\partial r^*$) will always be positive. Similarly, the risk effect ($-\ \sigma_u^2 p^2(nq^*)q^{*2}\alpha_B$) is always negative. The sign of the output effect depends upon the sign of $\partial q^*/\partial r^*$, which, for a stable equilibrium, depends on the presence of biological inefficiency. If there is no biological inefficiency, that is, if $g' < 0$, then the output effect will be positive.

Equation (37) and the above discussion, although suggestive of the fact that the crop-sharing equilibrium may not be socially optimal, do not strictly establish that crop sharing will ever be inferior to a wage contract. (Observe that if $dV^*/dr^* > 0$, the owner would prefer a wage contract, and conversely, with a negative sign, he would prefer sharing.) We introduce the following example to illustrate a case where crop sharing is the socially less desirable contract.

***Example 1***

Consider the following specification of production, growth, and demand functions.

$$f(L, x) = Lx \Rightarrow c(q, x; w) = wq/x$$

$$p(nq) = (nq)^{-1}$$

$$g(x) = x - x^2$$

Further assume that

$$n = 5$$

$$w = 1$$

$$\sigma_u^2 = 1$$

$$\alpha_B = 2$$

The bioeconomic equilibrium values of the variables are given by

$$q^* = \frac{4r^*}{25}\left(1 - \frac{4r^*}{5}\right)$$

$$x^* = \frac{4r^*}{5}$$

$$V^*(r^*) = \frac{2r^*}{25}$$

Note that whenever relative risk attitudes are such that $r^* < 5/8$, it follows that $x^* < .5$, which implies that biological inefficiency arises. Regardless of this inefficiency, however, $r = 1$ (i.e., the wage-contract case), characterizes the socially optimal contract in the sense that utility of the boat owners with the wage contract is 2/25 and is thus greater than any crop-sharing alternative. An interesting situation arises when both owner and crew have the same risk-aversion parameter and hence $r^* = .5$. In this case, the output per boat is the same under both contracting schemes, but the wage contract yields twice the utility to the boat owner because it is associated with a greater resource stock and thus a lower extraction cost.

A final important point that is highlighted by this example is the fact that the wage contract, although socially preferable, need not be privately optimal. That is, the wage contract may not be a Nash market equilibrium. To see that this is true, it suffices to show that the marginal profits to a crop-sharing firm at the wage equilibrium values is positive. Choose, for example, $\alpha_B = \alpha_C = 2$ so that $r^* = .5$, $x^* = 2/5$, $q^* = 6/125$, and $p(q^*) = 25/6$ in the above example. By substituting these values into the left-hand side of Eq. (34), we find that the expression is positive and equal to 1. Thus, at this point, crop-sharing firms would want to increase output. In fact, it is optimal for them all to do so. The result will be that the stock size, $x$, declines, thus causing costs to increase.

### *Licenses and Individual Quotas*

In the foregoing discussion, regulation affected the number of firms in the industry but not the output choices of these firms. An alternative and more restrictive regulation scheme would involve placing individual output quotas on these firms as well. It may be argued that in such a case, crop sharing would dominate given that, from Eq. (33), crop-sharing firms will have a smaller $r$ and hence, ceteris paribus, a greater utility level than a wage-contract firm. The flaw with this argument, however, is that the regulatory agency, although choosing the number of firms and quotas per firm in a socially optimal fashion, may not take account of the existing market contract scheme. Typically, regulation of the industry has taken place as if there were only wage contracts. This may be justifiable, as Anderson (1982, 448) suggested in a deterministic environment. However, in the stochastic case, if the licensed firms adopt crop-sharing contracts, society may still be worse off than if they had chosen wage contracts. To illustrate this point, we refer to Example 1 and assume that the government chooses to license five firms, each with a quota of 6/125 units. If boat owners and crew have similar preferences ($r^* = .5$), then the regulated industry will adopt a crop-sharing contract with a resource size of 2/5 and utility per boat of 1/25, whereas they could have had a utility of 2/25 if the resource stock had been allowed to grow to 4/5, as would happen under a wage contract. Once again, the socially optimal contract will not be reached by private firms.

## Summary and Conclusions

It has been argued in the resource economics literature that crop-sharing contracts will dominate wage contracts in a stochastic environment and that output and employment will both be greater. In this article we have examined these arguments in the more complete setting of bioeconomic equilibrium. We have shown that privately optimal sharing contracts in fisheries are not, in general, socially optimal. As well, output and employment differences between socially and privately optimal contracts are ambiguous because of their dependence on the characteristics of the resource growth equilibrium. These results hold true even when the industries are subject to conventional forms of regulation in terms of licenses and/or quotas.

In addition to providing a more complete characterization of optimal contracting in resource industries, the results of this research have important implications for optimal regulation. In particular, the regulator must design policy subject to the constraint that private firms will have an incentive to adopt a particular contract form. Furthermore, such implicit contract incentives may reduce the net benefits of implementing the regulatory policy. An interesting and important open question, then, involves the determination of the optimal regulatory policy that provides firms with the appropriate incentives to adopt the socially optimal labor contract.

## Notes

1. An interesting early discussion of the observed range of contract types can be found in Zoeteweij (1956). Pure wage contracts have been reemerging in some Canadian (Great Lakes and Newfoundland) and New Zealand fisheries (personal communication, Dr. T. Cowan, Department of Fisheries and Oceans, Ottawa).
2. The situation that arises is much like a prisoners' dilemma game.
3. This approach simplifies the exposition of the results and allows us to focus attention on the contracting issues.
4. The fact that the optimal shares ($r^*$, $1$-$r^*$) ratios depend solely on risk-preference parameters may be used to explain the observation that in many fisheries, these shares are relatively constant over time. See Anderson (1982), Hodgson (1957), and footnote 5 in Ferris and Plourde (1982) regarding time profiles of shares.
5. We use the term *employment* here to represent optimal man-hours in fishing. The employer/employee distinction in a sharing contract is blurred because, to some extent, the crew member is self-employed. This has been a source of difficulty for determining eligibility for social assistance (welfare) programs. In Canada, crew members are eligible for unemployment insurance benefits. For details, see Zoeteweij (1956) and Ferris and Plourde (1982).
6. For industry models of fishing in a deterministic environment, see Smith (1974), Quirk and Smith (1970), Anderson (1976), and Hartwick (1982).
7. The Routh-Hurwitz conditions can be found in Gantmacher (1959) or Takayama (1974).
8. See V. L. Smith (1974) for a complete comparison of the cases $g' < 0$ and $g' > 0$. If $g' > 0$, then from Eqs. (17) to (20), $p - 2kp^2q = \partial c/\partial q$, which is positive. By multiplying both sides by $q/p$ it follows that $(p - 2kp^2q)$ is also positive. Hence $|J|$ will depend on magnitudes of the variables and parameters.
9. In 1986–1987 the United States Federal Trade Commission argued that Canadian subsidies (such as for boat building) have given Canadian fisheries an unfair competitive advantage. So-called corrective countervailing duties have been imposed on various Canadian fish products sold in the United States.
10. Observe that the assumption that variance does not depend on the size of $x$ significantly simplifies the analysis. If, for instance, uncertainty results from search (a common problem in fish harvesting), then stock effects are much more complicated. We suggest this as a problem for further research.

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