Corporate Crime in Fisheries: A Principal-Agent Analysis

Abstract: Non-compliance with fisheries regulations occurs in most commercial fisheries. In the traditional fisheries enforcement literature, this is dealt with by treating the fishing firm as one cohesive unit or individual. The fishing firm violates a regulation if the expected marginal gains are larger than the expected marginal fine/punishment. However, in many cases violations are not committed by an individual, but by agents acting on behalf of an owner or a collective entity. This calls for analysis of the principal-agent relationship of the fishing firm and integrating this into the economic model of crime. We focus on the case in which the employees (the crew andskipper) do not necessarily obtain any direct benefits from corporate crime. The owner of the fishing firm may, on the other hand, benefit from such activity. Hence, the compensation scheme facing the employees may be set up to induce them to commit offences. In this paper, we reach two main results. First, the optimal quota rule depends on the compensation scheme. Second, the compensation scheme determines who shall be held liable for the illegal activity.

JEL code: Q2

Keywords: Regulatory non-compliance, principal-agent model, fisheries
1. Introduction

Illegal and unreported landings are a large problem in world fisheries (Sumaila et al. 2006, Agnew et al. 2009). This problem is due to the externality in harvesting, which is not removed even if quotas and other regulations are imposed. Illegal landings make it necessary to have an enforcement policy and traditional fisheries enforcement theory is based on Becker (1968). Violations of fisheries regulation occur when the expected gains are larger than the expected punishment. In the social optimum the expected marginal penalty equals the marginal externality costs of landings (see e.g. Anderson and Lee 1986). The literature contains many extensions of the basic model. However, common to the extensions is that the fishing firm is treated as a cohesive unit and, therefore, that owner and employee’s have the same objectives. Thus, any principal-agent problems between the owner and employee’s are disregarded.

For general regulation problems, violations are often conducted by an agent on behalf of an owner (Kornhauser 1982). Within fisheries, this is particularly important for large, commercial fishing vessels with a large crew of professional fishermen. Often, the owner is not on board the vessels but acts as managers and investors. In these cases the objectives of skipper and crew are not identical to the owner’s goals. Ideally, the owner wants to design an efficient payment scheme that maximizes his own profit (Bergland 1996). In practice payment of crew often follows simple sharing rules (Matthiasson 1999).

In this paper we use principal-agent theory to analyze the relationship between the owner (principal) and the skipper and crew (agent) in a situation where the vessel (or fishing firm) engages in illegal fishing. This is an important extension of traditional fisheries enforcement theory. We obtain two main results. First, we analyze an individual quota and find that the optimal quota in the principal-agent situation differs from the optimal quota when the fishing vessel is a cohesive unit. The reason for this result is that the quota must be corrected for the externality that arises because of the principal-agent relation within the fishing vessel. Second, we consider how liability should be divided between the principal and the agent on the fishing vessel. This turns out to depend on the payment scheme used in the fishing firm. If an efficient payment scheme are used it does not matter who is liable for the illegal activity. However, if the payment is based on the share of profit and share of revenue rules the agent should be liable for the illegal activity. Payment schemes based on sharing rules are in fact common within fisheries (Matthiasson 1999).

There is a large literature on corporate crime using principal-agent theory (see e.g. Mullin and Snyder 2010). In the majority of this literature, the agent acts in his best interest and benefits from the illegal activity. In the fishing industry, we have the opposite situation since the owner benefits from fishing in excess of quotas while the benefits of the agent depend on the compensation scheme. This situation is similar to that analyzed by Mullin and Snyder (2010) who focus on optimal sanctioning and whether employee’s should be punished.

There is a small literature on compensation systems in fisheries (e.g. Bergland 1995 and Matthiasson 1999). This literature focuses on how the owner can design a system to get employee’s to act in his best interest. An argument is that cost minimization occurs when cost shares (the agent covers a share of total cost) and revenue shares (the agent receives a share of total revenue) are equal. Bergland (1995) show that this argument only hold if the agent’s are risk-neutral and the share parameters do not influence willingness to
supply effort. Matthiasson (1999) consider agent specific costs and find that in such a situation, contracts with positive revenue shares and zero cost shares are optimal. Our analysis differs from this literature since we focus on how to design liability rules given such sharing systems.

The paper is organized as follows. In section 2 the model is presented while section 3 introduces the main results of the paper. The paper is concluded in section 4.

2. The model

We model a situation where a regulator, an owner (principal) and a crew (agent) is present. We begin with the crew’s maximization problem. Here a representative agent model is considered. Thus, we model the representative crew. Two interpretations of the representative agent model can be considered. First, we can assume that all agents are identical. In this case we can pick one agent as representing all agents. Second, the representative crew could be the average agent. In this case the crew’s is heterogeneous and is distributed around the average crew. We chose the second interpretation and are, thus, assuming that the representative agent is the average crew. However, the results in the paper are not sensitive to which interpretation of the representative agent that is chosen.

We assume that the representative agent have low cost or high cost. The low cost representative agent is labeled type 1 and the representative high cost agent is labeled type 2. Regulator and the owner do not know the type of agents but the representative agent knows his own cost type. Thus, there is asymmetric information about the cost type of the representative agent. Both types of agents determine avoidance effort, $e_{iat}$ for $i = 1,2$, and traditional production effort, $e_{ipt}$ for $i = 1,2$. In association with the fishing activity the representative agent incur effort cost labeled $U_i(e_{iat} + e_{ipt})$ for $i = 1, 2$. The asymmetric information problem arise because regulator and the owner does not know the effort cost function $U_i(e_{iat} + e_{ipt})$ for $i = 1, 2$. However, the representative crew knows the effort cost function.

In addition to the effort levels, the representative employee determine illegal landings, $h_{iat}$ for $i = 1, 2$, and legal landings, $h_{ilt}$ for $i=1, 2$. The representative crew receives a wage from the owner and the wage function can be made contingent on legal landings, illegal landings, avoidance effort and production effort. Thus, the wage function may be written as $W(h_{ilt}, h_{iat}, e_{iat}, e_{ipt})$ for $i =1, 2$.

An individual transferable quota, $Q_i$ for $i = 1, 2$, is imposed on the fishing firm. If the quota is exceeded and the firm is detected, the fishing firm pay a penalty, $F(h_{ilt})$ for $i =1, 2$. The probability of being detected if the quota is exceeded is $\lambda(h_{ilt}, e_{iat})$ for $i = 1, 2$. Note that the probability of being detected depends on illegal landings and avoidance effort. Of the expected value of the fine the owner pays a share, $\alpha \lambda(h_{ilt}, e_{iat})F(h_{ilt})$ while the representative employee pays a share, $(1-\alpha) \lambda(h_{ilt}, e_{iat})F(h_{ilt})$. In the following analysis we determine $\alpha$ in the benchmark model (this section) and within the share of revenue and share of profit case (next section).

With these assumptions, the representative employee’s maximization problem may be written as:

$$\begin{align*}
\max_{h_{ilt}, h_{iat}, e_{iat}, e_{ipt}} & \left[ W(h_{ilt}, h_{iat}, e_{iat}, e_{ipt}) - (1-\alpha) \lambda(h_{ilt}, e_{iat})F(h_{ilt}) - U_i(e_{iat} + e_{ipt}) \right] \\
\text{for } i =1, 2
\end{align*}$$

(1)
s.t.

\[ h_{lt} \leq Q, \quad \text{for } i = 1, 2 \]  \hfill (2)

Note that the representative employee takes the quota restriction (2), into account. In (1) legal landings, illegal landings, avoidance effort and production effort are decision variables. It seems reasonable that the representative employee select landings and effort.

The Lagrange-function assuming that the quota restriction, (2), is binding may be written as:

\[
MaxL = \text{Max}[W(h_{lt}, h_{lt}, e_{iat}, e_{ipt}) - (1 - \alpha)\lambda(h_{lt}, e_{iat})F(h_{lt}) - U_i(e_{iat} + e_{ipt}) + u_i(Q - h_{lt})]
\]  \hfill (3)

where \( u_i \) is a Lagrange-multiplier and measures the shadow price of the quota restriction.

With respect to (3) we have two policy instruments. These are the quota and the liability. For the high cost agent we assume that the quota restriction is binding. However, the representative high cost agent does not land illegal. The penalty imply that \( h_{lt} = 0 \). Thus, the penalty is so high that the representative crew does not land illegally. Contrary to this the low cost representative agent land illegally. The implication of this is that the quota is not an effective instrument for the representative crew. Thus, for the representative low cost agent we use the liability rule as policy instruments. With these assumptions and assuming Cournot-Nash expectation, the first-order conditions are:

\[
\frac{\partial L}{\partial h_{2lt}} = \frac{\partial W}{\partial h_{2lt}} - u_i = 0
\]  \hfill (4)

\[
\frac{\partial L}{\partial h_{lt}} = \frac{\partial W}{\partial h_{lt}} - (1 - \alpha)\lambda(h_{lt}, e_{iat})F'(h_{lt}) - (1 - \alpha)\frac{\partial \lambda}{\partial h_{lt}}F(h_{lt}) = 0
\]  \hfill (5)

\[
\frac{\partial L}{\partial e_{iat}} = \frac{\partial W}{\partial e_{iat}} - (1 - \alpha)\frac{\partial \lambda}{\partial e_{iat}}F(h_{lt}) - \frac{\partial U}{\partial e_{it}} = 0 \quad \text{for } i = 1, 2
\]  \hfill (6)

\[
\frac{\partial L}{\partial e_{ipt}} = \frac{\partial W}{\partial e_{ipt}} - \frac{\partial U}{\partial e_{it}} = 0 \quad \text{for } i = 1, 2
\]  \hfill (7)

where \( e_{it} = e_{ipt} + e_{iat} \) is total effort.

(4) states that for the representative high cost agent the marginal private benefit equals the marginal private cost. The marginal private benefit is the marginal wage \( \frac{\partial W}{\partial h_{2lt}} \) while the marginal private costs is the shadow price of the quota restriction. For \( h_{lt} \), (5) state that the marginal wage \( \frac{\partial W}{\partial h_{lt}} \) is equal to the marginal private costs. The marginal private cost is the marginal expected value of the fine.
\((1-\alpha)\lambda(h_{it},e_{iat})F(h_{it}) + (1-\alpha)\frac{\partial\lambda}{\partial h_{it}}F(h_{it})\). For avoidance effort marginal private benefits is also set equal to marginal private costs. The marginal private benefit is the marginal wage \(\frac{\partial W}{\partial e_{iat}}\) and the reduction in the marginal expected value of the fine \((1-\alpha)\frac{\partial\lambda}{\partial e_{iat}}F(h_{it})\) while the marginal cost is the marginal avoidance cost \(\frac{\partial U}{\partial e_{ip}}\). With respect to production effort the marginal wage \(\frac{\partial W}{\partial e_{ipt}}\) is set equal to the marginal cost \(\frac{\partial U}{\partial e_{ipt}}\).

The representative principal does not know the cost function of the representative agent. However, under standard assumptions about the properties of the cost function and a flexible wage function, the representative vessel owner can induce the representative employee to land any given quantity and use any given effort by changing the compensation scheme. In this section, no restrictions are imposed on the wage function and the representative principal can induce any landings though the wage function. Thus, although the representative agent chooses landings, the representative principal is the real decision maker, as he can induce the representative agent to land any given quantity. Thus, the representative owner controls legal landings, illegal landings, avoidance effort and production effort and \(h_{it}, e_{iat}\) and \(e_{ipt}\) are control variables. In addition, the representative owner bears the cost of the fishing activity and the cost function is written as \(c(h_{it} + h_{iat}, e_{ipt}, x_{i})\) for \(I = 1, 2\). \(x_{i}\) is the stock size and it seems reasonable that costs is influenced by the stock of fish. As mentioned above, the representative owner’s share of the expected value of the fine is \(\alpha\lambda(e_{iat}, h_{it})F(h_{it})\). The representative owner, also, receive the revenue associated with the fishing activity and this revenue may be written as \(p_{i}(h_{it} + h_{iat})\), \(p_{i}\) is the constant price for fish. We assume that the representative owner has imperfect information about the cost function of the representative agent and, therefore, assign a probability \(\pi_{1}\) to type 1 and \(\pi_{2}\) to type 2. Therefore, incentive compatibility (self-selection) and participation restrictions are included. Thus, the maximization problem of the representative owner may be written as:

\[
\begin{align*}
\text{Max} H &= \text{Max} \{\pi_{1}(p_{1}(h_{1Lt} + h_{1It}) - c(h_{1Lt} + h_{1It}, e_{1pt}, x_{i}) - W(h_{1Lt}, h_{1It}, e_{1at}, e_{1pt}) - \\
&\quad \lambda(e_{iat}, h_{iat})F(h_{iat}) + \pi_{2}(p_{2}(h_{2Lt} + h_{2It}) - c(h_{2Lt} + h_{2It}, e_{2pt}, x_{i}) - \\
&\quad W(h_{2Lt}, h_{2It}, e_{2at}, e_{2pt}) - \alpha\lambda(e_{iat}, h_{iat})F(h_{iat}))
\}
\end{align*}
\]

s.t.

\[
\begin{align*}
W(h_{1Lt}, h_{1It}, e_{iat}, e_{ipt}) - (1-\alpha)\lambda(e_{iat}, h_{iat})F(h_{iat}) - U_{1}(e_{iat} + e_{ipt}) &\geq X_{1}^{0}\tag{9} \\
W(h_{2Lt}, h_{2It}, e_{2at}, e_{2pt}) - (1-\alpha)\lambda(e_{2at}, h_{2It})F(h_{2It}) - U_{2}(e_{2at} + e_{2pt}) &\geq X_{2}^{0}\tag{10}
\end{align*}
\]
\begin{align*}
W(h_{1t}, h_{1b}, e_{1at}, e_{1pt}) - (1 - \alpha) \lambda(e_{1at}, h_{1b}) F(h_{1b}) - U_1(e_{1at} + e_{1pt}) & \geq 0 \\
W(h_{2t}, h_{2b}, e_{2at}, e_{2pt}) - (1 - \alpha) \lambda(e_{2at}, h_{2b}) F(h_{2b}) - U_1(e_{2at} + e_{2pt}) & \geq 0 \\
W(h_{2t}, h_{2b}, e_{2at}, e_{2pt}) - (1 - \alpha) \lambda(e_{2at}, h_{2b}) F(h_{2b}) - U_2(e_{2at} + e_{2pt}) & \geq 0 \\
W(h_{1t}, h_{1b}, e_{1at}, e_{1pt}) - (1 - \alpha) \lambda(e_{1at}, h_{1b}) F(h_{1b}) - U_2(e_{1at} + e_{1pt}) & \geq 0
\end{align*}

(11) and (12) are self-selection restrictions. They secure correct revelation of the representative employee type. Thus, (11) states that the representative type 1 agents payoff from revealing type 1, must be larger than the representative type 1 agents payoff from falsely revealing type 2. (12) is the equivalent condition for type 2.

(13) is a quota restriction indicating that the total expected quantity landed cannot exceed the quota.

(9) and (10) is participating restrictions stating that the representative agent must receive their reservation payoff to participate. Thus, (9) and (10) captures that the representative owner wants the representative employee to work on board the vessel. (11) and (12) are self-selection restrictions. They secure correct revelation of the representative employee type. Thus, (11) states that the representative type 1 agents payoff from revealing type 1, must be larger than the representative type 1 agents payoff from falsely revealing type 2. (12) is the equivalent condition for type 2.

We now introduce single-crossing property. This assumption states that if the total cost of type 2 is higher than the total cost of type 1 \((U_2(e_{2at}) > U_1(e_{2at})\) for \(I = 1, 2)\), marginal cost will also be higher \((\frac{\partial U_2}{\partial e_{1at}} > \frac{\partial U_1}{\partial e_{1at}}\) for \(I = 1, 2)\). Given single-crossing property it is in appendix shown that the self-selection restriction of type 1 and the participation restriction for type 2 is binding. The binding restrictions may be written as:

\begin{align*}
W(h_{2t}, h_{2b}, e_{2at}, e_{2pt}) = (1 - \alpha) \lambda(e_{2at}, h_{2b}) F(h_{2b}) + U_2(e_{2at} + e_{2pt}) + X_2^0 \\
W(h_{1t}, h_{1b}, e_{1at}, e_{1pt}) = (1 - \alpha) \lambda(e_{1at}, h_{1b}) F(h_{1b}) + U_1(e_{1at} + e_{1pt}) + X_1^0 + [U_2(e_{2at} + e_{2pt}) - U_1(e_{2at} + e_{2pt})]
\end{align*}

(14) express that the representative type 2 agent receive exactly the reservation payoff sufficient to participate. Since \(U_2(e_{2at} + e_{2pt}) - U_1(e_{2at} + e_{2pt}) > 0\), type 1 receives a rent. This rent is an information rent given in order to secure correct revelation of types. From (14) and (15) we see that part of the wage is the representative employee’s cost of working and the expected penalty. Thus, the representative principal is covering the costs of the representative agent and, in addition, is paying a rent. Hence the representative agent is fully insured.

Substituting (14) and (15) into (8) and setting up a Lagrange-function gives:
\[ \text{Max} L = \text{Max} \{ \pi_i (p_i (h_{1,t}, + h_{1,b}) - c(h_{1,t}, + h_{1,b}, e_{1pr}, x_i) - U_i (e_{1pr} + e_{1pt}) - \\
\lambda (e_{1at}, h_{1h}) F(h_{1h}) + [U_2 (e_{2at} + e_{2pt}) - U_i (e_{2at} + e_{2pt})]) + \\
\pi_i (p_i (h_{2,t} + h_{2,b}) - c(h_{2,t} + h_{2,b}, e_{2pr}, x_i) - U_i (e_{2at} + e_{2pt}) - \\
\lambda (e_{2at}, h_{2h}) F(h_{2h})] + e_i (Q - \pi_i h_{1t} + \pi_j h_{2t}) \} \]

where \( \varepsilon \) is the shadow price of the quota restriction.

Note that perfect shifting of costs between the representative principal and the representative agent occurs. Thus, the representative owner insures the representative employee and, in addition, pays an information rent to the representative type 1 agent.

As in connection with the representative agent´s maximization problem, the representative type 2 agent only land legal while the quota is a ineffective instrument for type 1 agents. Therefore, the first-order conditions with Cournot-Nash expectations are:

\[
\frac{\partial L}{\partial h_{2Lt}} = p_i - \frac{\partial c}{\partial h_{2t}} - \varepsilon = 0 \tag{17}
\]

\[
\frac{\partial L}{\partial h_{2ht}} = p_i - \frac{\partial c}{\partial h_{2t}} - \lambda (e_{1at}, h_{1h}) F(h_{1h}) - \frac{\partial \lambda}{\partial h_{1h}} F(h_{1h}) = 0 \tag{18}
\]

\[
\frac{\partial L}{\partial e_{1at}} = \frac{\partial \lambda}{\partial e_{1at}} F(h_{1h}) - \frac{\partial U_i}{\partial e_{1pr}} = 0 \tag{19}
\]

\[
\frac{\partial L}{\partial e_{1pt}} = -\frac{\partial c}{\partial e_{1pt}} - \frac{\partial U_i}{\partial e_{1pr}} = 0 \tag{20}
\]

\[
\frac{\partial L}{\partial e_{2at}} = \pi_2 \left( \frac{\partial \lambda}{\partial e_{2at}} F(h_{2h}) - \frac{\partial U_{2}}{\partial e_{2t}} \right) - \pi_1 \left( \frac{\partial U_{2}}{\partial e_{2t}} - \frac{\partial U_{1}}{\partial e_{2t}} \right) = 0 \tag{21}
\]

\[
\frac{\partial L}{\partial e_{2pt}} = -\pi_2 \left( \frac{\partial c}{\partial e_{2pt}} + \frac{\partial U_{2}}{\partial e_{2t}} \right) - \pi_1 \left( \frac{\partial U_{2}}{\partial e_{2t}} - \frac{\partial U_{1}}{\partial e_{2t}} \right) = 0 \tag{22}
\]

where \( h_i = h_{Li} + h_{bi} \) for \( i = 1, 2 \).

For \( h_{2Lt} \) (17) states that the marginal profit \(( p_i - \frac{\partial c}{\partial h_{2t}} )\) shall equal the shadow price of the quota restriction.

According to (18) the marginal profit of illegal landings \(( p_i - \frac{\partial c}{\partial h_{2t}} )\) is set equal to the expected marginal value of the fine \(( \lambda (e_{1at}, h_{1h}) F(h_{1h}) + \frac{\partial \lambda}{\partial h_{1h}} F(h_{1h}) )\). For avoidance effort for type 1 the expected marginal
net benefit is set equal to the marginal costs. The expected marginal net benefit is the reduction in the expected marginal value of the fine \( \frac{\partial \lambda}{\partial e_{lat}} F(h_{lt}) \) while the marginal costs is the marginal costs of avoidance effort \( \frac{\partial U}{\partial e_{lt}} \). For type 2 ((21)) and extra marginal cost arise with respect to avoidance effort. This cost is \( \pi_2 \left( \frac{\partial U_{2,1}}{\partial e_{2t}} - \frac{\partial U_{1,1}}{\partial e_{2t}} \right) \) and can be labeled marginal incentive cost. This cost is included because we must secure that the representative type 1 agent reveal his type correct. For \( e_{1,pt} \) ((20) the total marginal cost of the representative principal \( \frac{\partial c}{\partial e_{1,pt}} \) and the representative agent \( \frac{\partial U}{\partial e_{lt}} \) is set equal to zero. With respect to production effort for type 2 ((22)) the marginal incentive costs is included as an extra element.

Concerning regulator four issues must be settled. First, we must discuss if illegal rents shall be included in the objective function. This could, naturally enough, be questioned. However, in their enquiry into the social value of criminal gain, Lewin and Trumbull (1990) argue that the value of regulatory offences should be accounted for. This assumption is supported by Milliman (1986) who argues that under certain circumstances it is optimal to included welfare from illegal landings in the objective function for regulator. Therefore, we include rents from illegal activities in the welfare function. Second, we must clarify if avoidance activities shall be incorporated in the objective function. It may be argued that these activities shall not be incorporated. However, because we include rents from illegal activities it is natural to include avoidance activities. Third, we must clarify if information rents shall be included in the objective function of regulator. Because we have included illegal rents and effort costs, a natural choice is to include information rents. Forth, we must discuss if enforcement costs shall be included. Naturally enough enforcement costs is real social costs that shall be included. However, we are interested in the first-order condition for legal and illegal landings. Making enforcement costs a function of enforcement effort does not change these first-order conditions. Consequently, we may exclude enforcement costs in the objective function.

Regulator has two objectives with regulation. First, he is interested in the optimal quota. Second, optimal liability is a desire. Consequently, regulator has two control variables. The first control variable is legal landings (the quota), and the second control variable is illegal landings (liability). For regulator, as for the owner, two types of agent’s exist and regulator assigns the same probabilities to type 1 and type 2 as the owner. Thus, \( \pi_1 \) is the probability of type 1 and \( \pi_2 \) is the probability of type 2. With maximization of expected present value of current and future rents as objective, the maximization problem becomes:

\[
\begin{align*}
\text{Max} & \int_0^\infty \left[ \pi_1 \left( p_1(h_{1Lt} + h_{1lt}) - c(h_{1Lt}, e_{1,pt}, x_1) - U_1(e_{1,at} + e_{1,pt}) - 
U_2(e_{2,at} + e_{2,pt}) \right) + 
\pi_2 \left( p_2(h_{2Lt} + h_{2lt}) - c(h_{2Lt}, e_{2,pt}, x_2) - U_2(e_{2,at} + e_{2,pt}) \right) \right] e^{-\delta t} dt \\
\text{s.t.} & 
\end{align*}
\]
\[ K(x_i) - \pi_1(h_{1L} + h_{1H}) - \pi_2(h_{2L} + h_{2H}) = \dot{x}_i \]  

(24)

where:

- \( K(x_i) \) is the natural growth function
- \( \delta \) is the discount rate

(24) is a resource restriction indicating that the change in stock size between time periods shall equal the natural growth minus expected landings.

Based on (23) and (24), a current-value Hamiltonian can be set up:

\[
Max H = Max \{ \pi_2(p_t(h_{1L} + h_{1H}) - c(h_{1L} + h_{1H}, e_{1pt}, x_i) - \\
U_1(e_{1ut} + e_{1pt}) - [U_2(e_{2pt} + e_{2ut}) - U_1(e_{2pt} + e_{2ut})]) + \\
\pi_1 p_t(h_{2L} + h_{2H}) - c(h_{2L} + h_{2H}, e_{2pt}, x_i) - U_2(e_{2ut} + e_{2pt}) + \\
\gamma_t(K(x_i) - \pi_1(h_{1L} + h_{1H}) - \pi_2(h_{2L} + h_{2H})) \}
\]

(25)

where \( \gamma_t \) is the co-state variable. Because legal and illegal landings are control variables we must state the optimality conditions with respect to these variables. As for the owner, we are interested in the optimality conditions with respect to \( h_{2L} \) and \( h_{2H} \). These conditions are:

\[
\frac{\partial H}{\partial h_{2L}} = p_t - \frac{\partial C}{\partial h_{2L}} - \gamma_t = 0
\]

(26)

\[
\frac{\partial H}{\partial h_{2H}} = p_t - \frac{\partial C}{\partial h_{2H}} - \gamma_t = 0
\]

(27)

\( \gamma_t \) can be interpreted as the marginal value of the stock externality and is sometimes referred to as the marginal user cost of the fish stock (see Anderson 1986). This cost captures that landings today (both legal and illegal landings) have an effect on landings of other vessels and the possibility of future landings through the resource restriction. According to (26) and (27) marginal profit of legal and illegal landings is set equal to the marginal user cost of the fish stock. Note that (26) determines the optimal legal landings and, thereby, the quota. (27) fixes the optimal illegal landings and, thus, the liability policy.

Note that (26) and (27) depend on \( e_{ut} \) and \( e_{pt} \). Thus, (26) and (27) may be solved for the effort levels:

\[
e_{ut} = b(h_{1H}, h_{1L}, x_i, \gamma_t)
\]

(28)

\[
e_{pt} = g(h_{1H}, h_{1L}, x_i, \gamma_t)
\]

(29)

Note that (28) and (29) express costs and benefits of avoidance and production effort. However, (28) and (19) only secure a second-best optimum. A first-best optimum would require that effort levels are control variables. However, treating the effort levels as control variables is not reasonable because we can only control the quota and the liability.
Under standard assumptions about the properties of the cost function and a flexible wage function, the representative vessel owner can induce the representative employee to land any given quantity by changing the compensation scheme (see Laffont and Tirole 1993). In this section no restrictions are imposed on the wage function. Thus, although the representative agent chooses landings, the representative principal is the real decision maker, as he can induce the representative agent to land any given quantity. The assumption that the representative principal is the real decision maker is well-known from the principal-agent literature (see Laffont and Tirole 1993).

With the representative principal as the decision maker we may equate private and social optimality conditions for legal landings ((17) and (26)). Then we obtain a condition for the point at which the private and social optima for \( h_{Lt} \) are equal:

\[
\epsilon_i = \gamma_i
\]  

(30)

Thus, a social optimum for legal landings is secured if the marginal user cost of the fish stock is equal to the shadow price of the quota restriction. This is a well-known optimality condition for ITQs and constitute a first-best case against which the share of profit and share of revenue rules will be compared against.

Similarly, the optimality condition for \( h_{It} \) is found by equating (27) with (18):

\[
\gamma_i = \lambda(e_{iut}, h_{iut})F'(h_{iut}) + \frac{\partial \lambda}{\partial h_{iut}} F(h_{iut})
\]  

(31)

Thus, the social optimality of illegal landings occurs if the marginal user cost of the fish stock is equal to the total marginal value of the fine. As with (30), (31) constitute a first-best case against which we will evaluate the share of profit and share of revenue case.

From the optimality condition for illegal landings given by (31), it is seen that three possibilities exist for the social planner with respect to optimal liability:

\[
\alpha = 1
\]  

(32)

\[
\alpha = 0
\]  

(33)

\[
0 < \alpha < 1
\]  

(34)

The first possibility is that the social planner holds the representative owner liable for the damage that illegal landings generate. Full owner liability is by (32) and secures an optimum. A second alternative is full agent liability which is given by (33). In this case the regulator constructs the liability scheme so that the representative employee is fully liable, whereas the representative owner is not punished. Employee liability also secures an optimum. Remember, however, that the representative principal is the real decision maker and, therefore, that the costs of the representative agent are transferred to the representative principal though the wage scheme. Thus, in reality, it is the representative owner that pays the penalty for the representative employee. The third possibility is given by (34) and involved combining agent and principal liability which also secures an optimum. However, as with (33), the penalty costs of the representative employs are transferred to the representative owner though the wage scheme.
By equating (28) with (19) we reach the following optimality condition for $e_{1at}$:

$$
\frac{\partial \lambda}{\partial e_{1at}} F(h_{1t}) - \frac{\partial U}{\partial e_{1t}} = b(h_{1t}, h_{1t}, x_t, \gamma_t) - e_{1at}
$$

(35)

Thus, optimal avoidance effort occurs where the social optimal effort is equal to the private optimal effort.

For $e_{p1}$ we reach:

$$
\frac{\partial c}{\partial e_{1p1}} - \frac{\partial U}{\partial e_{1t}} = g(h_{1t}, h_{1t}, x_t, \gamma_t) - e_{p1}
$$

(36)

Thus for production effort for type 2 the optimum occurs when marginal private net benefits is equal to marginal social net benefits.

For effort levels for type 2 a difference arise:

$$
-\pi_2 (\frac{\partial \lambda}{\partial e_{2at}} F(h_{1t}) + \frac{\partial U}{\partial e_{2t}}) - \pi_2 (\frac{\partial U_2}{\partial e_{2t}} - \frac{\partial U_1}{\partial e_{2t}}) = b(h_{1t}, h_{1t}, x_t, \gamma_t) - e_{2at}
$$

(37)

$$
-\pi_2 (\frac{\partial c}{\partial e_{2p1}} + \frac{\partial U}{\partial e_{2t}}) - \pi_2 (\frac{\partial U_2}{\partial e_{2t}} - \frac{\partial U_1}{\partial e_{2t}}) = g(h_{1t}, h_{1t}, x_t, \gamma_t) - e_{2p1}
$$

(38)

Compared to type 1 the marginal incentive costs are included. It is necessary to include these costs in the effort rules because the representative type 1 agent must be given an incentive to reveal the correct cost type.

3. Main results

In this section we discuss the share of profit rule (section 3.1) and the share of revenue rule (section 3.2). The results from these sections are the main contribution of the paper.

3.1. The share of profit rule

The share rule is a commonly used wage scheme in fisheries. There exists several versions of this rule and in the two next subsections we analyze two specifications. First, we analyze the share of profit rule and, second, we analyze the share of revenue rule. The optimal legal and illegal landings obtained from the regulators dynamic optimization problem are unaffected by the compensation scheme of the representative employee. The optimal quota and sanctioning scheme, on the other hand, will depend on the compensation scheme. We start out by looking at the share of profit rule. In this case, the representative employee receives a share of the representative vessel’s profit from fishing. By proper selection of the quota, optimal sanction and effort, a second-best optimum can be secured.

Assume that the representative employee receive a fraction, $\beta$, of the representative owner’s profit. Now the wage function is:

$$
W(h_{1t}, h_{1t}, e_{1at}, e_{1p1}) = \beta [p_1(h_{1t} + h_{1t}) - c(h_{1t} + h_{1t}, e_{p1}, x_t) - \alpha \lambda(e_{1at}, h_{1t}) F(h_{1t})]
$$

(39)
Note that the representative employee receives a share of the profit from both legal and illegal landings. (39) can be substituted back into the profit function of the representative owner ((8)). However, the representative owner can now only set the share parameter, $\beta$, which is not enough to enable the representative principal to dictate the landings of the vessel, because $\beta$ is introduced linearly in both the representative principal and agent’s optimization problem. By changing $\beta$, the representative owner can only decide whether or not he wants the representative employee to work. If the representative owner wants the vessel to operate, it is optimal to set $\beta$ as low as possible. Thus, the representative owner is forced to accept the representative agent’s choice in the wage system. He must take the wage system as given and cannot change the representative agent’s action within the wage system.

We have established that in the share of profit case, the representative agent is the real decision maker that determines legal and illegal landings. We must, therefore, consider the optimization problem of the representative agent and derive conditions for optimal quotas, liability and effort based on this. The Lagrange-function of the representative agent’s optimization problem is as in section 2, but with the share of profit wage replacing the general wage function. Note that the analysis is conducted under asymmetric information. However, the representative agent has perfect information about the effort cost function and so no correction is made for asymmetric information for the representative agent. In addition, as shown in section 2 the probabilities of various types cancels out for legal and illegal landings in regulator’s problem. Thus, with the representative agent as decision maker there is no need to reveal information and the asymmetric information problem need not to be considered.

Using the first-order conditions of the problem with respect to legal landings, illegal landings and effort and the optimality conditions for regulator, it can be shown that the following conditions must hold in optimum:

$$
\gamma_i = (1 - \beta)(p_i - \frac{\partial c}{\partial h_{2i}}) + u_i, \quad (40)
$$

$$
\gamma_i = (1 - \beta)(p_i - \frac{\partial c}{\partial h_{1i}}) + \beta(1 - \alpha)\lambda(e_{uat}, h_{1i})F(h_{1i}) + (1 - \alpha)\frac{\partial \lambda}{\partial h_{1i}}F(h_{1i}) \quad (41)
$$

$$
e_{iat} - b(h_{iat}, h_{ih}, x_i, \gamma_i) = \beta\alpha\frac{\partial \lambda}{\partial e_{iat}}F(h_{1i}) - \frac{\partial U_i}{\partial e_{iat}} \text{ for } i = 1, 2 \quad (42)
$$

$$
(1 - \beta)\frac{\partial c}{\partial e_{ipt}} - \frac{\partial U_i}{\partial e_{it}} = g(h_{iat}, h_{ih}, x_i, \gamma_i) - e_{ipt} \text{ for } i = 1, 2 \quad (43)
$$

The first optimality condition, (40), states that the quota for type 2 should be set so that the marginal user cost of the fish stock shall equal the representative employee’s shadow price on the quota restriction plus the marginal profit of the representative principal ($(1 - \beta)(p_i - \frac{\partial c}{\partial h_{2i}})$). In section 2 we reached that the shadow price of the quota should equal the user cost of the fish stock. Thus, in (40) a correction is made. This correction is necessary because under this compensation scheme, no good mechanism exist for
transferring costs and benefits between the representative employee and owner. The regulator must, therefore, internalize the externality of the representative employee who ignores the effect of his choice on the representative principal. The modified quota optimality condition is a new contribution to the literature on ITQs. In section 2 we reached \( \gamma_t = \lambda(e_{iat}, h_{it}) F'(h_{it}) + \frac{\partial \lambda}{\partial h_{it}} F(h_{it}) \) as the optimal liability rule. Thus, the liability rule is corrected in (41). Again this correction is done to internalize the externality of the representative employee that does not take into account all relevant effects in their decision on behalf of the representative owner. (41) states that the shadow price of the fish stock must equal the marginal profit of the representative principal plus the marginal penalty of the agent

\[
\beta[(1 - \alpha) \lambda(e_{iat}, h_{it}) F'(h_{it}) + (1 - \alpha) \frac{\partial \lambda}{\partial h_{it}} F(h_{it})]
\]

\( \alpha \). From (41) it is clear that in terms of liability, regulator only have agent liability as an option \( \alpha = 0 \). This, the only liability rule that secures an optimum is employee liability.

Concerning avoidance effort one correction is made with the share of profit rule compared to section 2. In (42) the representative principal share of avoidance costs is included. With respect to production effort only the representative principal’s cost are included. The corrections in effort are made because the representative agent does not fully take into account the interests of the representative principal.

Next we turn to the share of revenue rule.

3.2. Share of revenue rule

Another commonly used specification of the share rule is that the representative receives a share of the value of landings. Thus the rule may be formulated as a requirement that the wage is equal to a share, \( \beta \), of the revenue from legal and illegal landings:

\[
W(h_{it}, e_{iat}, e_{iges}) = \beta(p_{i}(h_{it} + h_{it}))
\]

(44)

As for the share of profit rule (section 3.1) the representative owner cannot by means of economic incentives influence the quantity landed by the representative employee. The owner can only influence \( \beta \) whether or not fishing occurs at all, and the optimal given positive landings is the lowest possible value that induces the representative agent to participate. Thus, as in section 3.1. the representative owner’s
cost are not included. The real decision maker is again the representative agent whose maximization problem can be set up according to (1) and (2) but substituting the share of revenue function given by (44) for the general wage function.

Now we may combine the first-order conditions from the representative agent’s problem with the corresponding conditions for the regulator’s problem. This gives optimality conditions for quotas, liability and effort:

\[
\gamma_i = u_i + (1 - \beta) p_i - \frac{\partial c}{\partial h_{2i}}
\]

\[
\gamma_i = (1 - \beta) p_i - \frac{\partial c}{\partial h_{2i}} + (1 - \alpha) \lambda (e_{iat}, h_{iL}) F(h_{iL}) + (1 - \alpha) \frac{\partial \lambda}{\partial h_{iL}} F(h_{iL})
\]

\[
(1 - \alpha) \frac{\partial \lambda}{\partial e_{iat}} F(h_{iL}) - \frac{\partial U}{\partial e_{iat}} = e_{iat} - b(h_{iL}, h_{iL}, x, \gamma_i)
\]

\[
\frac{\partial c}{\partial e_{ipt}} - \frac{\partial U}{\partial e_{it}} = g(h_{iL}, h_{iL}, x, \gamma_i) - e_{ipt}
\]

When wages are determined according to the share of revenue rule, two additional terms enter into the optimal quota rule ((45)). As in section 3.1 these terms are included to correct for the fact that there is no mechanism that transfers the full costs and benefits from the representative owner to the representative agent. The terms are the share of revenue of the representative owner \((1 - \beta) p_i\) and the representative owner’s marginal cost.

Optimal liability can be determined by (46). Two points is important to note with respect to this condition. First, notice that the condition only includes the expected penalty of the representative agent. Thus, the only liability rule that can insure a second-best optimum is employee liability with the expected marginal penalty set equal to the user cost of the fish stock minus the marginal profit of the representative owner. Second, the marginal profit of the representative is included because the wage contract has no mechanism to transfer all relevant costs and benefits from the representative owner to the representative agent who is the decision maker.

Concerning avoidance effort, one difference arises compared to section 2. It is only the representative employee’s share of the marginal expected penalty that is included. This term is included because no mechanism exists for transferring costs and benefits between the representative principal and agent. For production effort share of revenue does not included the representative principal’s cost. Again this arises because transferring costs between the representative principal and agent is impossible.

Summing up, a second-best optimum can be reached with both the share of profit and share of revenue rules. However, in both cases only agent liability works.
4. Conclusion

The purpose of our study is to include principal-agent theory into a fisheries compliance model. The motivation for this is that decisions on illegal activities are often made by a company or agent that acts on behalf of the owner. The owner is the principal while the crew is the agent. Adopting a principal-agent approach in illegal activities within fisheries allow us to study implications of liability rules and compensation on quotas and punishment.

Landed fish, typically, belong to the owner. The principal, therefore, benefits from illegal activities. Decisions on landings, however, are made by agent’s, but the agent’s only benefits from illegal activities through the compensation scheme. The principal can induce agent’s to land any given quantity by altering the wage function. This result requires that the wage function is flexible. If the wage function is not flexible the agent is the real decision maker who determines landings.

The main findings are that as long as relevant costs are perfectly shifted between the employee’s and owner it is irrelevant who is fined. If costs are not perfectly shifted this liability result breaks down and only agent liability is optimal since agent’s determine landings. If the wage function is flexible the principal is the real decision maker and takes cost and benefits of agent’s into account. Therefore, full agent liability will work in this case. Furthermore, full agent liability also works if the wage function is not flexible.

There are several possibilities for future work. First, we may include risk-aversions in the model. Second, we may consider the effect of moral hazard due to unobservable landings. Third, we can consider a case study of real world fisheries. Forth, asymmetric information between the owner and the regulator may be introduced. Last, we may consider non-constant probabilities of detection.
References


Appendix

For type 1 we have a self-selection restriction and a participation restriction and these may be written as:

\[ W(h_{1t}, h_{1h}, e_{1at}, e_{1pt}) \geq (1 - \alpha) \lambda (e_{1at}, h_{1h}) F(h_{1h}) + U_1(e_{1at} + e_{1pt}) + X_1^0 \] (A.1)

\[ W(h_{1t}, h_{1h}, e_{1at}, e_{1pt}) \geq (1 - \alpha) \lambda (e_{1at}, h_{1h}) F(h_{1h}) + U_1(e_{1at} + e_{1pt}) + \]
\[ [W(h_{2t}, h_{2h}, e_{2at}, e_{2pt}) - (1 - \alpha) \lambda (e_{2at}, h_{2h}) F(h_{2h}) + U_1(e_{2at} + e_{2pt}) \] (A.2)

Since wages enters with a negative sign in the objective function of the representative principal one of these restrictions are binding.

According to the participation restriction of type 2:

\[ W(h_{2t}, h_{2h}, e_{2at}, e_{2pt}) \geq (1 - \alpha) \lambda (e_{2at}, h_{2h}) F(h_{2h}) + U_2(e_{2at} + e_{2pt}) + X_2^0 \] (A.3)

Single-crossing property implies that:

\[ -U_1(e_{2at} + e_{2pt}) \geq U_2(e_{2at} + e_{2pt}) \] (A.4)

(a.3 and (a.4) implies that:

\[ W(h_{2t}, h_{2h}, e_{2at}, e_{2pt}) - (1 - \alpha) \lambda (e_{2at}, h_{2h}) F(h_{2h}) - U_1(e_{2at} + e_{2pt}) \geq \]
\[ W(h_{2t}, h_{2h}, e_{2at}, e_{2pt}) - (1 - \alpha) \lambda (e_{2at}, h_{2h}) F(h_{2h}) - U_2(e_{2at} + e_{2pt}) \geq X_2^0 \] (A.5)

Therefore, the expressions in the bracket of (a.2) are larger than the reservation utility and it must be the self-selection restriction for type 1 that is binding.

Since wages enters with a negative sign in the representative owner’s objective function, one of the restrictions for type 2 must be binding. Can it be the self-selection restriction? If this restriction is binding and the binding self-selection restriction for type 1 is substituted into the self-selection restriction for type 2, the following condition is obtained:

\[ U_1(e_{2at} + e_{2pt}) - U_1(e_{1at} + e_{1pt}) = U_2(e_{2at} + e_{2pt}) - U_2(e_{1at} + e_{1pt}) \] (A.6)

(A.6) violates single-crossing property. It must, therefore, be the participation restriction for type 2 that is binding.