SNF Working Paper No. 45/06

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by

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SNF project No. 5255: "Strategic Program in Resource Management"

The project is funded by The Research Council of Norway

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, NOVEMBER 2006
ISSN 1503-2140

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Abstract

In this paper, a dynamic model of fishermen's compliance is developed and used to analyse several issues. There are two parties involved in the fishery; the regulator and the fishermen. The regulator takes on a long term view and sets the total quota at the beginning of every period in order to keep the stock at a predetermined level. Fishermen act on a period by period basis, seeking to maximise welfare within every period. In addition to buying a quota and legally harvest the quota quantity, they have the possibility to harvest illegally in excess of quotas. I introduce non-monetary moral costs of illegal harvesting that varies across the population of fishermen and is also affected by a social norm of compliance. The first part of the paper analyse optimal fisherman behaviour in terms of compliance and quota purchase. In the second part, I use these results to analyse the dynamics of the fishery.

*I am grateful to Jon M. Conrad, Rögnvaldur Hannesson and Aaron Hatcher for comments on earlier versions. All remaining errors and omissions are my own.

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1 Introduction

The purpose of the study is twofold. First, to introduce the effects of social influence and moral norms with respect to violating quota regulations into the fishermen's compliance decision process. Second, to consider fishermen's compliance and fishery regulation in a dynamic framework. Several studies have been done on fishermen's compliance, but most studies keep the analysis within a static framework. The extent of non-compliance to harvest regulations affects the future availability of fish. In addition, it is possible that the actions of fishermen today affect the social norms of the fishermen in the future. These aspects disappear if we analyse fishermen's compliance in a static model.

Unreported landings are a problem in most commercial fisheries. If fishermen harvest more than their given quota and the fishery manager does not take this into account when determining the total quota, one should think the fish stock would decline. Most fishery managers will probably try to avoid this, e.g. by reducing the quotas below desirable levels. Even if the manager cannot observe the unreported harvest, he can observe the stock size, possibly with measurement error, before setting a period's total allowable catch. Extending the static analysis by introducing stock dynamics makes it possible to analyse some of the implications of this. Another interesting aspect of using a dynamic model is that in an ITQ fishery with heterogeneous fishermen, the fishermen with the highest propensity to harvest illegally, or the lowest moral cost of violating quotas, could drive their more honest and law abiding colleagues out of the fishery over time.

The traditional compliance literature ignores this aspect of the fishermen's violation decision (e.g. Sutinen & Andersen, 1985). Fishermen are assumed to exhibit a pure profit maximising behaviour, maximising the expected profits from legal and illegal harvesting given the cost of harvesting and the expected punishment if violating regulations.

An alternative approach has been taken in the literature, in which compliance is analysed under the assumption that individual agents also take social norms and moral obligations into account. Sutinen & Kuperan (1999) divide the determinants of compliance into illegal gain, expected penalty, and social influence and moral obligation. In addition, several empirical studies of determinants of fishermen's compliance indicate that social norms and moral obligations play an important part in the fishermen's compliance decision process (see e.g. Hatcher et al., 2000; Hatcher & Gordon, 2005).

Elster (1989) discusses the difference in the models used by economists and sociologists for describing human behaviour. The two extremes are the economic model in which behaviour is based on instrumental rationality, and the sociological model where the individual acts not out of self interest, but to fulfill social roles. As many others, Elster (1989) argues that "both norms and self-interest enter into the proximate explanations of action."[1] The purpose of the current study is to develop a conceptual model that can be used to analyse some of the implications if we acknowledge that the individual fisherman may be driven by other forces than the pure profit maximising motives of the economic man.

This is not a new line of research, as similar topics have been studied in the literature. An often cited example is Sethi & Somanathan (1996) who develop an evolutionary model of common property resource use. In their model, the number of agents who comply with the norm of cooperation increases if the payoff of doing so exceeds the average payoff in the population. Their analysis shows that cooperative norm based behaviour may be stable. The current study differs from the existing literature in several respects, e.g. by focusing on how differences in individual moral norms affect the dynamics of the fishery and the distribution of catches. To my knowledge, little or no work has previously been done on this topic.

In the following I present a possible modelling framework for analysing implications of fishermen's social and moral norms on quota compliance.[2] This is done by developing and analysing a simple conceptual bioeconomic model of quota compliance. Most parts of the model should be familiar from the fisheries economics literature. The novel feature of the model is the introduction of a non-monetary moral cost, which depends on personal moral standards and a social norm of regulatory compliance. The model is used to analyse *inter alia* the conditions under which fishermen violate quotas, optimal harvest quantity and quota purchase, and how social and moral norms can affect these decisions. Furthermore, I investigate the dynamics of the fishery in terms of how social norms of compliance evolve, along with the dynamics of the stock, harvests, and quota compliance.

The paper is organised as follows. In the next section, I develop a simple conceptual model of a fishery allowing for non-compliant behaviour by the fishermen. In section 3, the model is further specified and analysed. The first part of this section analyses the fishermen's optimal behaviour (static optimisation), before the

[1] See also Ostrom (2000) and references therein.

[2] In what follows, the term "moral" is used rather loosely to refer to the fishermen's preferences with respect to violating quota regulations. Elster (2006) distinguishes between social and moral norms in the following way: "The violation of a moral norm triggers simultaneously guilt in the violator and anger in the observer of the violation, if there is an observer. The violation of a social norm triggers first contempt in the observer, and the observation of that reaction triggers in turn shame in the violator."

regulator is introduced and the dynamic model is analysed next. The last section concludes.

2 The Model

In this section, I develop a model of a fishery regulated with individual transferable quotas (ITQ) and harvested by a single fishing fleet. The fleet consists of $n < \infty$ (potential) fishermen, all of whom take the rental price of quota $r \geq 0$ as given. The fish stock can be harvested and marketed at a given price p, exogenous to the fishermen.

There are two types of agents in the fishery. The resource manager, who at the beginning of every period sets the total quota, and the fishermen harvesting the stock. If harvesting the stock is viable, the total quota in period t is given by Q_t, of which harvester i demands a quota share q_{it}. The quota market clears in every period, and consequently $\sum_{i=1}^{n} q_{it} = Q_t$ in market equilibrium.

The dynamics of the fish stock is given by:

$$X_{t+1} - X_t = G\left(X_t\right) z_t - Y_t, \tag{1}$$

where X_t is the resource stock at the beginning of period t, Y_t is total harvest in period t, and z_t is environmental variability affecting stock growth. z_t is an iid random variable with mean one and a given statistical distribution, which is assumed known. This is how Reed (1979) introduced uncertainty to his stochastic bioeconomic model. The term $G\left(X_t\right)$ in equation (1) represents the relationship between stock and stock growth in the deterministic case and is assumed given by $G\left(X_t\right) = aX_t\left(1 - \frac{X_t}{K}\right)$, where a is the intrinsic growth rate of the stock, and K is the carrying capacity of the environment.

The objective of the regulator is to keep the stock at a predetermined level. The problem facing the regulator is thus that of setting the total quota Q_t in order to keep the stock at the given reference level $\bar{X}$. This means that Q_t is set so that next period's expected initial stock equals $\bar{X}$:

$$E_t\left[X_{t+1}\right] = X_t + G\left(X_t\right) - E_t\left[Y_t|Q_t\right] = \bar{X}. \tag{2}$$

Whereas the regulator has to deal with uncertainty when deciding on a period's total quota, the individual fishermen are assumed to know the exact size of the fish stock when making their harvesting and quota purchase decisions. This can be thought of as uncertainty about stock growth being revealed after the regulator makes his quota decision. This may not be as far fetched as it sounds, as the stock level affects the fishermen's production function and thereby their cost of harvesting. It can therefore be argued that the fishermen, when they start harvesting, have better knowledge of the conditions of the stock than the regulator had when he set the period's quota.

Harvesting cost for agent i is given by the variable cost function $C(X_t, y_{it}) = \frac{cy_{it}^2}{X_t}$, where $c > 0$ is a constant cost parameter and y_{it} is the harvest of agent i.[3] The cost function is convex and increasing in harvest, and it is decreasing in stock.[4]

In an ITQ fishery, the agents can buy and sell (rent) quotas to adjust the quantity harvested. In addition, they have the possibility of violating their harvest quotas. This is done at the risk of detection, with a subjective probability of detection given as a function of total harvest y_i, quota q_i, and the strength of enforcement efforts Φ.[5] Agents are assumed to be risk neutral.

The subjective probability of detection can thus be written as $\Psi(y_{it}, q_{it}, \Phi)$. If a violator is detected he must pay a monetary fine given by $\mathcal{F}(y_{it}, q_{it})$. A penalty function can thus be defined as[6]

$$\mathcal{P}(y_{it}, q_{it}, \Phi) = \Psi(y_{it}, q_{it}, \Phi)\,\mathcal{F}(y_{it}, q_{it}). \tag{3}$$

If an agent is not violating his harvest quota, the probability of detection is zero. By definition, $\Psi(0, 0, \Phi) = 0$ and obviously there is no expected punishment without violation of quota ($\mathcal{P}(0, 0, \Phi) = 0$). Furthermore, the subjective probability function $\Psi(y_{it}, q_{it}, \Phi)$ is increasing in y_{it} and decreasing in q_{it}.

The model presented thus far follows the traditional literature on fishermen's compliance. However, I now introduce *moral* and *social norms*. This has been mentioned by several authors as important factors in determining fishermen's compliance behaviour (*op. cit.*). Defying a moral norm, e.g. harvesting in violation of regulations, may generate a sense of dissatisfaction or disutility, reducing the agent's welfare. Moral and social norms are introduced to the model as follows. There is a social norm of cooperative harvesting of the stock. Depending on the agent's moral beliefs and on the social norm of compliance, violating the harvest

[3]Total harvest by the fleet is given as the sum of individual harvest quantities: $Y_t = \sum_{i=1}^{n} y_{it}$.

[4]Within season stock effects are ignored.

[5]Enforcement Φ is assumed exogenous to the model.

[6]Sanctioning behaviour is not discussed in the paper, but can easily be accounted for in the model, e.g. by letting the penalty function represent both sanctioning by other fishermen and formal punishment enforced by laws and regulations.

quota comes at a moral cost to the agent in terms of reduced welfare. Moral costs, as opposed to material costs, refer to the pressure placed upon commonly respected moral norms and values, in this case compliance with quota regulations. The moral cost is therefore not a cost the agent is billed for. Rather, it is the monetary value of an agent's reduced utility or welfare when violating the moral norm. As such, the moral cost is taken into account by the individual fishermen when deciding on how much to harvest legally and illegally.

Formally, moral and social norms are introduced to the model as follows. Each potential fisherman has a given moral norm represented by the variable m_i, where $0 \leq m_i \leq \infty$ for all i. In addition, I introduce the social norm with respect to quota compliance S_t as a second state variable of the model, with dynamics given as follows:

$$S_{t+1} - S_t = \omega \left(\max \left[\frac{Y_t}{Q_t}, 1 \right] - S_t \right), \tag{4}$$

where $\omega \in [0, 1]$ is an adjustment parameter. I assume all agents have the same subjective impression of the size of S_t. Using this specification, S is a measure of how the harvesting industry as a whole complies with the total quota. To actually obtain a measure of S is probably not straight forward for any fisherman, but equation (4) can be thought of as a proxy describing the underlying realities.

The reference value of the social norm variable is $S = 1$, the level at which the whole industry complies. $S > 1$ implies that illegal harvesting is socially acceptable to a certain degree. As long as fishing is profitable, the model ensures that fishermen always harvest the full quota. Thus, the social norm variable will never take on values below one. The max operator in equation (4) is to ensure that the social norm variable is unaffected in a situation where harvesting is not profitable for the fleet although the quota is positive (i.e., when $Y < Q$).

Individual i's moral cost of violating the harvest quota in period t is then given by the function $M(y_{it}, q_{it}, m_i, S_t)$. By definition, the moral cost function is always zero if $m_i = 0$, in other cases it is increasing in y_{it}, and decreasing in q_{it} and S_t. As m_i increases, the moral cost of violating regulations will at some point outweigh the marginal revenue of violating quotas and the agent complies regardless of other factors. Each agent's moral norm is private knowledge and cannot be used strategically by the fishery regulator or by any other agent.

The introduction of moral costs adds an additional term to the fishermen's welfare maximisation problem, which can be written:[7]

$$\max_{y_i,q_i} py_i - C(X, y_i) - rq_i - \mathcal{P}(y_i, q_i, \Phi) - M(y_i, q_i, m_i, S), \tag{5}$$

subject to $y_i \geq q_i \geq 0$. Welfare is measured in the same unit as costs and price.

Optimising behaviour for an agent who complies with the current quota regulations is given by:

$$p - \frac{\partial C_i(\cdot)}{\partial y_i^*} = r, \tag{6}$$

where $y_i^* = q_i^* \geq 0$. This condition merely states that marginal revenues are equal to the marginal cost, which is given as the sum of marginal harvesting costs and the rental price per quota unit.

Correspondingly, optimising behaviour for non-compliant agents is defined by the following conditions:

$$p - \frac{\partial C_i(\cdot)}{\partial y_i^*} = \frac{\partial \mathcal{P}_i(\cdot)}{\partial y_i^*} + \frac{\partial M_i(\cdot)}{\partial y_i^*}, \tag{7}$$

$$-r = \frac{\partial \mathcal{P}_i(\cdot)}{\partial q_i^*} + \frac{\partial M_i(\cdot)}{\partial q_i^*}. \tag{8}$$

The individual fisherman complies with quota regulations as long as the sum of marginal expected punishment and marginal moral costs are higher than the marginal net revenues from harvesting the stock. Compared to the case of no moral costs in the model, the only difference is that the fishermen now also take into account the marginal moral costs of increasing harvest quantity and decreasing quota holdings.

In the next section I analyse the dynamics of the fishery in terms of stock and social norm dynamics, harvest, and compliance.

3 Analysis

Before further analysing the dynamics of fishermen's compliance, functional forms are specified. This is done in the first part of this section. Next, optimal individual fisherman behaviour is analysed, and the regulator's quota policy is discussed. Finally, a numerical example is presented.

Model specification:

- Stock growth uncertainty: z_t is assumed to be uniformly distributed over the

[7]For ease of notation, the time dependence of all variables is mostly suppressed throughout the paper.

interval $z_t \in [1-\epsilon_g, 1+\epsilon_g]$.

- Moral cost function: $M(y_i, q_i, m_i, S_i) = \alpha m_i (y_i - q_i) / S_t$, where α is a positive constant. The non-monetary moral cost of violating regulations is increasing in the absolute quota violation. Furthermore, stronger moral norms increase the value of $M(\cdot)$, whereas a higher acceptance for harvesting in excess of quotas, as reflected in a higher value of S, decreases the moral cost.
- Moral parameter: In the numerical analysis, it will be assumed that the moral norm parameter m is log-normally distributed, with mean $\bar{m}$ and standard deviation σ_m.[8]
- Punishment function: $\mathcal{P}(y_i, q_i) = \phi (y_i - q_i)^2 / q_i$, where $\phi > 0$ is a constant. The enforcement level parameter Φ has been normalised to unity and is therefore left out in what follows. Expected punishment is seen to be increasing in total harvest and decreasing in total quota, which seems reasonable.

Putting this together gives us the following welfare function to be maximised by the individual agent (cf. equation 5):

$$\max_{y_i, q_i} W = py_i - \frac{cy_i^2}{X} - rq_i - \frac{\phi (y_i - q_i)^2}{q_i} - \frac{\alpha m_i (y_i - q_i)}{S}. \tag{9}$$

Necessary and sufficient first order conditions are:[9]

$$W_y = p - \frac{2cy}{X} - \frac{2\phi (y-q)}{q} - \frac{\alpha m}{S} \leq 0 \tag{10}$$

$$W_q = -r + \frac{\phi (y^2 - q^2)}{q^2} + \frac{\alpha m}{S} \leq 0 \tag{11}$$

If y and q are larger than zero, equations (10) and (11) hold with equality.

3.1 Fishermen's harvest and compliance

When the punishment function is defined as above, it is never optimal to harvest the stock without a positive quota holding as the expected punishment approaches infinity as $q \to 0$ and $y > 0$. This reduces the possible options for the individual fisherman to (i) harvesting in compliance with quota ($y = q > 0$), (ii) harvesting in excess of quota ($y > q > 0$), and inactivity ($y = q = 0$). In the following, I derive

[8]The number of potential fishermen in the population is assumed constant over time ($n_t = n \forall t$).

[9]The welfare function is concave and the first order conditions are therefore necessary and sufficient for a maximum.

the fishermen's optimal actions (y^*, q^*) as functions of the other parameters of the model.

(i) Compliance: $\mathbf{y} = \mathbf{q} > \mathbf{0}$

According to the first order conditions given by equations (10) and (11), a compliant agent acts according to the following condition:

$$p - \frac{2cy_{it}}{X_t} = r_t, \tag{12}$$

where, of course, $y_{it} = q_{it}$. This can easily be solved for the optimal harvest and quota purchase as follows:

$$y_{it}^* = q_{it}^* = \frac{X_t}{2c}(p - r_t). \tag{13}$$

It is easily confirmed that per period harvest by agent i is increasing in stock size (due to lower costs of harvesting a larger stock), decreasing in cost of harvesting (c), increasing in price of fish (p), and decreasing in the rental price of quota (r). The highest price a compliant agent is willing to pay per unit quota is $\bar{r}_{it}^c = p$. At quota prices above this, he will rather not harvest at all.

(ii) Non-compliance: $\mathbf{y} > \mathbf{q} > \mathbf{0}$

Non-compliance is optimal behaviour by agent i in period t if $r_t > \alpha m_i / S_t$. In this case, the gain from violating the quota outweighs the loss. When it is optimal for an agent to violate his harvest quota, the maximising conditons (equations 10 and 11) can be solved for optimal values of total harvest and quota purchase as follows:

$$\begin{aligned} y_{it}^* &= \frac{X_t}{2c}\left[p - 2\phi(\gamma_{it} - 1) - \frac{\alpha m_i}{S_t}\right] && (14) \\ q_{it}^* &= y_{it}^* / \gamma_{it}, && (15) \end{aligned}$$

where $\gamma_{it} \equiv \sqrt{\frac{1}{\phi}(r_t + \phi - \alpha m_i / S_t)} \geq 1$. γ is also the ratio of total harvest to quota y/q.

It is easily confirmed that both y and q are increasing in stock size X and price p, and decreasing in the cost parameter c. An increase in expected punishment through ϕ reduces the relative quota violation γ, but leads to an increase in both quota purchase q and total harvest y. An increase in the rental price of quotas has the opposite effect, as it is seen to reduce both q and y, whereas γ, the y/q ratio, increases. Turning to the effects of changes in moral norms m_i, the effect on quota purchase q depends on the relationship between p, r, and $\alpha m/S$. An increase in moral costs ($\alpha m/S$) leads to an increase in q if $\alpha m/S > 2r - p$. If, on the contrary, $\alpha m/S < 2r - p$, the opposite is the result. A rise in moral costs has a less ambiguous effect on y and γ as they are both decreasing independently of what happens to q. Consequently, the lower the fisherman's moral norm m_i, the higher the total harvest (and γ). Also, an increase in S, the social norm with respect to quota violation, reduces the moral cost of violating quotas for all agents and will thereby lead to higher total harvest relative to total quota in the future (as long as some agents violate their quotas).

The highest price a non-compliant agent is willing to pay per unit of quota is:

$$\bar{r}_{it}^{nc} = p + \frac{(p - \alpha m_i/S_t)^2}{4\phi}. \tag{16}$$

The non-compliant agent would not harvest unless $p > \alpha m_i/S_t$. It follows that the non-compliant agent is willing to pay a higher quota price than compliant agents ($\bar{r}_{it}^{nc} > \bar{r}_{it}^{c} = p$).[10]

(iii) Inactivity: $\mathbf{y = q = 0}$

For a compliant agent, the price must be at least as high as the quota price for harvest to take place ($p > r_t$), otherwise profits are negative. Similarly, it can be shown that for harvesting to be profitable for a non-compliant agent, price must be higher than $p > \alpha m_i/S_t + 2\phi(\gamma_{it} - 1)$, where γ_{it} is defined as above. These conditions are similar to the conditions that define the maximum quota price the compliant and non-compliant agents, respectively, are willing to pay.

The results thus far are summarised in table 1.

3.2 Market clearing in the quota market

If all agents are identical ($m_i = m \forall i$), each agent will buy a share of the total quota $q^* = \frac{1}{n}Q$ (if fishing is viable). The quota price is determined by the market clearing condition. There are two possibilities; either all agents comply with the quota or all agents violate the quota.

By inserting $q^* = \frac{1}{n}Q$ into the equations stating optimal quota purchases under compliant and non-compliant behaviour q_c^* and q_{nc}^*, respectively, we get equations

[10] Note that this is not a general result. See Hatcher (2005) for a more detailed discussion of how non-compliance affects the quota price in an ITQ fishery.

Table 1: Optimal fisherman behaviour[a]

	Compliance $r_t \leq \alpha m_i / S_t$	**Non-compliance** $r_t > \alpha m_i / S_t$
Active	$r_t \leq p$ $y_{it}^c = q_{it}^c = \frac{X_t}{2c}(p - r_t)$	$r_t \leq p + \frac{1}{4\phi}\left(p - \frac{\alpha m_i}{S_t}\right)^2$ $y_{it}^{nc} = \frac{X_t}{2c}\left[p - 2\phi(\gamma_{it} - 1) - \frac{\alpha m_i}{S_t}\right]$ $q_{it}^{nc} = y_{it}^{nc} / \gamma_{it}$
Inactive	$r_t > p$ $y_{it}^c = q_{it}^c = 0$	$r_t > p + \frac{1}{4\phi}\left(p - \frac{\alpha m_i}{S_t}\right)^2$ $y_{it}^{nc} = q_{it}^{nc} = 0$

[a]Where $\gamma_{it} = \sqrt{\frac{1}{\phi}(r_t + \phi - \alpha m_i / S_t)}$.

that can be solved for equilibrium quota prices. This gives the following:

$$r_c^* = p - \frac{2cQ}{Xn} \tag{17}$$

$$r_{nc}^* = \left[\left(\frac{p + 2\phi - \alpha m/S}{\frac{2cQ}{Xn} + 2\phi}\right)^2 - 1\right]\phi + \frac{\alpha m}{S}. \tag{18}$$

By combining this with the agents' compliance conditions given in table 1, it can be shown that agents comply if the following condition holds:

$$\frac{Q}{n} \geq \frac{X}{2c}\left(p - \frac{\alpha m}{S}\right). \tag{19}$$

This is because the higher the total quota, the lower the quota price, everything else held constant. In addition we know that agents comply when quota price is low, and prefer to violate quotas at high quota prices.

If agents are heterogeneous, the distribution of moral norms determines the quota price and each fisherman's quota demand. I will get back to this when we turn to the numerical example in the next section.

3.3 Numerical Analysis

The focus of this part of the study is on the dynamics of a fishery, in particularly, on the impact of dynamic social norms, and on the assumptions taken by the regulator as to whether illegal harvesting takes place. This is analysed by use of numerical simulations. The parameters used in the numerical analysis are given in table 2.

Table 2: Parameter specification

Parameter	Value	Description
K	100	Carrying capacity of the stock
a	0.5	Intrinsic growth rate of the stock
ϵ_g	0.2	Parameter, z_t distribution
p	2	Price
c	0.5	Parameter, harvesting cost function
n	100	Number of (potential) fishermen in fleet
α	1	Parameter, moral cost function
$\bar{m}$	1.35	Mean, moral norm distribution (m_i)
σ_m	0.1	Standard deviation, moral norm distribution (m_i)
ω	0.25	Adjustment parameter, social norm (S_t)
ϕ	5	Parameter, punishment function

I assume that the desired stock level $\bar{X}$ has been determined by someone who seeks to maximise expected net discounted profits from the fishery. The optimisation problem to be solved is then

$$\max_{\bar{X}} E_0 \left\{ \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} \left(pY_t - \frac{cY_t^2}{X_t} \right) \right\}, \tag{20}$$

where $Y_t = X_t + G(X_t) - \bar{X}$, subject to the stock dynamics equation (1). For discount rate $\delta = 0.07$ and other parameters as given in table 2, the optimal stock level is $\bar{X} = 45.17$. This is used as the target biomass level in what follows.

The regulator is assumed to base his decisions on the initial stock size. The actual total harvest as a response to the quota he sets is not known as he cannot observe the agents' moral norms m_i nor the social norm variable S_t. Neither does he know the total quantity landed. As a benchmark case, I assume the regulator expects total harvest to be given by the sum of profit maximising harvest if all agents are identical and have no moral costs ($m_i = 0 \forall i$). Notice that as there are no moral costs involved, the regulator assumes the fleet always violates quotas to some degree (cf. table 1). Consequently, he has the following expectation about harvest as a function of quota (cf. equation 2):

$$E_t [Y_t | Q_t] = \frac{nX_t}{2c} \left[p + 2\phi - \phi \left(\frac{p+2\phi}{\frac{cQ_t}{nX_t} + \phi} \right) \right]. \tag{21}$$

Equation (21) is found by inserting the market clearing quota price r^*_{nc} from equation

(18) into equation (14), which gives optimal harvest by a non-compliant agent, and multiplying by the number of fishermen n. By not taking into account moral and social norms, the regulator expects total harvest to be higher or, at least as high, as what will occur.

By inserting expected harvest from equation (21) into equation (2) and solving for Q_t, I get the following quota rule:

$$Q_t = \frac{2\phi\left(X_t + G(X_t) - \bar{X}\right)}{p + 2\phi - \frac{2c}{nX_t}\left(X_t + G(X_t) - \bar{X}\right)}. \tag{22}$$

If $X_t + G(X_t) \leq \bar{X}$, the quota is zero.

As time passes by, the regulator may learn more about the agents' response to quota. Based on historic data, he can learn how to improve predictions of total harvest as a function of quota and other model parameters. This is investigated numerically by analysing two different cases; (A) the regulator follows the quota policy given by equation (22), and (B) quota is set using an unbiased expectation of harvest as a function of quota (cf. equation 21). The more the regulator learns about the harvesting behaviour of the fishermen, the closer he will get to case (B).

The results presented in what follows are obtained by use of numerical simulations. The results are based on 500 simulations over $T = 50$ time periods. The initial stock is set to $X_0 = 0.45$ and the initial value of the social norm variable is $S_0 = 1$.[11] When determining the market clearing rental price of quotas for each simulation and time period, a root-finding method is used. For every simulation, n values of the moral norm variable m_i $(i = 1, ..., n)$ are drawn randomly from a log-normal distribution, and T values of the stochastic growth parameter z_t $(t = 1, ..., T)$ are drawn from a uniform distribution (cf. table 2).

Some of the numerical results are shown in table 3. Since I assume the regulator under A ignores agents' moral norms when calculating expected total harvest as a function of quota, he ends up with a stock that is higher than the target level ($\bar{X} = 45.17$).

The social norm variable increases over time and levels out at about 1.09. The compliance dynamics of the model is shown in figure 1. With the parameter specification from table 2, no agents harvest in compliance with quotas. Either they are inactive or they harvest more than legally allow for by their quota. As the social norm variable increases, the number of active, non-compliant fishermen de-

[11] Neither the choice of initial values for X and S, nor the other parameter values qualitatively affect the results. The only requirement is that fishing is viable and that at least some fishermen find it optimal to violate their quotas.

Table 3: Numerical Results. (*Mean values with standard deviations in parentheses.*)

Parameter	A		B	
X	46.345	(1.440)	45.181	(1.430)
Y	12.431	(1.360)	12.381	(1.498)
Q	11.336	(1.244)		
r	2.037	(0.002)		
S	1.097	(0.002)		
Share, inactive	0.587	(0.044)		
Share, compliant	0.000	(0.000)		
Share, non-compl.	0.413	(0.044)		
$PV_0(\pi)$	339.886	(7.082)	349.880	(7.072)

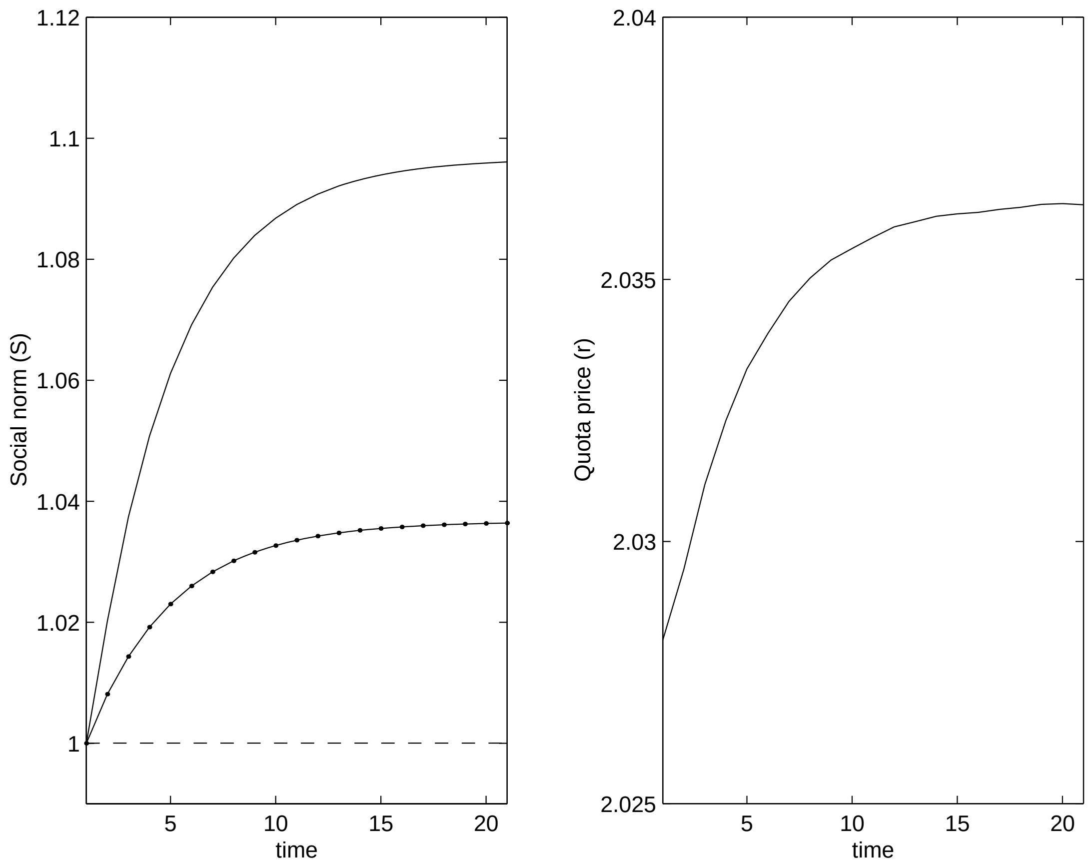
clines and levels out at some 40% (base case). If, however, the price is reduced, the level of non-compliance is also reduced. This can be seen in the first panel of figure 1. A lower price means that it is less profitable to harvest one additional fish. The reduced marginal revenue from illegal harvesting reduces the degree of non-compliance (cf. equations 14 and 15).

The second panel of figure 1 shows the rental price of quota for the base case ($p = 2$, cf. table 2). As the social norm increases, the moral cost of violating quota regulations decreases and the agents are willing to pay more per unit of quota. This explains why the quota price is seen to exhibit the same dynamics as the social norm variable S.

Since the regulator knows the stochastic distribution of the growth of the stock, as well as all the economic parameters of the fleet (harvesting costs and revenues), he will learn more about the fishing fleet's response to total quota as time passes by. I therefore expect the total harvest to approach that of case B over time. This will also increase the present value of the fishery. This can be seen in table 3, where PV_0 represents the present value of future net-revenues from the fishery at time zero. The difference in value between cases A and B can be thought of as the value of information, as information about the fishing fleet's response to harvest quotas is what separates case A from case B.

Turning to the moral norms m_i of the active fishermen (under case A), agent i is active if he has a moral norm $m_i \leq 1.25$ (mean over simulations). The average value of m over the population of active (and also non-compliant) fishermen is 1.17. In comparison, recall that m was distributed log-normally with a mean of 1.35.

Figure 1: Compliance Dynamics: Social Norm and Quota Rental Price. (*Mean values. Social norm evaluated at different values of price; base case* $p = 2$, $p = 1.5$ *dotted line, and* $p = 1$ *dashed line.*)

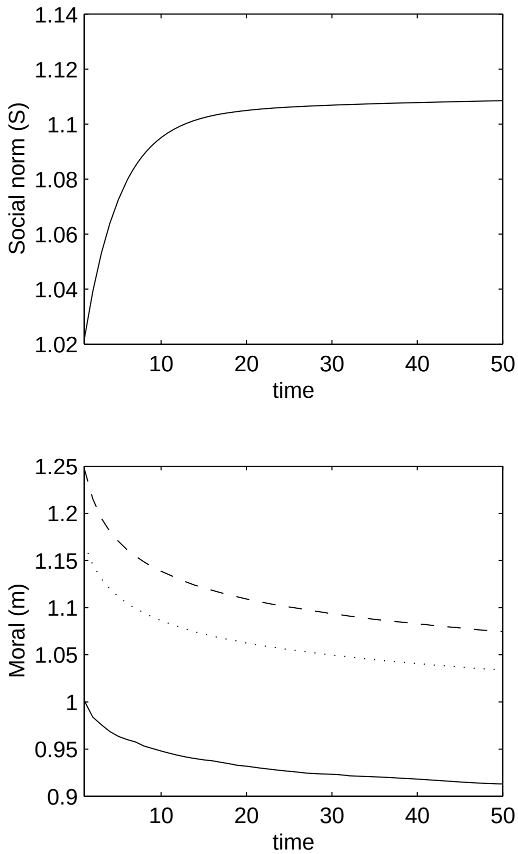


The average fisherman in terms of moral norms is therefore not participating in the fishery. Only the agents with relatively low moral standards participate. Thus, non-compliant fishermen drive honest fishermen out of the fishery.

In the benchmark case, it was assumed that the moral norm parameters m_i ($i = 1, ..., n$) were drawn randomly in every time period. Let us now assume that only the inactive fishermen are replaced by new ones from one period to the next. The moral parameter of the newcomers will as before be drawn randomly from the log normal distribution. The implication of setting it up this way, is that the fishermen with relatively strong moral norms will be replaced, while those with weaker moral norms remain in the fishery. Thus, a stronger effect is expected in terms of quota violations, social norm dynamics, etc. over time.

Some of the results are shown in figure 2. As expected, the social norm variable

Figure 2: Compliance Dynamics: Social Norm, Quota Rental Price, Moral Distribution of Active Fishermen (minimum, mean, and maximum values), and Number of Active Fishermen. (*Mean over simulations.*)



levels out at a higher level than in the base case. Notice also that whereas S and r in the benchmark case seem to reach their long-run equilibrium levels within 20 time periods, these variables are still adjusting toward their long term equilibrium level after 50 time periods in the current case (cf. figure 2). This is because the fishermen with relatively strong moral standards gradually are replaced by fishermen with weaker morals. This is easily seen in the lower-left panel of the figure, which plots the change in the m parameters of the active fishermen over time. Both the minimum, mean, and maximum values are decreasing over time, and are approaching levels far below the average of the population ($\bar{m} = 1.35$). A consequence of this is a higher quota price in this case than what was found when analysing the base case (cf. r in figures 1 and 2).

Furthermore, when only inactive fishermen are replaced from one period to the next, the number of active fishermen is seen to increase over time. This is as expected, as replacement of fishermen will happen until no further deterioration of moral norms can occur, i.e., when no fishermen are replaced by newcomers with weaker moral norms. This means that a higher share of the population of fishermen at all times is active than what was found in the base case scenario. Furthermore, the active fishermen are becoming more and more similar over time.

The results for the other variables of the model are similar to what I found above. After 50 time periods, average values of stock size, total harvest, and total quota are close to, although slightly smaller than, those reported in table 3.

4 Concluding Remarks

The paper develops a dynamic model of a fishery where the fishing fleet has the option to violate the harvest quota. The fishermen act on a period by period basis, and seek to maximise individual welfare from harvesting the stock. In addition to the more traditional parts of a bioeconomic model, I introduce what I have referred to as moral and social norms of quota compliance. This can be thought of as the individual agent's preferences to violating quota regulations. Formally, I do this by introducing a *moral cost*, representing reduced individual welfare of violating harvest quotas. In addition, a social norm of cooperative harvesting is introduced as a state variable in the model. The higher the value of the social norm variable, the lower the welfare loss of harvesting in excess of quotas, as perceived by the individual agent, everything else held constant. The model is used to analyse optimal behaviour by individual agents, as well as the dynamics of the fishery assuming the regulator is seeking to keep the stock at a certain predetermined level. A numerical example is presented to illustrate some of the results.

Fishermen with weak moral norms are more likely to violate harvest quotas. In addition, non-compliant agents may be willing to pay more per unit quota than their compliant colleagues. It was therefore expected that agents with weaker moral norms would dominate the fishery. This was seen to be the case in the example provided. The result is not general, but was seen to hold under what I believe are reasonable assumptions about a fishery. There is obviously a need for further work on this in order to identify more general conditions for when heterogeneity in moral norms leads to a solution in which agents with relatively weak moral norms increase their share of the catches in a fishery whereas agents with stronger moral norms sell out.

Another feature of the model worth noticing is the increased effect of stronger enforcement (i.e., increasing Φ in the model) when accounting for the indirect effects of the social norm. As in traditional models of fishermen's compliance, there is a direct effect of increasing the enforcement level through an increase in expected punishment, which reduces non-compliant behaviour. However, we now also have an indirect effect of strengthening regulatory enforcement. When fishermen today reduce their illegal harvests as a result of tougher enforcement, this will affect the social norm (cf. equation 4), which in turn will have a deterrent effect on non-compliant behaviour in subsequent time periods.

It should also be noted that when analysing real world fisheries, the importance of social and moral norms is likely to depend on the characteristics of the fishery. In his study of regulatory compliance in a fishing community in Norway, Gezelius (2002) finds that "informally enforced moral obligation to obey the law was the single most important factor explaining compliance." The fishing vessels studied by Gezelius (2002) were small coastal vessels. It is unlikely that one would reach the same conclusions if one studied larger, distant-fleet, fisheries where highly mobile vessels can travel long distances to participate in various fisheries. One reason is that the group that creates the social pressure to obey the norm of cooperative harvesting, might be less well-defined in this case (Sethi & Somanathan, 1996).

Little work has been done on how fishermen's social and moral norms can be implemented into bioeconomic models and the implications of this. There are therefore many possibilities of extending the current work. First, I have illustrated how quotas may end up on the hands of people with weaker moral norms, everything else being equal. A cap on the share or number of quotas a single individual can buy or own could weaken this negative effect. One example would be the case of a fishery managed with non-transferable quotas. In this case the agents with weaker moral norms with respect to quota compliance cannot buy quotas from those with stronger moral norms. The loss is the possibility of increasing cost efficiency, as also trade between fishermen with high and low efficiency is banned. A study of these aspects calls for a model in which fishermen are heterogeneous also with respect to harvesting costs. Another possibility for future work is to focus on the game between the fishery manager and the fishermen, e.g. what is the economically optimal strategy for the fishery manager facing a non-compliant fishing fleet? Yet another possible line of research is to take a closer look at what determines social norms in fisheries, e.g. by drawing on experimental economics and field studies.

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