

THE DYNAMICS OF FISHERMEN'S COMPLIANCE

Linda Nøstbakken, Centre for Fisheries Economics, SNF, linda.nostbakken@snf.no

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. Regulator takes on a long term view and sets quota at the beginning of every period in order to maximise an objective function. Fishermen act on a period to 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. 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.

Keywords: Fisheries economics, bioeconomic modelling, quota compliance.

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. Second, to consider fishermen's compliance and fishery regulation in a dynamic framework. Several studies have been done on 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. 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 including stock dynamics makes it possible to analyse some of the implications of this 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? Another interesting aspect of including dynamics is that in an ITQ fishery with heterogenous 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.

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 the regulations.

Another approach has also 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 compliance show how social norms and moral obligations play an important part in the fishermen's compliance decision process (see e.g. Hatcher & Gordon, 2005, and references therein).

This study seeks to present a possible modelling framework for analysing implications of fishermen's moral norms in a simple conceptual bioeconomic model.¹ I analyse *inter alia* the conditions under which fishermen violate quotas, optimal harvest quantity and quota purchase, and how social and moral norms can affect the decisions. The next step is to investigate the dynamics of the fishery.

The paper is organised as follows. In the next section I set up 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 dynamic problem of the regulator is presented and analysed next. The last section concludes.

2 The Model

In this section, I develop a model of a fishery regulated with individual transferrable 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. 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:

$$X_{t+1} - X_t = G(X_t) z_{t+1} - Y_t, \quad (1)$$

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 assumed known by the resource manager. This is how Reed (1979) introduced uncertainty to his bioeconomic model. The term $G(X_t)$ in (1) represents the relationship between stock and stock growth in the deterministic case and is assumed given by $G(X_t) = aX_t \left(1 - \frac{X_t}{K}\right)$, where a is the intrinsic growth rate of the stock, and K is the carrying capacity of the environment.

It is assumed the regulator seeks to keep the stock at a certain 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} :

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

¹The term "moral" is used here rather loosely to refer to the fishermen's preferences with respect to violating regulations and social norms.

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.

Harvesting costs 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 .² The cost function is convex and increasing in harvest, and it is decreasing in stock (stock effects are ignored within season).

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 .³

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

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

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

The model presented thus far follows along the line of 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 with 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. Depending on the agent's moral beliefs and on the social norm with respect to quota compliance, violating the harvest 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 (measured in value) 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, with dynamics given as follows:

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

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 of the underlying realities.

²Total harvest by the fleet is given as the sum of individual harvest quantities: $Y_t = \sum_{i=1}^n y_{it}$.

³Enforcement Φ is assumed exogenous to the model.

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, at some point the moral cost of violating regulations outweighs the marginal revenue of violating quotas and the agent always complies. Each agent's moral norm is private knowledge and cannot be used (strategically) by the fishery regulator or anybody else.

The introduction of moral costs adds another term to the fishermen's welfare maximisation problem, which can be written:⁴

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

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:

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

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

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

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

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

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 morals in the model, the only difference is that the fishermen now also takes into account the marginal moral cost 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

In this section, I start out by specifying the bioeconomic model. 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 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.

⁴For ease of notation, the time dependence of all variables is mostly suppressed throughout the paper.

- 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 . To reflect that fishermen may come and go from the fishermen population from period to period, n values of m is drawn randomly every period.⁵
- 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 the following.

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

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

The first order conditions are:⁶

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

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

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 $q \rightarrow 0$ 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 the fishermen's optimal actions (y^*, q^*) as functions of the other parameters of the model.

(i) Compliance: $y = q > 0$

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

$$p - \frac{2cy_{it}}{X_t} = r_t, \quad (12)$$

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

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

It is easily confirmed that per period harvest by agent i is increasing in stock size (due to reduced cost of harvesting from 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.

⁵For simplicity, the number of fishermen in the population is assumed constant over time ($n_t = n \forall t$).

⁶The welfare function is concave and the first order conditions are therefore necessary and sufficient for a maximum.

(ii) Non-compliance: $y > q > 0$

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 conditions (equations 10 and 11) can be solved for optimal values of total harvest and quota purchase as follows:

$$y_{it}^* = \frac{X_t}{2c} \left[p - 2\phi(\gamma_{it} - 1) - \frac{\alpha m_i}{S_t} \right] \quad (14)$$

$$q_{it}^* = y_{it}^* / \gamma_{it}, \quad (15)$$

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

It is easily seen 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 degree of 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:

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

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 ($\bar{r}_{it}^{nc} > \bar{r}_{it}^c = p$).

(iii) Inactivity: $y = q = 0$

For a compliant agent, the price must be higher than 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 those defining 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; all agents comply or all agents violate the quota.

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

Table 1: Optimal fisherman behaviour^a

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

^aWhere $\gamma_{it} = \sqrt{\frac{1}{\phi} (r_t + \phi - \alpha m_i / S_t)}$.

equilibrium quota prices. This gives the following:

$$r_c^* = p - \frac{2cQ}{Xn} \quad (17)$$

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

By combining this with the conditions for whether agents comply with their quotas (cf. table 1), I find that agents comply if the following condition holds:

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

This is because, the higher the total quota, the lower the quota price, every thing 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 heterogenous, the distribution of moral determines the quota price and each fisherman's quota demand. I will get back to this in the numerical example in the next section.

3.3 Numerical Analysis

The focus of this part of the study is on how the dynamics of a fishery depends 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.

I assume that \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

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

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 of 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

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. In addition to this, he knows the size of the total quota with certainty. The actual total harvest as a response to the quota is not known as he cannot observe the agents' moral norms m_i nor the social norm variable S_t . 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 ($m_i = 0 \forall i$). Consequently, he has the following expectation about harvest as a function of quota (cf. equation 2):

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

Notice that as there is no moral costs involved, the regulator assumes the fleet always violates quotas to some degree (cf. table 1). By inserting expected harvest from equation (21) into equation (2) and solving for Q_t , I get the following quota rule:

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

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. All simulations are run in

Matlab. The initial stock is set to $X_0 = 0.45$ and the initial value of the social norm variable is $S_0 = 1$. When determining the market clearing rental price of quotas for each simulation and time period, Newton’s method is used. For every simulation, n values of the moral norm variable m_i ($i = 1, \dots, n$) is drawn randomly from a log-normal distribution, and T values of the stochastic growth parameter z_t ($t = 1, \dots, T$) is drawn from a uniform distribution (cf. table 2).

Table 3: Numerical Results. (*Mean values, 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)

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 ($\bar{X} = 45.17$).

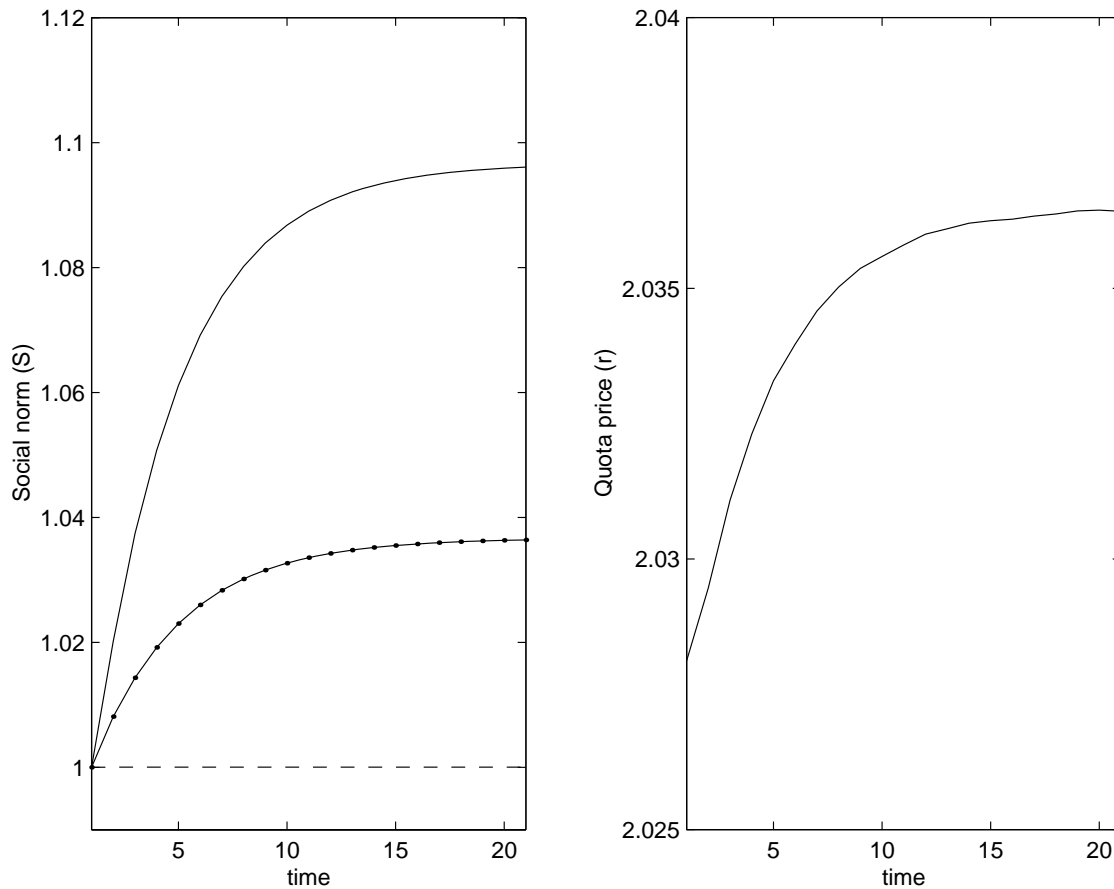
The social norm variable increases over time and levels out at about 1.09. The compliance dynamics of the model is shown in figure 1. With the parameter specification from table 2, no agents harvest in compliance with quotas. Either they are inactive or they harvest more than their quotas allow for.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

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 decrease 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 the quota he sets as time passes by. I therefore expect the total harvest to approach the case B. 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 all future monetary profits 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

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.*)



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. The average fisherman in terms of moral norms is therefore not participating in the fishery. Only the agents with relatively low moral standards participates.

4 Concluding Remarks

The paper develops a dynamic model of a fishery where the fishing fleet is allowed to violate the harvest quota. The fishermen act on a period to 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. 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, social norm is introduced as a state variable in the model. The higher the value of the social norm variable, the lower the moral cost as perceived by the individual agent, everything else being 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.

References

- Hatcher, A. & Gordon, D. V. (2005). Further investigation into the factors affecting compliance with U.K. fishing quotas. *Land Economics*, 81(1), 71–86.
- Reed, W. J. (1979). Optimal escapement levels in stochastic and deterministic harvesting models. *Journal of Environmental Economics and Management*, 6, 350–363.
- Sutinen, J. G. & Andersen, P. (1985). The economics of fisheries law enforcement. *Land Economics*, 61(4), 387–397.
- Sutinen, J. G. & Kuperan, K. (1999). A socio-economic theory of regulatory compliance. *International Journal of Social Economics*, 26(1-3), 174–193.