

**Working Paper No. 27/08**

**When is fish quota enforcement worth while?  
A study of the Northeast Arctic cod**

**by**

**Rögnvaldur Hannesson**

SNF Project No. 5181

The effect of political uncertainty in fisheries management:  
A case study of the Northeast Arctic cod fishery

The project is financed by the Research Council of Norway

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS  
ADMINISTRATION  
BERGEN, September 2008  
ISSN 1503-2140

© Dette eksemplar er fremstilt etter avtale  
med KOPINOR, Stenergate 1, 0050 Oslo.  
Ytterligere eksemplarfremstilling uten avtale  
og i strid med åndsverkloven er straffbart  
og kan medføre erstatningsansvar.



# **When is fish quota enforcement worth while?**

## **A study of the Northeast Arctic cod**

Rögnvaldur Hannesson  
The Norwegian School of Economics and Business Administration  
Helleveien 30  
N-5045 Bergen

Phone: +47 55 95 92 60

Fax: +47 55 95 95 43

E-mail: rognvaldur.hannesson@nhh.no

### **Abstract**

Many fish stocks are controlled by fish quotas divided among individual firms. Such quota regimes need an enforcement mechanism in order to be effective. Whether or not quota management regimes are worth while depends on whether the rents generated by such regimes cover their costs. Cost-efficient quota regimes would attain an optimal deterrence through minimal control and high fines, but in practice there are likely to be socially-determined limits on how high fines could be set. For shared stocks, the optimal degree of enforcement in one country depends critically on the degree of enforcement achieved by the other countries involved. We analyze these questions for the Northeast Arctic cod stock, using data on enforcement of Norwegian fish quotas.

March 2008

## 1. INTRODUCTION

The absence of sole ownership to fish stocks necessitates control of the fishing industry.<sup>1</sup> Under open access, individual firms have incentives to deplete fish stocks below their rent-maximizing level, possibly to extinction. Over the years these controls have increasingly come in the form of catch quotas. To avoid excessive fleet capacity and unnecessarily short fishing seasons, overall catch quotas have been divided among the firms in the industry and often made tradable.

Unfortunately, individual firms have incentives to overfish their quotas. Even if such overfishing leads to lower future rents, this loss is borne collectively by all firms, with only a small part being borne by the offending firm in an industry with many firms. Management by individual boat or firm quotas will thus be less than fully effective without monitoring whether the firms abide by their quotas, followed by suitable punishment if they do not. This is a typical situation of choosing whether or not to engage in illegal activities. Ever since Becker's essay on the economics of crime (Becker, 1968), economists have tended to look at this as a rational decision where the expected utility of criminal behavior is compared to the utility of abiding by the law.

Becker's approach gives little leeway to moral and other issues often expected to affect criminal behavior. In his own words "[I]t is suggested, for example, that a useful theory of criminal behavior can dispense with special theories of anomie, psychological inadequacies, or inheritance of special traits and simply extend the economist's usual analysis of choice" (Becker, 1968. p. 170). While it may be preposterous to dismiss all non-economic issues to the margin or beyond, it is highly likely that such issues impact criminal behavior differently, depending on the kind of offense involved. As for overfishing, it seems likely that such decisions have few moral or non-economic overtones and will be influenced predominantly by a rational calculus of economic gain and loss.

To our knowledge, Andersen and Sutinen (1985) were the first to apply Becker's approach to the fishing industry. In their paper, enforcement is an integral part of fisheries management, and its costs depend on the quantity caught and the size of the fish stock. The optimal rate of exploitation depends on enforcement costs, so that both are determined simultaneously through maximizing the fishing industry's contribution to social welfare. Anderson and Lee (1986) and Charles et al. (1999) provide further theoretical refinements comparing input and output control instruments. A recent theoretical contribution is Chavez and Salgado (2005), which considers an ITQ fishery where there is imperfect enforcement, dealing specifically with how quota markets might affect the incentives to overfish and how the regulatory authorities might avoid negative feedback on compliance from quota markets. Over the years, a number of empirical investigations of enforcement of fisheries regulations have appeared (Sutinen and Gauvin, 1989; Furlong, 1991; Kuperan and Sutinen, 1998; Bodman, Campbell and Skinner, 2002), all of which have relied on Becker's approach.

---

<sup>1</sup> The classic reference on sole ownership is Scott (1955).

This paper deals with overfishing of the Northeast Arctic cod stock, in the spirit of Becker and Andersen and Sutinen. Fishing firms are assumed to overfish their quotas if their rent from doing so in the current fishing period exceeds what they would obtain from their own quotas alone, given the probability of being detected and the resulting punishment. The capacity to overfish is simply assumed to exist, but one may ask why it does so and to what extent. It is highly likely that overfishing capacity depends on the effectiveness of enforcement, so that lax enforcement will generate incentives to invest in such capacity; without any enforcement at all we would probably end up in a situation similar to open access. We shall not pursue these questions here, but concentrate on the question how much loss a given capacity to overfish will produce and what are the implications for the enforcement activity.

One question we shall pursue in some detail is the implications of the cost structure in the industry for overfishing. By cost structure we mean whether or not the unit cost of fish caught is sensitive to the size of the exploited stock. One popular approach is the Schaefer production function, which implies that the cost per unit of fish caught is inversely proportional to the stock size. Another possibility at the opposite end of the spectrum is that the unit cost of fish is independent of the stock size. We shall examine both of these. It turns out that the implications for overfishing are quite different in these two polar cases.

Enforcement costs are seen as arising from activities that affect the probability of detecting overfishing. We assume that this probability depends only on the enforcement activities and is independent of the quantity caught. Furthermore it is always possible to find a suitable combination of enforcement and fine to ensure full compliance. Hence the optimal overall quota is independent of enforcement costs; in this we depart from Andersen and Sutinen (1985). We do not consider any feedback from quota markets (Chavez and Salgado, 2005), as leasing of fish quotas is not permitted in the case at hand, even if there is a restricted long-term transferability of quota allocation rights.

We begin (Section 2) by presenting the theoretical framework. In Section 3 we move on to a simplified empirical model of the fish stock under study. This is an aggregate biomass model with annual recruitment to the stock where stock growth is partly stock-dependent, but also governed by random, environmental effects. Recruitment, which apparently is only weakly or not at all related to the size of the stock, is determined by a random effect but serially correlated. The fishery is regulated by global quotas set on the basis of a target exploitation rate, taken to be rent-maximizing.

Next (Section 4) we consider the rent loss from overfishing in the absence of enforcement, for various constellations of capacity to overfish and costs of fishing. We then (Section 5) consider enforcement activities; how much enforcement would be worthwhile, and what would be the appropriate fine for any given level of enforcement.

The said calculations are carried out for the stock as a whole, as if there was only one regulatory authority. In reality the stock is shared evenly between two countries, Norway and Russia. It is natural, then, to ask whether enforcement by one country makes sense if

the other does not enforce its own quotas. This is the subject of Section 6, and the answer, not surprisingly perhaps, is no.

Finally (Section 7) we ask whether the Norwegian enforcement activities would be reasonable, provided that the other part enforces its quotas likewise. We provide a rough estimate of the cost of the probability of detecting overfishing and compare the fines meted out in a number of court cases involving overfishing to what would be an appropriate deterrent.

## 2. THEORETICAL FRAMEWORK

We assume a price-taking, profit-maximizing firm. To maximize profits, marginal cost ( $C$ ) must be equal to price ( $p$ ):

$$(1) \quad p = C(q, S)$$

Marginal cost will depend on the quantity of fish caught ( $q$ ) and, usually, on the size of the fish stock ( $S$ ) as well. The larger the fish stock, the lower the marginal cost is likely to be, all else equal. The larger the fish stock, the more dense it is likely to be, so more fish will get entangled in nets or be caught by trawls per unit of time, or the more easily suitable concentrations of fish will be found.

We shall consider a management regime where the firm is allowed to catch a certain quantity of fish,  $\bar{q}$ , within a certain period of time, referred to as quota. In case this is less than the quantity that equalizes price and marginal cost (Equation [1]), the firm will have an incentive to exceed its quota. If quotas are enforced, there will be a certain probability that a quota-exceeding firm will be found out and punished for its violation. The punishment, which we shall assume is a fine, could be related to by how much the firm's quota is exceeded, but we shall for simplicity disregard that and assume that there is a lump sum fine depending only on whether or not the quota has been exceeded.<sup>2</sup> Denoting the given fine by  $F$  and the probability of detection by  $a$ , the firm will maximize

$$(2) \quad \pi(q) = pq - \int_0^q C(x, S) dx - K - aF(q - \bar{q})$$

where  $F > 0$  and given if  $q > \bar{q}$  and zero otherwise, while  $K$  denotes fixed costs.<sup>3</sup> To ensure that the firm stays within its quota limit, it is necessary that

---

<sup>2</sup> It would not be entirely correct to characterize fines for overfishing in Norway as lump sums, but they are certainly not proportional to the catch value or amount of fish caught beyond quota (see Table 9 below for some cases that have gone to court). There exists a legal authorization for confiscating catches and fishing gear, but this is not much used; in the period 1997-2004 such confiscations amounted to less than 0.1 percent of the catch value (Directorate of Fisheries, 2006).

<sup>3</sup> Note that the  $S$  (the stock level) is not constant as we integrate from 0 to  $q$ , as any fishing reduces the stock, but this is beyond the control of the individual firm. As we integrate over  $q$  we implicitly assume a simultaneous change in  $S$  given by the fishing patterns of all firms in the industry.

$$(3) \quad p\bar{q} - \int_0^{\bar{q}} C(x, S) dx \geq pq^* - \int_0^{q^*} C(x, S) dx - aF$$

where  $q^*$  is the catch volume that would satisfy (1). Because of the lump sum character of the fine it pays to overfish to the point where the marginal cost of fish equals the price. To avert overfishing the gain from exceeding one's quota must be less than the expected fine for doing so.

One important thing to note from (3) is the trade-off between the size of the fine and the probability of detection. Since the latter depends on costly enforcement activity while the fine is primarily a monetary transfer, the most efficient solution is to impose a very high fine and use a minimum of enforcement activity. However, there are likely to be social limits to how high the fine could be set, such that it could not be too far out of line with the offense committed. There could also be real social costs of very high fines; such fines might seriously reduce the economic options of those who have to pay the fine.

Fisheries management measures such as quota control are put in place to improve the future profitability of the fishery. Under the worst of circumstances, such control could even be necessary to ensure the future viability of the fish stock. The economic benefit of quota control and the necessary enforcement can be evaluated by intertemporal bioeconomic models, such as the one to be presented below. At this point we may note that the harmful effects of overfishing will depend critically on the effect of the stock on the marginal cost of fishing. Differentiating (1), with  $p$  constant, yields (subscripts denote partial derivatives):

$$(4) \quad \frac{dq}{dS} = -\frac{C_s}{C_q} > 0 \text{ if } C_s < 0$$

that is, a larger stock will entice the firm to fish more if it lowers the marginal cost of fishing, all else equal. But this does not necessarily mean stronger incentives to overfish. Usually catch quotas are set on the basis of stock assessment in such a way that the quota rises with the stock and vice versa. Denoting the quota-setting rule by  $G(S)$ , overfishing will change as a consequence of an increasing stock as follows:

$$(5) \quad \frac{dq}{dS} - \frac{d\bar{q}}{dS} = -\frac{C_s}{C_q} - G'$$

Since  $G' > 0$ , overfishing will fall if the stock increases, unless the marginal cost of fishing is sufficiently sensitive to the size of the fish stock ( $-C_s$  is sufficiently large). As an example, consider the case where the catch quota is a certain fraction of the stock,  $\bar{q} = kS$ . We then get

$$(5') \quad \frac{dq}{dS} - \frac{d\bar{q}}{dS} = -\frac{C_s}{C_q} - k = k \left( \frac{\text{El}_s}{\text{El}_q} - 1 \right)$$

where El is the elasticity of the marginal cost function at the point  $q = \bar{q}$ . If the marginal cost function is less sensitive to the stock size than to the quantity caught, a decline in the fish stock will lead to overfishing, the reference situation being one where there was none to begin with and there is not sufficient deterrence to overfishing.

That overfishing will increase if the stock declines is a particularly undesirable situation. The smaller the stock, the less able it is to withstand excessive exploitation. The risk of depleting it below a possible minimum level of viability will be all the greater. This is what happens if the marginal cost of fishing is insensitive to, or independent of, the size of the stock. This is a variation on a theme well established in the literature; the only thing that protects an open access fish stock from extinction is that the cost per unit of fish rises sufficiently as the stock is depleted. The opposite situation where overfishing increases with the stock is much less of a problem, even if undesirable, as a larger stock is better able to withstand overexploitation.

### 3. THE MODEL

Empirical management models of the Northeast Arctic cod are of the Beverton-Holt type, i.e., age-structured. For our purposes it appears sufficient, and much simpler, to employ a biomass model, where the stock ( $X$ ) at the beginning of each year depends on recruitment ( $R$ ) to the stock each year and the stock less fishing ( $Y$ ) the previous year:

$$(6) \quad X_{t+1} - R_{t+1} = a(X_t - Y_t) - b(X_t - Y_t)^2$$

Data on these variables were taken from ICES (2007). Table 1 shows the results of estimating the parameters  $a$  and  $b$ .<sup>4</sup> The model is capable of reproducing the development of the stock rather well, as illustrated in Figure 1. The simulation in Figure 1 takes the initial stock (1946) as given and then updates it according to the parameters in Table 1, the estimated recruitment each year, and the fraction of the stock that is caught each year.<sup>5</sup>

As is evident from Figure 1, the stock fluctuates considerably over time. These fluctuations are generated by fluctuations in recruitment. There is also a strong serial correlation in recruitment (cf. Table 2),<sup>6</sup> but apparently only weak or no relation at all

<sup>4</sup> The estimation procedure is OLS with the “robust” option, which corrects for heteroscedasticity. The Breusch-Pagan test soundly rejects homoscedasticity, and as we shall see later, the residuals from the regression are approximately lognormally distributed.

<sup>5</sup> For further details on the model, see Hannesson (2007); here the data have been updated in accordance with ICES (2007), which had a minimal effect on the estimates.

<sup>6</sup> Also here the estimation procedure is OLS with the robust option. As we shall see later, the residuals from the regression are approximately lognormally distributed, and the Breusch-Pagan test rejects homoscedasticity.



between recruitment and the size of the spawning stock, as indicated by Figure 2. After accounting for the serial correlation in recruitment, the residual recruitment is approximately lognormally distributed, after a suitable transformation,<sup>7</sup> as shown in Figure 3.

Table 1

Results of estimating the coefficients in Equation (1), with a constant ( $a_0$ ) added, from data for 1946-2005. Significance at the 1 percent level is denoted by \*\*. Numbers in parentheses are t-values. The numbers in the last row are estimates without a constant and used in the paper.

$a_0$	$a$	$b$	$R^2$	$D-W$ statistic
71.4 (0.82)	1.4658** (10.96)	0.000121** (3.07)	0.94	2.26
	1.558	0.000145		

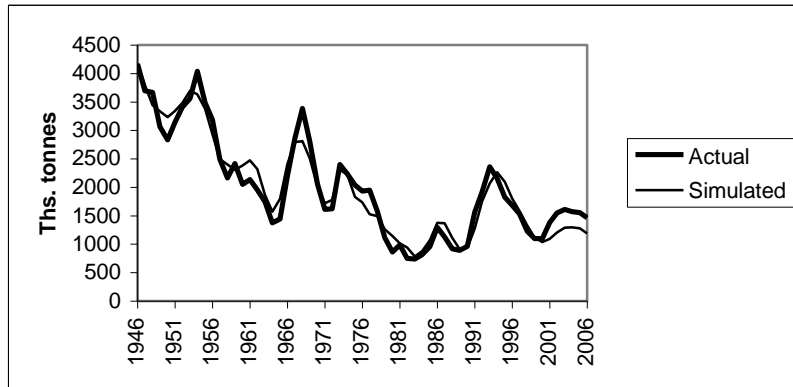


Figure 1: Actual and simulated development of the Northeast Arctic cod stock.

<sup>7</sup> The residual recruitment is  $R_t - a_0 + a_1R_{t-1} + a_2R_{t-2}$ . After taking logarithms we adjust the mean so that the absolute value of the logarithm of the highest and lowest disturbance is the same. The resulting distribution is shown in Figure 3.

Table 2

Results of estimating the equation  $R_t = a_0 + a_1R_{t-1} + a_2R_{t-2} + a_3R_{t-3}$ . Significance at the 1 (10) percent level is denoted by \*\*(\*) . Numbers in parentheses are t-values.

$a_0$	$a_1$	$a_2$	$a_3$	$R^2$ (adj.)
132.4** (4.52)	0.6407** (3.301)	-0.2823* (-1.87)		0.29
144.4** (4.74)	0.6160** (3.11)	-0.2279 (-1.32)	-.0863 (-1.13)	0.28

The growth of the existing stock is also influenced by random environmental events. The random fluctuations in growth are given by the residuals in (6) and turn out to be approximately lognormally distributed, after a transformation similar to the one applied to the random disturbances in recruitment (Figure 4). There is no significant serial correlation in the growth disturbances.

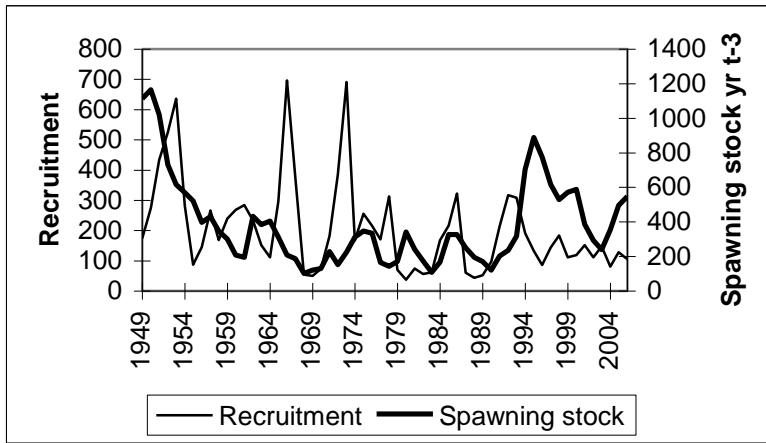


Figure 2: Recruitment (biomass of 3 years old fish) and spawning stock 3 years earlier (ths. tonnes).

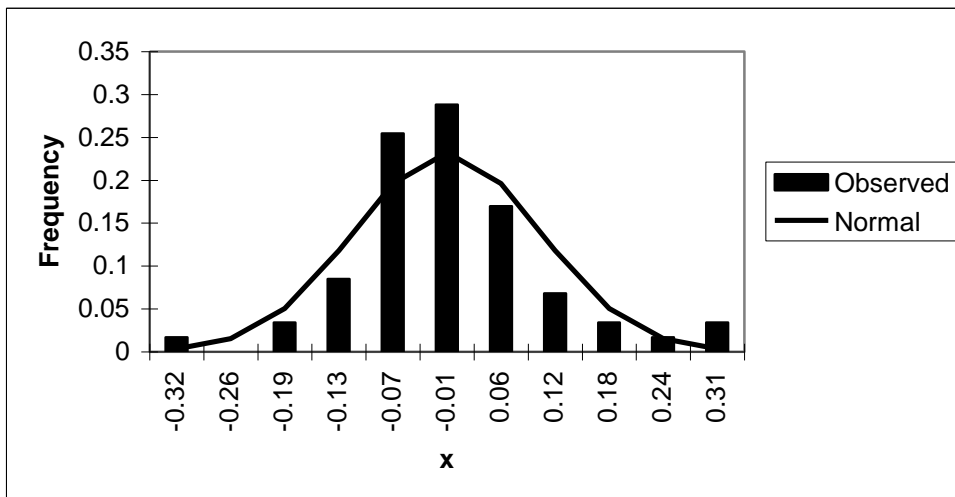


Figure 3: Distribution of the transformed disturbances ( $x$ ) to a serially correlated recruitment compared with a normal variable.

To investigate the effects of overfishing, we assume that annual quotas are set on the basis of a constant rate of exploitation that maximizes the present value of rents in the fishery. We then look at the net present value of rents with and without enforcement. The stock is simulated 2000 times over a 100 year time horizon for given starting values by drawing random variables that influence recruitment and stock growth each year.<sup>8</sup> The comparison between overfishing and adherence to quotas is made for the same drawings of the random variables over each 100-year period, whereafter expected values are taken over the number of simulations.

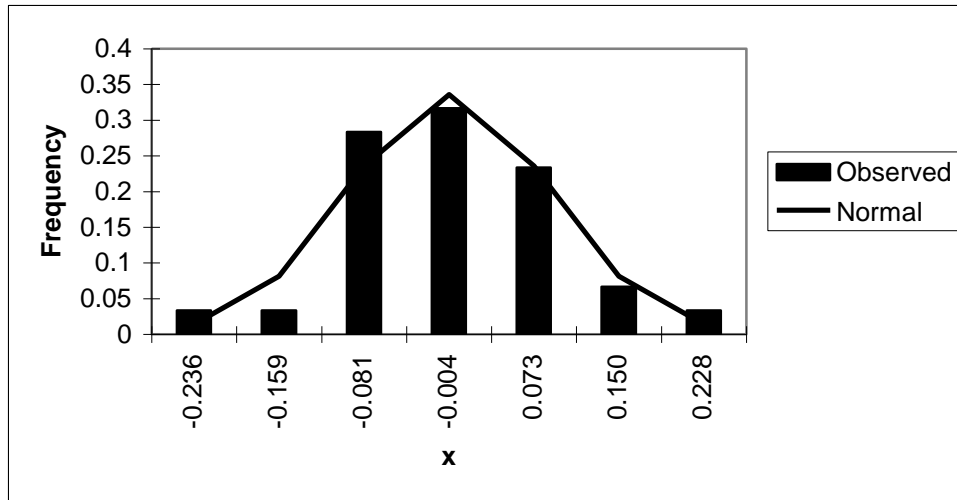


Figure 4: Distribution of the transformed disturbances ( $x$ ) to the growth equation compared with a normal variable.

#### 4. THE LOSS FROM OVERFISHING

In Section 2 above we presented a theoretical framework for the analysis of overfishing, focusing on the importance of the dependence of marginal costs on the size of the fish stock. In the absence of empirically well-founded marginal cost functions for the Norwegian fishing fleet, we shall use two stylized cost functions which bring to the fore the critical importance of how costs depend on the fish stock. One is based on the well-known Schaefer production function and implies a strong dependence of the marginal cost of fish on the size of the stock:<sup>9</sup>

$$(7) \quad Y = EqS$$

<sup>8</sup> The starting value for the stock in each case is set close to the average standing stock with a sustained exploitation at the optimal level.

<sup>9</sup> Another possibility would be a weaker stock-dependence than in (2), such as  $Y = EqS^b$ ,  $0 < b < 1$ , but we shall not pursue that matter further here.

where  $Y$  is the catch of fish,  $E$  is fishing effort and  $S$  is the fish stock. With a constant cost per unit of effort, this leads to the following expression for the rent ( $\pi$ ) in year  $t$ :

$$(8) \quad \pi = p(X_t - S_t) - c(\ln X_t - \ln S_t)$$

where  $p$  is the price of fish, which we will normalize at unity,  $c$  is a cost parameter which, with  $p = 1$  and  $q = 1$ , is equal to the break-even level of the stock,  $X$  is the stock in the beginning of the year, and  $S$  is the stock left after fishing.<sup>10</sup>

Identifying  $E$  with the number of fishing vessels used for normal operating time per year, their capacity to catch fish will depend on the size of the stock. In the absence of regulations, the stock would be depleted to the break-even level  $c$ . A regulation which aims at always catching a given share  $k^*$  of the stock would automatically be satisfied if  $E$  is determined as  $E^* = k^*/q$  and given that all boats are used for normal operating time. But if  $E$  exceeds this value, either because there are more boats than necessary or the boats are used more intensively, overfishing in terms of tonnes will be proportional to the stock size, for any given amount of excessive effort. We shall take the somewhat crude approach that the capacity to overfish is a given percentage of what would be needed to capture the optimal quota and will always be fully used, except that fishing will stop if the stock is reduced to the break-even level.<sup>11</sup>

The other cost function we shall consider is one where the marginal fishing cost is constant up to a certain catch volume, whereafter it becomes vertical, and independent of the size of the fish stock. We then get the following expression for the rent:

$$(9) \quad \pi = (p - c_v)Y - c_f N, \quad Y \leq qN$$

where  $c_v$  is variable cost per unit of fish,  $c_f$  is the fixed cost per boat, with the catch being proportional to the number of boats ( $N$ ) if fully used. The implications for overfishing are radically different under this assumption. Suppose that the stock is controlled by a target catch. The target catch would in all probability be a rising function of the stock size; two possible management rules that would lead to that outcome are a target rate of exploitation (such as the  $k^*$  above) and a target escapement (target stock to be left behind after fishing). In this case the degree of overfishing would be inversely related to the stock. Suppose that the stock is controlled by a target exploitation rate and that we have exactly the right number of boats to catch the fish we are allowed to take when the stock is at a normal level. But when the stock is below normal because of adverse environmental circumstances the existing boats could catch more fish, and since the marginal cost of fishing is independent of the stock size the boats would, in the absence

<sup>10</sup> In this formulation, growth and natural mortality are assumed to take place after fishing, for convenience.

<sup>11</sup> This implies a linear cost function of fishing, until the capacity limit is reached, at which it becomes vertical. As the stock is depleted the marginal cost line drifts upwards, and fishing becomes uneconomical when the break-even stock level has been reached. The break-even level will be determined by variable costs and would thus be below the  $c$ -parameter if the latter includes fixed costs, but we shall not pursue that matter further here.

of any controls, be fully used, the catches of fish would be the same as otherwise, and the overfishing would be greater the smaller the stock is.

The loss from overfishing stems from reducing the stock to a lower level than otherwise would be the case, leading to lower future rents, given that the set quotas maximize the present value of aggregate rents. Consider, first, the Schaefer case (7) and let the stock be controlled by a target exploitation rate  $k^*$  maximizing the present value of rents. If we have more boats than we need to take the stipulated share of the stock, the boats will overfish their quotas by a certain percentage, except that they would never deplete the stock below the break-even level ( $c$ ).

Running the model of Section 3 with and without overfishing and ignoring enforcement produces the results in Table 3. Overfishing capacity of 10 percent results in only a moderate reduction in rents, of the order of 1-2 percent, while overfishing capacity of 50 percent reduces rents by 20-30 percent, depending on fishing costs. The table also shows the average size of the stock, with and without overfishing.<sup>12</sup> Ignoring fishing costs the stock is reduced by about one-half by a 50-percent overfishing, but the reduction in total catches is only about 20 percent, because (i) there are diminishing returns to increasing the stock up to the maximum sustainable yield level; (ii) recruitment is unrelated to the stock size, and (iii) both recruitment and stock growth are affected by environmental factors unrelated to stock size. The stock reduction due to overfishing becomes less as the cost rises; 50-percent overfishing reduces the stock by only about 10 percent in the highest cost case in Table 1 ( $c = 2500$ ), but by almost 30 percent in the intermediate case ( $c = 1400$ ). High cost limits the effect of overfishing, because there will be more years than otherwise in which it is not profitable for the fishermen to overfish at full capacity, as this would reduce the stock below its break-even level ( $c$ ). This protective effect of high costs leads to lesser loss of rent in the high cost case than in the intermediate case, or 20 percent as against 30 percent, compared with optimal fishing. The two cases with positive costs reported in Table 3 represent an average rent of about 50 versus 25 percent of the gross catch value.

Table 3: Percent loss of present value of rents due to overfishing. Average stock in parentheses. Discount rate: 5 percent.

c	$k^*$	Overfishing capacity (%)		
		10	25	50
2500	0.15 (3672)	1.1 (3591)	6.9 (3470)	19.8 (3316)
1400	0.22 (3216)	1.8 (3047)	10.1 (2762)	32.9 (2347)
0	0.30 (2505)	1.1 (2219)	6.4 (1783)	19.2 (1195)

The zero cost case in Table 3 produces an exploitation rate that is optimal, given that the unit cost of fish is constant and just a given share of revenue, provided the market price is constant as well. Fixed costs add a slight complication. With costs that have to be paid whether or not a boat is used for fishing, it becomes an optimization problem in its own

<sup>12</sup> Note that the starting value is the same in both cases, so the long-term stock reduction caused by overfishing is somewhat greater than the numbers in Table 1 indicate.

right to determine the right number of boats if the allowable catch varies from year to year. Even if the target rate of exploitation is constant, the allowable catch will not be constant if the stock varies for environmental reasons, and the higher the fixed cost of boats the less rewarding it will be to invest in fishing capacity that can take large but infrequent catches.

The average annual catch with an exploitation rate of 0.3 (last line in Table 3) is about 750 (thousand tonnes). Assigning alternative values to  $c_v$  and  $c_f$  produces the optimal capacity shown in Table 4. When determining these cost parameters we considered the costs of the Norwegian trawler fleet and found that in the period 1998-2006 the variable costs varied between 75 and 90 percent of revenues, while fixed costs varied between 18 and 31 percent.<sup>13</sup> Cost parameters in the higher end of these ranges produce an unprofitable fishery, but cost parameters at or below the lower bound result in positive rents (last two lines in Table 4). For comparison we also include still lower cost parameters; as there still is some overcapacity in the Norwegian trawler fleet, the cost parameters of an optimal fleet are likely to be lower than the actual values in recent years.

The lowest cost parameters in Table 4 produce a very significant difference in the present value of rents with and without overfishing; the first row shows that the rent with optimal fishing would be about twice that with overfishing.<sup>14</sup> The reason is that overfishing totally depletes the stock at some point within the 100 years time horizon. This happens even if the fleet capacity is only about 3 percent greater than the average annual quota (770 as against 750). The permitted quota often is less than this, because of adverse environmental conditions, and as soon as the returning stock falls short of the capacity to fish it will disappear, there being no decline in the catch per unit of effort that would provide protection in the form of declining profitability of overfishing. As the cost parameters become greater the difference between the rents with and without overfishing declines; the bottom line in Table 4 shows that rents are “only” about 30 percent higher without overfishing (280 versus 214) The reason is that in this case the fleet capacity is well below the average permitted quota (690 against 750). There will thus be much fewer years in which the permitted quota falls short of the capacity to fish, and depletion of the stock is less likely to happen, or will in any case happen later than with lower costs.

---

<sup>13</sup> These figures are taken from the annual cost and earnings studies carried out by the Directorate of Fisheries, except that we have set fixed costs equal to depreciation plus 5 percent of the replacement value of the boats, which is well above book value.

<sup>14</sup> This difference is somewhat exaggerated, as the model assigns fixed costs to the entire 100-years time horizon irrespective of when the stock goes extinct, but some capital loss would in any case be involved if the stock crashes.

Table 4: The loss from overfishing if the unit cost of fish is insensitive to the size of the stock. Total quota 30 percent of the stock.

$c_v$	$c_f$	Optimal capacity	Average stock	Present value of rent	
				Optimal fishing	Overfishing
0.6	0.15	770	2762	3745	1993
0.75	0.15	740	2886	1470	922
0.8	0.15	720	3020	723	505
0.75	0.2	720	3036	716	428
0.8	0.18	690	3194	280	214

## 5. ENFORCEMENT

Would it be worthwhile to enforce quotas? Enforcement involves two steps. First, the authorities must put in place a mechanism that causes overfishing to be detected with some probability. This is a costly activity and should not be undertaken unless it costs less than the savings of rents that it generates. Second, once detected, those who exceed their fishing quotas must be punished so that overfishing is made unprofitable, in terms of expected profits. As mentioned in Section 2, these punishments will be treated here as pure transfers, i.e., they have no real costs for either of the parties, which is largely but not entirely true; severe punishments, even if only monetary, may prevent those who are being punished from engaging in legal and gainful economic activity.<sup>15</sup>

Let us now assume that the cost of the probability of detecting overfishing is linearly related to the probability generated (in reality these costs are likely to be rising, but the proportionality assumption suffices to illustrate some important points). Rent with enforcement will be net of these enforcement costs. Following the economic theory of criminal behavior, the fishermen are assumed to decide whether or not to overfish on the basis of expected profit per fishing trip, where the expected fine for overfishing (fine times the probability of being detected) is subtracted from the profits with overfishing. Since all fishermen are assumed to be identical, all will either overfish or stick to their quotas. This relieves us from explicitly modeling fishing trips, and so we consider overfishing and fines for the entire fleet on an annual basis.

---

<sup>15</sup> It is tempting to also include the costs of pursuing a case through the court system, but if the fine is made sufficiently high to deter all illegal activity such costs would be avoided.

Table 5: Consequences of enforcement. Overfishing capacity (percent of legal quotas): 25; probability of detection: 12 percent; enforcement cost per unit probability: 150;  $c = 1400$ .

<b>Fine</b>	<b>Years with Gain/loss overfishing (%)</b>	<b>Catch ('000 tonnes)</b>	<b>Overfishing Gain per ('000 tonnes)</b>	<b>year due to overfishing</b>
0	99.9	-5.8	760	152
200	94.5	-3.9	761	147
400	71.7	2.5	758	120
600	34.6	9.1	739	64
800	7.6	10.4	717	16
1000	0.5	10.1	708	1
1200	0.0	10.0	708	0

Table 5 illustrates the effect of the fine, for the Schaefer function.<sup>16</sup> If there were no fine and no deterrence the enforcement would only mean costs without any benefits, and the expected rent per year net of enforcement costs would be less than without any enforcement. As the fine increases, overfishing becomes less profitable, and there are fewer years with overfishing. The rent gain per year of overfishing (last column in Table 5) is always higher than the expected fine (12 percent of the first column in Table 5), but the higher the fine the fewer the years when overfishing is profitable. A fine of 1200 would virtually eliminate the overfishing (some simulations produce the odd year of overfishing, which disappear in the rounding off, as the second column in Table 5 shows years of overfishing per simulation). It takes a fine of about 300 to make enforcement worthwhile, but overfishing would occur about 80 percent of the time, and overfishing per year would amount to more than 15 percent of the catch per year. With a high enough fine to deter all overfishing (1200) the gain would be about 10 percent of the rent.<sup>17</sup> Note that in all cases the costs of enforcement are the same, so it would make sense to set the fine as high as possible, unless it would contradict social norms that the fine should be in relation to the damage caused.

Still sticking with the Schaefer function and the same cost parameters as in Table 5, Table 6 shows the gain in rent per year from setting the fine high enough to fully prevent all overfishing, for different levels of probability of detection. The table illustrates two points. First, there is the trade-off between enforcement activities and the fine for infractions. Less enforcement (lower probability of being detected) can have the same deterrence as greater enforcement if it carries a higher fine. A fine of 1600 would be necessary if the probability of being caught is only 10 percent, while only a quarter of this would be sufficient if the probability is 40 percent. Since a higher probability means more costly enforcement it would be desirable to have little enforcement and a high fine, but this, as already stated, may run counter to norms stipulating a correspondence between

<sup>16</sup> The probability assumed and the enforcement cost correspond to our findings below about the Norwegian enforcement activities. The value of the fishing cost parameter  $c$  implies rents net of enforcement costs of 50 percent of catch value on the average.

<sup>17</sup> Because of rounding-off of the optimal exploitation rate, some overfishing (2 percent) would in fact be optimal.



the damage done and the fine. The expected rent in the fishery is about 360 per year, and the gain from preventing overfishing with a 10 percent probability of detection would be about 11 percent. The necessary fine in this case (1600) is more than four times the expected rent and thus many times greater than the loss from overfishing. Substantial gain could, however, be obtained with a lower fine, even if it would not eliminate all overfishing.

Table 6: Gain or loss from enforcement, in percent of expected rent. Overfishing capacity (percentage): 25; enforcement cost per unit probability: 150;  $c = 1400$ .

Probability of detection	Fine	Gain (%)
0.1	1600	11.0
0.2	800	6.2
0.3	533	1.3
0.4	400	-3.5

The other point illustrated by Table 6 is that if there is a limit to how high the fine for overfishing can be set, enforcement that totally eliminates the probability of getting away with overfishing does not necessarily make sense, unless the enforcement activities are cheap enough. Here it would not make sense to raise the probability of discovering infractions much beyond 30 percent. With a 40 percent probability of getting caught there is a small loss from the enforcement activity, even if the fine is high enough to eliminate all overfishing.

## 6. ENFORCEMENT WITH TWO PARTIES

The Northeast Arctic cod stock is managed jointly by Norway and Russia. An overall quota is split equally between the two countries, after setting aside a small amount for third countries. For a number of years the Norwegian authorities have been concerned that the enforcement of the Russian quotas is not effective. The problem has been acknowledged by the Russian side, but there is no agreement on how serious it is. In any case, the question of incomplete enforcement by one side raises the question whether effective enforcement by the other side would be worth while.

We shall analyze this in the Schaefer framework, assuming that the overall quota is split evenly between the two countries and thus ignoring the portion going to third countries. Both countries are assumed to have the same possibility to overfish their quotas and to face identical price and costs. The question then is whether it would be worthwhile for one country to enforce its quotas when the other country does not.

There are two ways of modeling the fishing costs at this level of aggregation. One is by assuming that both countries fish their quotas simultaneously, with the overfishing country using a greater fishing capacity. The other option is to assume that both fish with the same capacity, but that the overfishing country continues fishing after the other has taken its quota. These two alternatives lead to the following cost functions, assuming that

both have the same cost parameters (subscripts  $c$  and  $n$  denote the complying versus non-complying country):

$$(10a) \quad C_c = \frac{Y_c}{Y_c + Y_n} c(\ln X_t - \ln S_t) \quad C_n = \frac{Y_n}{Y_c + Y_n} c(\ln X_t - \ln S_t)$$

$$(10b) \quad C_c = 0.5c(\ln X_t - \ln(X_t - 2Y_{c,t})) \\ C_n = 0.5c(\ln X_t - \ln(X_t - 2Y_{c,t})) + c(\ln(X_t - 2Y_{c,t}) - \ln S_t)$$

The case where both fish simultaneously (10a) produces the greatest benefit for the overfishing country and the lowest benefits for the complying country, but the difference is not large.

Table 7 shows the rent resulting from various combinations of compliance and no compliance, in percent of the rent with compliance ( $V_c$ ), in the absence of enforcement costs.<sup>18</sup> It is clearly profitable for one country to overfish if the other country does not retaliate by also overfishing, as  $V_{n,c} > V_c$ . Taking enforcement costs into account would make this a still more profitable strategy.<sup>19</sup> There are diminishing returns to overfishing, however; the largest gain is achieved at an overfishing rate of 30 percent. It is not necessarily true that the complying country would come out better by also overfishing, as  $V_n < V_{c;n}$  in case the overfishing is severe enough, but it is certainly likely, as we have not taken into account the enforcement costs incurred by the complying country, which would have to be subtracted from  $V_{c;n}$ . Ignoring enforcement costs, compliance is the best response by one country to overfishing by the other ( $V_{c,n} > V_n$ ) if overfishing exceeds 30 percent. Since both countries get the same  $V_n$  if neither one complies, there is some incentive for the offending country to mend its ways in case the other one retaliates by also overfishing; at an overfishing rate of 50 percent the payoff is only about two-thirds of what it would be if both complied. These results could, however, be turned around by high enough costs of enforcement; this could produce  $V_c < V_n$ , and in that case both countries would be better off by not enforcing the quotas.

---

<sup>18</sup> The numbers in Table 7 pertain to the case where the non-complying country continues fishing after the other has stopped. The difference between the two cases increases with the degree of overfishing; the bottom entries for  $V_{c,n}$  and  $V_{n,c}$  would be 71.9 and 107.1 instead of 75.3 and 104.4.

<sup>19</sup> This is as expected. In Hannesson (2007) it is shown that it is a profitable strategy for Russia to overfish her quota if Norway does not retaliate, and vice versa.

Table 7: Present value of rents, in percent of value without overfishing.  $V_c$ : value with compliance;  $V_{c,n}$ : value for the complying part if the other does not comply;  $V_{n,c}$ : value for the non-complying part if the other part does comply;  $V_n$  value without compliance. Enforcement costs are ignored.

Percent overfishing $V_c$	$V_{c,n}$	$V_{n,c}$	$V_n$	
10	100	95.4	103.5	98.2
20	100	90.6	105.8	93.4
30	100	85.7	106.8	85.8
40	100	80.6	106.3	76.3
50	100	75.3	104.4	67.1

## 7. ENFORCEMENT IN NORWAY

Monitoring and enforcement of fisheries regulations in Norway is carried out by the Coast Guard and the Directorate of Fisheries. The Coast Guard is responsible for controls at sea, while the Directorate of Fisheries has inspectors who control boats while in harbor. There is some cooperation and synchronization of effort between the two. The controls pertain to the fishing gear (e.g., undersized meshes in nets), catches of undersized fish, and fishing over quota. Monitoring of catches involves checking whether the entries in the logbook correspond to the actual catch (underreporting in the logbook would be in preparation of underreporting landings), and whether the landings and transactions reports agree with the logbook and landings. The focus of this paper is on overfishing of quota, and it is our impression that this is the major problem with respect to the Northeast Arctic cod. This is certainly the case if we include the Russian overfishing.

The overfishing of the Norwegian quota is estimated to have been between 3 and 10 percent of landings (3-11 percent of quota) in the years 2003-2005 (Riksrevisjonen, 2007, p. 26). Needless to say, the capacity to overfish could be much greater than this, depending on how effective a deterrent the control activity is. The Russian overfishing is in all likelihood much greater. Norwegian sources estimate this at 40-100 percent of the Russian quota for the period 2003-2005 (Riksrevisjonen, 2007, p. 28). The Russian overfishing is to a large extent due to transshipments at sea, which are insufficiently monitored. An overfishing capacity of 50 percent or more is thus not out of line for the Russian fleet. In addition there is probably some discarding of fish at sea, but apparently much less than the overfished quantity being landed (Riksrevisjonen, 2007, pp. 38 and 46).

Table 8: Northeast Arctic cod: agreed quota (ths. tonnes) and overfishing (Norwegian estimates) in thousand tonnes and percent of agreed quota. Source: ICES (2007), Table 3.1a and Institute of Marine Research (2006), pp. 48-52.

	<b>Agreed quota</b>	<b>Total stock</b>	<b>Quota as share of stock</b>	<b>Overfishing</b>	<b>Overfishing (percent)</b>
2002	395	1549	26	90	23
2003	395	1612	25	115	29
2004	486	1572	31	90	19
2005	485	1552	32	166	34
2006	471	1462	32	127	27

Table 8 shows the total overfishing, according to Norwegian estimates. According to this, the overfishing of the Northeast Arctic cod has been 20-30 percent of the agreed quota in recent years. Above (see Table 3) we found that overfishing of 25 percent would result in a rent loss of 6-10 percent in the Schaefer case, depending on fishing costs. This is a substantial loss, albeit less in percentage terms than the overfishing itself.

Table 8 also shows the target exploitation rate, defined as the agreed quota in percent of the total stock biomass. This has in recent years been about 30 percent and thus comparable to what we found for the zero cost case in Table 3 above. This would be near-optimal if the cost per unit of fish is independent of the stock size. It is also possible, and indeed likely, that the two countries are uninterested in rent maximization and more concerned with maximizing the total catch over the long term, in which case an exploitation rate of 30 percent would be about right. In that case the appropriate measure of loss due to overfishing would not be rent but the expected total catch per year. The last line in Table 3 provides an estimate of this, in present value terms, as the rent at zero cost and given price is equal to the catch volume. According to the last line in Table 3 the loss of catch from 25 percent overfishing would be about 6 percent, well below the overfishing percentage.

As to the probability of detecting overfishing, only about 1 percent of all Norwegian landing events of cod 2003-2005 north of the 62<sup>nd</sup> parallel were controlled by the Directorate of Fisheries. This low percentage is due in part to the multitude of small boats engaged in the fishery. The large boats are controlled more often, and so 4-23 percent of the quantity landed in the said period was subject to control, varying between areas (Riksrevisjonen, 2007, p. 84). If we weight these percentages by the share of the areas in total landings, we find that 12 percent of all catches are subject to control. With our simplifying assumption of a homogenous fleet this would be the probability of being detected if overfishing, provided controls are random. In reality controls are not random; apparently there are some boats that are considered more likely to overfish than others, and both the Directorate of Fisheries and the Coast Guard have identified such boats and direct their activities more towards them than other boats whose skippers are believed to be more law-abiding. Hence the probability of catching those who overfish may be somewhat greater than this. Furthermore, the fact that once caught a skipper can look forward to more frequent controls can be seen as an additional punishment, given that controls probably cause some inconvenience. Since the said probability pertains only to

each fishing trip, the probability that one single boat will be controlled at least once each year is much higher and is in fact equal to one for some categories of boats (Riksrevisjonen, 2007, p. 83). In addition to the controls by the Directorate of Fisheries there are controls by the Coast Guard. Most of these controls are, however, aimed at foreign fishing vessels, and those that are aimed at Norwegian vessels are typically followed up by controls in harbor by the Directorate of Fisheries, so the controls by the latter probably give a roughly correct picture of the control activity aimed at Norwegian vessels.

Table 9: Overview of court cases 1994-2007 involving overfishing of cod and similar species by Norwegian boats (other court cases, not included here, involve breach of other types of regulations or foreign boats)

Type of offense	Value of catch	Fines
Incorrect logbook	360,000	360,000 for the firm and 15,000 for the skipper
Incorrect logbook (underreporting of 20-30 percent of cod and other types of fish)	Not specified	Fine of firm not reported, fine of skipper: 14,000
Incorrect logbook	110,000 (underreported catch)	60,000 for the firm and 10,000 for the skipper.
Landings from Boat X reported as from Boat Y	138,000	80,000 for one skipper and 117,000 for the other
Landings from Boat X reported as from Boat Y	300,000	50,000 for each skipper
Incorrect logbook (37 percent underreporting)	42,000	62,000 for the firm and 15,000 for the skipper
Incorrect logbook	1,040,000	400,000 and 10,000 for each of two skippers involved
Incorrect logbook	Unreported	25,000 for the firm and 8,000 for the skipper

The deterrence, as already stated, depends on the fine imposed on those who overfish. Only about 5 percent of all controls have uncovered any illegal activity (Riksrevisjonen, 2007, p. 85). Of those, most are minor and result only in a written reprimand. If serious enough, the infraction is reported to the police, which investigates and refers the case to the attorney general if the evidence is strong enough. These are the kind of breaches that most need to be deterred and which we had in mind in the exposition above. The offices of the attorney general in the two northernmost counties of Norway have assembled a report of the court verdicts on various breaches of the Norwegian fisheries regulations for the period 1994-2007. These court cases stem both from the Supreme Court and lower courts. There are only a few cases of serious overfishing by Norwegian vessels in this report. These cases involve incorrect entries in the logbook and falsified reporting of catches on landings or transaction documents. An overview of the cases is presented in Table 9.

Two of the cases in Table 9 involve transactions which in a different regulatory regime would not have been breaches at all; that is, a transfer of an unused quota from one boat to another. Because leasing of boat quotas is not permitted in the Norwegian regulatory system, this constitutes a breach of regulations and is apparently quite harshly punished.

In the remaining six cases fines were imposed, both on the firm and the skipper involved. The fine imposed on the firm is by far the highest and ranges from 40 to 150 percent of the value of the total landings.

Is the Norwegian enforcement activity worthwhile? Hardly, if we take into account the results of Section 6, which showed that the best Norwegian reply to Russian overfishing would be to also overfish. But what if the compliance on the Russian side were of a similar magnitude as on the Norwegian side? To analyze that we need to look at the costs of the enforcement activities and compare them with the rents saved by the enforcement activity. It is not possible to provide but a very rough estimate of what the enforcement activity costs per unit of probability of detection. We go about this as follows: We take the budget of the Directorate of Fisheries and find the cost of enforcement by multiplying by the fraction of man-years devoted to enforcement activities (20 percent). Enforcement in the demersal fisheries, of which the cod fishery is by far the most important and often occurs jointly with fishing of other demersal species, probably accounts for well over a half of all enforcement costs, because of the large number of boats in this fishery, but we shall use one-half as a rough estimate, providing a lower bound of the enforcement costs. To this we add the part of the costs of the Coast Guard which can be attributed to controls of Norwegian vessels. About 70 percent of the expenses of the coast guard are for monitoring fisheries, and of that again about 40 percent is directed at Norwegian boats.

Table 10: Calibrating enforcement costs for Northeast Arctic cod.

Cost of Directorate of Fisheries 2006 (mill. kroner)	286
Cost of Coast Guard 2006 (mill. kroner)	810
$0.5 \times (0.2 \times 286 + 0.7 \times 0.4 \times 810)$ of above	142
Maximum and minimum value of landings of demersal fish in Norway 2004-07 (mill. kroner)	4,400; 6,200
Enforcement costs in percent of above	3.2; 2.3
Average annual catch of Northeast Arctic cod 2003-2006 (ths. tonnes)	600
3 percent of above	18

The resulting cost estimate is shown in Table 10 and amounts to about 140 million kroner. This is roughly 3 percent of the landed value of cod and similar species. Total annual landings of Northeast Arctic cod averaged about 600,000 tonnes in 2003-2006, so in terms of landings the enforcement costs amounted to 18,000 tonnes, taking the Norwegian enforcement costs as indicative of enforcement costs for the entire stock. As stated above, the risk of being caught if overfishing seems close to 12 percent, on the basis that 12 percent of the quantity caught is controlled and provided that the control is random. This produces a cost per unit probability of 150 (thousand tonnes).

Obviously these cost calibrations are subject to uncertainty. There are three major types of uncertainty involved. First, are the Norwegian enforcement costs indicative of what would obtain in an efficiently enforced management of the entire stock? No one really knows, but there is no better option as a first approximation. Second, the costs listed above are estimates made on the basis of accounting costs. We shall deal with this by calculating critical costs, i.e., how high the cost would have to be in order to overturn our conclusions. Third, the cost per unit of probability depends critically on the probability of detection produced by the enforcement activities. We only have a very rough estimate of this, but as it turns out, the results are not sensitive to this, provided the fines are set high

enough to deter all overfishing. If the probability of detection produced by the enforcement activity is higher than we have estimated the cost per unit of probability would be correspondingly lower. What is sensitive to the probability of detection produced by the enforcement activity is the fine necessary to deter all overfishing; a lower probability of detection must be compensated by a correspondingly higher fine, in order to avoid a positive expected gain from overfishing (cf. Equation [3]).

Table 11: Rent gain per year (percent), necessary fine to prevent overfishing, and enforcement cost per unit probability critical for making enforcement worthwhile. Cost per unit probability: 150; probability of detecting overfishing: 12 percent.

Overfishing capacity (%)	c = 2500			c = 1400			c = 0		
	Gain	Fine	Critical cost	Gain	Fine	Critical cost	Gain	Fine	Critical cost
10	-10.8	270	22	-2.2	530	87	0.4	1030	177
25	-4.0	650	107	10.1	1300	410	9.8	2650	698
50	13.9	1290	278	58.9	2480	1206	35.9	5360	1769

Table 11 shows the results of running the model with a 12 percent probability of detecting overfishing at a cost of 150 per unit probability, for the cost levels shown in Table 3 for the Schaefer function. In the high cost case, which implies a rent of about 25 percent of catch value, overfishing capacity has to be quite large (well over 25 percent) in order to make the enforcement activities worthwhile. In the low cost case, implying that rent is about a half of revenues, overfishing capacity has to exceed 10 percent to be worthwhile. Ignoring costs, deterring an overfishing capacity of 10 percent is just barely worthwhile. Table 11 also shows the cost critical for making enforcement worthwhile. These numbers are per unit probability of detection and should be compared to the above estimate of 150. This critical cost exceeds the estimated cost by a wide margin if the overfishing capacity is as high as 50 percent. The critical cost is, however, much lower than the estimated cost if the overfishing capacity is only 10 percent, except when fishing costs are ignored.

The probability of detection produced by the enforcement activities does not matter, as long as there is no restriction on the fines to be imposed; a low probability of detection can always be compensated for by a high fine. Table 11 shows the fine necessary to deter all overfishing and thus to maximize the gains from enforcement. Some of these fines are problematic, from the point of view that the fines should not be too far out of line with the damage caused by overfishing. In the high cost case the annual catch is about 550 (thousand tonnes) on the average when there is no overfishing. The necessary fine with an overfishing capacity of 50 percent is more than twice that, and more than four times the average annual rent (note that the fine is calculated for the entire fleet on an annual basis). In the low cost case the average catch per year is about 700, and in the costless case about 750, and the necessary fine to deter all overfishing with a 50 percent capacity is 3.5 versus 7 times that. The highest of the fines in Table 11 thus seem out of line with what would be deemed reasonable; the highest fine recorded in the court cases reported in Table 9 is about one and a half times the catch value. If the enforcement activity results in lower probability of detection than we have assumed, the fines would have to be higher

still, in order to prevent overfishing. Reducing the probability of detection by a quarter (from 0.12 to 0.09) would raise the necessary fine by one third (cf. Equation [3]). For an overfishing capacity of 50 percent we would, in the intermediate cost case ( $c = 1400$ ), need a fine of 3,300, which is six times the average annual catch.

Table 12: Results with and without enforcement when the unit cost of fish is independent of stock size.  $V_N$ : rent per year with no enforcement,  $V_E$ : rent per year with enforcement. Probability of enforcement: 0.12, enforcement cost per unit probability: 150.

$v_c$	$f_c$	<b>Fleet capacity</b>	<b>Fine</b>	$V_N$	$V_E$	<b>Critical cost</b>	
	0.6	0.15	770	1610	-5.6	161.7	1544
	0.75	0.15	740	910	-13.5	51.8	695
	0.8	0.18	690	600	2.5	-47	90

Table 12 shows the gains or losses from enforcement for the case when the unit cost of fish is insensitive to the stock size. The last line in the table shows operating costs and capital costs close to the ones observed for the Norwegian trawler fleet (cf. Table 4 and accompanying text). The column entitled fleet capacity shows the capacity that would be optimal at these costs, given an effectively enforced total quota (cf. Table 4). This results in overfishing when the total allowable catch is less than the available fishing capacity, so if overfishing is sufficiently profitable for the individual firm, the actual capacity could be greater than this. We see that with these high costs there is a small positive rent per year. Enforcement would result in a lower rent, because overfishing does not happen very often; the fleet capacity is well below the average annual quota and exceeds the actual quota only infrequently. Yet a fine that exceeds the catch value at fully used capacity is necessary to deter overfishing.

With lower costs, the average annual rent in the absence of enforcement turns negative.<sup>20</sup> The reason is that overfishing depletes the stock and typically leads to extinction within the hundred year period. Exactly when this happens depends on the random environmental variable; when the combined effect of overfishing and unlucky draws of nature deplete the stock below the catch capacity of the fleet it will go extinct. Enforcement averts this and produces a positive annual rent, thus doing better than paying for itself. The critical enforcement cost is in these two cases much higher than the estimated cost of enforcement. The fines necessary to deter overfishing are high, however; in the low cost case (first line in Table 12) more than double the gross catch value with a full use of fleet capacity and about ten times the rent per year.

---

<sup>20</sup> Note that the present value of rents would be positive (cf. Table 4), but the numbers in Table 11 refer to undiscounted rent per year. The fishery starts out with a large and viable stock and it will take some time before it crashes, due to overfishing and adverse environmental effects. The negative numbers are due to fixed costs assumed to accrue even if the stock has been depleted. If the stock crashes early in the 100-year period much of these could be avoided, but we have not considered that here.



## 7. CONCLUSION

There is no doubt that fishing in excess of an optimal quota is economically wasteful, although the rent loss may be less in relative terms than the overfishing activity itself. But this does not mean that overfishing should be prevented at any cost. The cost of prevention must be compared to the benefits it provides, just as in any other economic activity. Provided that criminals are governed by the expected value of their activities, preventive activities could be kept at a minimum by sufficiently harsh punishments. Punishments are, however, likely to be constrained by what is perceived as a reasonable proportionality between the damage caused and the punishment inflicted. The punishment in the Norwegian court cases reported here certainly is greater than the individual gain from overfishing; fines for overfishing have typically been as high as or greater than the value of the gross value of the catch, which is well above the gain, since to obtain the latter we would have to subtract all costs. But in order to deter, punishments must be greater than the gain.

How serious the effects of overfishing are likely to be depends critically on whether or not the unit cost of fish is sensitive to the size of the fish stock. When the unit cost of fish is independent of the fish stock, the result is altogether more sinister than with the Schaefer function. Overfishing will occur when fish quotas are smaller than the capacity of the fleet, which is particularly damaging, as the rate of exploitation, including the overfishing, will be higher the smaller the stock is. The result is that sooner or later the stock will be totally depleted. How soon depends on the degree of overcapacity and how bad the draws of nature turn out to be. Since extinction of fish stocks is about as rare as fishing beyond quota is common it is perhaps tempting to dismiss this case as unrealistic, that sooner or later the unit cost of fish will start to rise and provide protection against a total depletion. The point is, however, that this might kick in fairly late; over a wide range the unit cost of fish could be only weakly related to the size of the stock. A weak relationship of this kind was one factor behind the Northern cod debacle in the early 1990s and the stock is still commercially if not biologically extinct.

Looking specifically at the fishery for the Northeast Arctic cod we find that the Norwegian enforcement activities are likely to be close to what is warranted, provided that the overall enforcement is adequate. This, unfortunately, is not the case; there is no doubt that the enforcement of the Russian quota leaves much to be desired. It was shown above that the best Norwegian reply to this would be no enforcement at all and an overfishing of the Norwegian quota as well. Nevertheless the Norwegian government persists in its enforcement activities. This could be rational, if it is conceived as an example acting together with other persuasive arguments to convince the other part to mend its ways. Time will show whether this is a fruitful approach or just wishful thinking.

## REFERENCES

Andersen, P. and J.G. Sutinen (1985): The economics of fisheries law enforcement. *Land Economics* 61: 387-97.

Anderson, L.G. and D.R. Lee (1986): Optimal governing instrument, operation level, and enforcement in natural resource regulation: the case of the fishery. *American Journal of Agricultural Economics* 68: 678-90.

Becker, G.S. (1968): Crime and punishment: an economic approach. *Journal of Political Economy* 76: 169-217.

Bodman, P.M., H. Campbell and R.B. Skinner (2002): The one that got away? Crime and punishment in Queensland's commercial fisheries. *Australian Economic Papers* 41: 320-28.

Charles, A.T., R.L. Mazany and M.L. Cross (1999): The economics of illegal fishing: a behavioral model. *Marine Resource Economics* 14: 95-110.

Chavez, C. and H. Salgado (2005): Individual transferable quota markets under illegal fishing. *Environmental and Resource Economics* 31: 303-24.

Directorate of Fisheries (2006): *Prosjekt salgslag*. Available at [http://www.fiskeridir.no/fiskeridir/fiskeri/rapporter\\_utredninger/salgslag/prosjekt\\_salgslag\\_fiskeri\\_direktoratet](http://www.fiskeridir.no/fiskeridir/fiskeri/rapporter_utredninger/salgslag/prosjekt_salgslag_fiskeri_direktoratet)

Furlong, W. (1991): The deterrent effect of regulatory enforcement in the fishery. *Land Economics* 67: 116-29.

Hannesson, R. (2007): Cheating about the cod. *Marine Policy* 31: 698-705.

ICES (2007): *Report of the Arctic Fisheries Working Group 2007*. International Council for the Exploration of the Sea, Copenhagen.

Institute of Marine Research (2006): *Havets ressurser og miljø 2006*. Available at [http://www.imr.no/produkter/publikasjoner/havets\\_ressurser/2006](http://www.imr.no/produkter/publikasjoner/havets_ressurser/2006)

Kuperan, K. and J. Sutinen (1998): Blue water crime: legitimacy, deterrence and compliance in fisheries. *Law and Society Review* 32: 309-38.

Riksrevisjonen (2007): *Forvaltning og kontroll av fiskeressursene i Barentshavet*. Available at [http://www.riksrevisjonen.no/Revisjonsresultater/Dokumentbase\\_Dok\\_3\\_2\\_2007\\_2008.htm](http://www.riksrevisjonen.no/Revisjonsresultater/Dokumentbase_Dok_3_2_2007_2008.htm).

Scott, A.D. (1955): The fishery: the objectives of sole ownership. *Journal of Political Economy* 63: 116-24.

Sutinen, J.G. and J.R. Gauvin (1989): An econometric study of regulatory enforcement and compliance in the commercial inshore lobster fishery in Massachusetts, in Neher, P., R. Arnason and N. Mollett (eds.): *Rights Based Fishing*. Kluwer, Dordrecht, pp. 415-428.