

Cost and Benefits of Control Strategies

- the case of Norway lobster trawl fishery in Kattegat and Skagerrak

WP 5

Estimation of Benefit functions, enforcement-probability function and enforcement-cost function

Lone Grønbæk Kronbak
University of Southern Denmark[^]

Frank Jensen
Institute of Food and Resource Economics^{^^}

Work in progress

Abstract

Within the EU Sixth Framework Programme an ongoing research project, COBECOS, has developed a theory of enforcement and a software code for computer modeling of different fisheries with fisheries enforcement cases.

The case of the Danish fishery for Nephrops faces problems with landings of undersized lobsters and illegal bycatch of cod. The enforcement to avoid the illegal activities consists of physical control, such as dock side inspections and boarding, and administrative control with integration of different databases.

This paper presents the first steps in the application of the theory on fishery enforcement from the COBECOS project to a specific case. It is done by estimations of functional relationships' for describing 1) the fisheries benefit function 2) the shadow value of biomass 3) the connection between the probability of being detected and apprehended for different enforcement levels and 4) the connection between different enforcement levels and costs. The purpose of estimating the functional relationships are for future application in the COBECOS computer modeling in order to carry out a cost-benefit analysis of control strategies and thereby find the optimal mix and level of different types of enforcement.

General problems when trying to apply empirical data to the standardized fisheries enforcement model are summarized.

Key Words: Fisheries Enforcement, Cost of enforcement, Bio-economic modeling, probability of detection, Nephrops fishery

JEL Classification: Q22, A13, C31, C53, C89, D61

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[^] Department of Environmental and Business Economics, Niels Bohrs Vej 9, DK-6700 Esbjerg, Denmark, Ph.: +45 6550 4182, e-mail: lg@sam.sdu.dk

^{^^} Fisheries Economics and Management Division, Faculty of Life Sciences, University of Copenhagen, Rolighedsvej 25, DK - 1958 Frederiksberg C, Ph.: +45 3533 6898, e-mail : fje@foi.dk

1. Introduction

This working paper is part of an ongoing research project called “Costs and Benefits of Control Strategies” with the acronym COBECOS. The project is funded by the European Union’s (EU) Sixth Framework Programme, Policy-Oriented research. The primary objective of COBECOS is to conduct a cost-benefit analysis of control schemes for management strategies relevant for the Common Fisheries Policy and, based on this analysis, infer the potential economic benefits which might accrue from proper enforcement of the management measures. We propose to achieve this objective on the basis of: 1) an appropriate theory of fisheries enforcement, 2) empirical research involving intensive case studies and estimation of theoretical relationships and 3) computer modelling of fisheries enforcement (based on the theory and empirical estimations). On this basis we expect to be able to contribute significantly to answering questions such as: What are the costs and benefits of increased enforcement effort in particular fisheries? If compliance alters (exogenously) in certain fisheries what are the costs and benefits? What are the impacts of increased penalties for violations of fisheries rules? How do different control schemes compare when the cost of enforcement is taken into account?

The appropriate theory of fisheries enforcement, referred to above, is developed under work package 3.¹ This working paper merely deals with the empirical research of one of the case studies, Norway lobster trawl fishery in Kattegat and Skagerrak, and the estimation of the theoretical relationships. The computer modeling and the computer application to the case studies is still on its incipient stage. This working paper therefore corresponds to the deliverable from the case study, Norway lobster trawl fishery in Kattegat and Skagerrak to work package 5 with the objective to estimate the basic relationships in the theoretical enforcement model for use in the computer model. The following relationships will be estimated:

- A probability of penalty function that relates enforcement effort to the probability that a violation will entail a sanction. We refer to this as the enforcement-probability function.
- A fisheries benefit function including a private benefit, the shadow value of biomass and from this the determination of the social benefit function.
- A fisheries enforcement cost function that relates enforcement effort (along its various dimensions) to costs of enforcement.

All the estimations will be based on the data collection which is available under the deliverable for work package 2, where a description of the applied case study in this working paper, Norway lobster trawl fishery in Kattegat and Skagerrak, also is available. Compared to the description of work in WP5 we start out by determining the data for the enforcement level, the probabilities and the fines and then estimating the enforcement-probability function. We have chosen this order of estimation since we apply the probability of being apprehended and the fines when determining the private benefit function.

In section 2 an enforcement effort measure is determined in order to be compatible with the COBECOS code to be applied in the future. It is followed by estimates of the enforcement-probability function. Section 3 relates the enforcement effort to the costs of enforcement. The private benefit function will be estimated in section 4, a discussion and a calculation of the shadow value of biomass be presented in section 5. Section 6 will determine the social benefit function. Section 7 summarizes and concludes

¹ The technical annex and the deliverable for all work packages completed can be found at the project website: <https://maritimeaffairs.jrc.ec.europa.eu/web/cobecos/1>

2. Enforcement effort and probability

In the mixed trawl fishery in Kattegat and Skagerrak the most important species are Norway lobster, Atlantic cod, Common sole and European plaice. Norway lobster and Atlantic cod have a catch value around half of- to more than two thirds of the total value of landings. In addition these two species are categorized as species in the control strategy for the Danish enforcement (The Danish Directorate of Fisheries 2006) with a high risk of overfishing compared to quotas and a moderate to very high consequences for the resource. Therefore the Directorate of fisheries risk-rank these two species to require a full enforcement effort and likely to substantial additional enforcement initiatives according to the control strategy (The Danish Directorate of Fisheries 2006). Thus, these two species are among the target species for the control and enforcement of the Danish fishery.

In our dataset we have all individual landings from Kattegat and Skagerrak from 2005 and 2006 having Norway Lobster or Cod included. This is a record of some 40,000 landings. Data are anonymous but all landings for a single vessel can be identified and for each landing there is information about type of control (if controlled) and violations and sanctions (if such exist).

Enforcement Effort

The Danish Directorate of Fisheries (2006) has a control strategy with the aim of working pro a biological and economical sustainable fishery. To reach this aim they perform “*thoughtfulness regulation and control*”. From the report “*The control is targeted where illegal fishery has the largest consequences for sustainability. ... In addition the control is concentrated when it is considered to be crucial.*” Specific information about the actual perceived increased risk of inspection and detection of a contravention resulting from selecting the businesses, persons, actions or areas to be inspected are, however, not available. Therefore we make deliberate simplification and assume there is non-selective control of potential offenders.

For adjusting our data to be applicable in the COBECOS software we need a series of data with the enforcement effort for different types of enforcements and the connected probability of being penalised. In COBECOS effort and probability are restricted on their parameter values to be between 0.001 and 0.999. In order to scale the effort we apply the following function:

$$\text{Effort} = \frac{\# \text{Inspections for specific vessel}}{\# \text{Landings for a specific vessel}} \quad (1)$$

Where

- # Inspections for specific vessel is categorised into different enforcement categories
- # Landings for specific vessel in the total number of types the vessel have been in harbour with cod or Norway lobster from Kattegat or Skagerrak

This scaling returns an effort value for the different types of enforcement effort (in our case (boarding or dock side) which is between zero and one. An enforcement effort equal to one corresponds to all landings are being inspected and an enforcement effort of zero corresponds to no landings being inspected. The vessels with no landings being inspected are irrelevant for the further analysis and are therefore not included in the further derivation of the enforcement probability function. The enforcement effort is therefore a function of the number of fishing trips. Thereby can a single fisherman indirectly reduce the enforcement effort (employed by the authorities) by increasing his number of fishing trips. This might not be fully in accordance with the theoretical

model where the penalty probability function is strictly exogenous, but it is still our best estimate of enforcement effort.

Probability of being penalized

The probability of being penalized (or sanctioned) connected to the different enforcement effort levels are now to be derived on an individual cross-section (2005-2006) level. The probability of being sanctioned is illustrated in figure 1.

Figure 1
The probability of being sanctioned

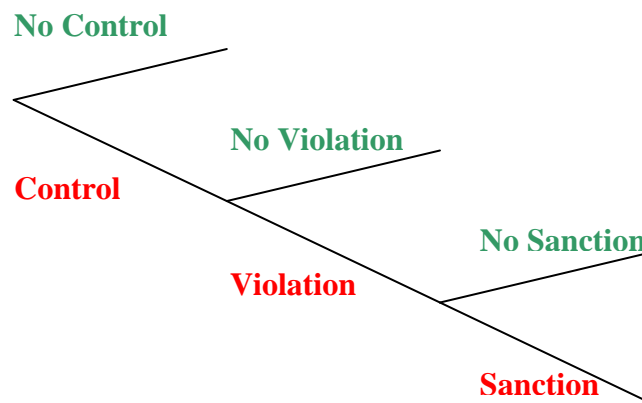


Figure 1 illustrates that there is a probability of being controlled, and given control, there is a probability of having violated, and if violation has occurred there is a probability of being sanctioned.² This approach assumes that the probability of being sanctioned for the probability enforcement function is determined by the probability of being sanctioned given that violation occurs. This corresponds to follow the ‘red path’ in figure 1. Formally written this equals the probability of being controlled given violation times the probability of being sanctioned given that the person is violating and controlled:³

$$p(S / C) = p(V / C) \times p(S / V \cap C) \tag{2}$$

Where

- S: Sanction
- V: Violate
- C: Control

A simplification of this approach is to assume the probability of being sanctioned given that the person is violating and is controlled equals one, which is $p(S / V \cap C) = 1$. It appears from the Danish data set that it is not always true, but one can argue that if a fisherman receives a written

² One might argue that the tree in figure 1 should start with the violation/no violation then followed by control/no control and finally sanction/no sanction. The reason why we have not chosen that approach is, that we have no estimate of how large a fraction of the fishermen do actually violate, we have only estimates of how many violations does actually occur among those fishermen controlled.

³ This approach implicitly assumes that only violators can be sanctioned.

remark about a violation it will always requires resources from that fisherman to avoid being sanctioned, and this in itself can be regarded as a penalty. The simplified approach therefore becomes:

$$p(S|C) = p(V/C) \quad (3)$$

We thus need to derive the probability of violating given the vessel is controlled:

$$p(V|C) = \frac{\# \text{Violations for specific vessel}}{\# \text{Controls for specific vessel}} \quad (4)$$

The number of violations represents only the number of violations that are actually been sanctioned.

The probability of being sanctioned given violation, which is assumed to be equal one moving from (2) to (3):

$$p(S|V \cap C) = \frac{\# \text{Sanctions for specific vessel}}{\# \text{Violations given controlled for specific vessel}} \quad (5)$$

This probability is assumed to be equal one in the following estimates.

The probability of being controlled is:

$$p(C) = \frac{\# \text{Controls for specific vessel}}{\# \text{Landings for specific vessel}} \quad (6)$$

If we combine the probability of being controlled with the probability of violating given the vessel is controlled (combining (4) and (6)) this reveals the probability of violation given the enforcement effort⁴:

$$\pi(e) = p(V/C) \times p(C) = \frac{\# \text{Violations for specific vessel}}{\# \text{Landings for specific vessel}} \quad (7)$$

To the Kattegat/Skagerrak we apply the above approach to derive the enforcement probability function. This approach returns the actual probability of being detected and fined given the actual enforcement effort, it is thus not the expected or perceived probability, but it is our best estimate.

Adjusted Data for the Danish Case to be applied in the COBECOS software

In the first step all vessels having a written remark (In Danish: 'erhvervsøvertrædelse') are included. This corresponds to 78 written remarks. Some vessels have more written remarks and the number of written remarks is therefore not corresponding to the number of vessels. For each vessel, the actual applied enforcement effort is calculated according to (1) and the corresponding probability of being sanctioned is calculated according to (7). The enforcement effort and the

⁴ We are aware that equation (7) does not include the number of controls/inspections for the single vessel, but this is an ad hoc probability and it is only meaningful together with the ad hoc enforcement effort for the specific vessel.

corresponding probabilities are calculated for each separate type of controls. For some written remarks it is not possible to identify the type of form, which has been applied, either because the information is not available or because it is an administrative control.⁵ In our case we have form 1 (dockside inspections) and form 2 (boardings) where information about controls are recorded not matter whether it results in a written remark or not. The following works with enforcement effort *E1* (dock side inspections) and *E2* (boardings), respectively. The applied enforcement probability dataset is summarised in table 1.

Table 1
Enforcement and probability of apprehension for year 2005 and 2006 in the Kattegat/Skagerrak Norway lobster and cod fishery.

<i>E1</i>	<i>Prob</i>	<i>E2</i>	<i>Prob</i>
0.031	0.008	0.011	0.011
0.020	0.020	0.037	0.009
0.025	0.006	0.024	0.016
0.037	0.015	0.048	0.048
0.018	0.009	0.035	0.012
0.023	0.004	0.030	0.030
0.004	0.004	0.158	0.053
0.018	0.004	0.034	0.011
0.032	0.008	0.011	0.011
0.032	0.008	0.021	0.005
0.030	0.010		
0.020	0.020		
0.125	0.021		
0.063	0.031		
0.024	0.012		
0.081	0.012		
0.067	0.067		
0.029	0.014		
0.009	0.009		
0.036	0.036		
0.075	0.025		
0.037	0.009		
0.021	0.021		
0.055	0.014		
0.045	0.011		
0.036	0.006		
0.082	0.020		
0.016	0.016		

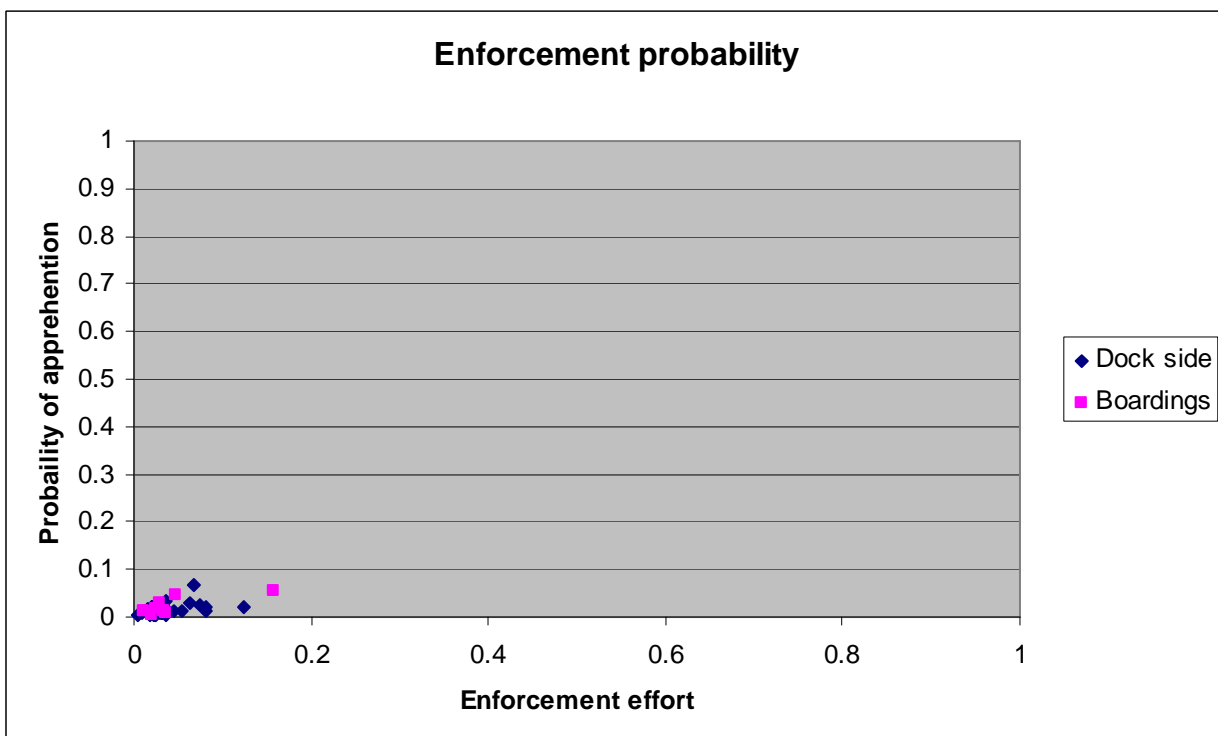
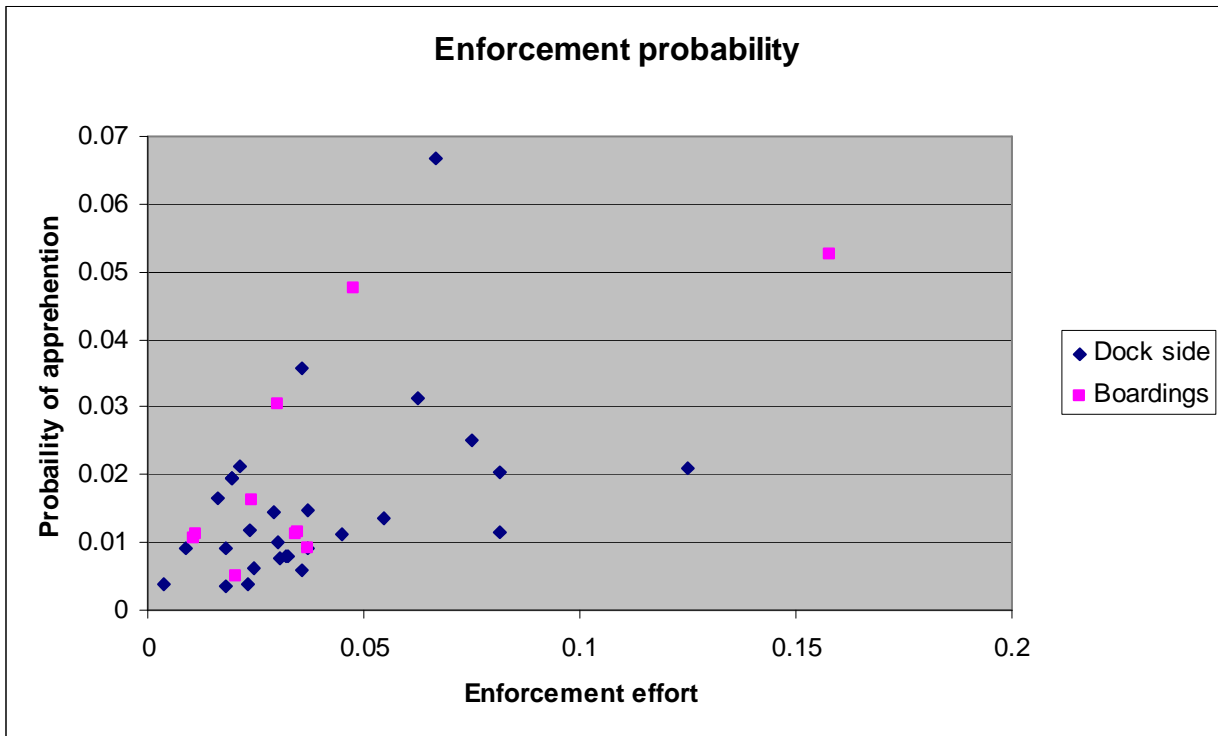
Note:

E1 = Dock side inspections

E2 = Boardings

⁵ For administrative and paper control the controls that do not lead to a written remark are not included in the record. It is therefore not possible to estimate a probability of being sanctioned for these types of controls.

Figure 2.1
Plot of the enforcement probabilities and the enforcement effort levels



With respect to models we estimate three different models:

$$y = a + bx \quad (\text{model 1}) \quad (8.1)$$

$$y = a + b \ln x \quad (\text{model 2}) \quad (8.2)$$

$$y = ae^{-bx} \quad (\text{model 3}) \quad (8.3)$$

where:

y is the probability of being apprehended

x is enforcement effort

a, b are parameters to be estimated.

Equations (8.1)-(8.3) are estimated for both dock side inspections and boardings. The data set for control data contains cross-sectional data for both 2005 and 2006. It is, therefore, reasonable to include a yearly dummy variable in the estimation not to disregard differences over time. Including the dummy equations (8.1)-(8.3) become:

$$y = a + bx + cD \quad (\text{model 1}) \quad (9.1)$$

$$y = a + b \ln x + cD \quad (\text{model 2}) \quad (9.2)$$

$$y = ae^{-bx} + cD \quad (\text{model 3}) \quad (9.3)$$

Where:

D is a yearly dummy variable with value 0 in 2005 and value 1 in 2006

c is the parameter to be estimated.

The statistical program “Eviews 6” with its estimations techniques is applied for estimation. Table 2 summaries the results.

Table 2
Estimation results for three different types of enforcement-probability functions.

	Dock side inspections			Boardings		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
a	0.01 (2.34)	0.05 (4.02)	0.01 (3.87)	0.01 (2.54)	0.08 (3.65)	0.014 (2.74)
b	0.21 (2.49)	0.01 (2.61)	7.98 (2.33)	0.32 (3.11)	0.02 (2.92)	8.72 (3.42)
c	-0.005 (-1.27)	-0.005 (-1.27)	-0.005 (-1.22)	-0.004 (-0.46)	-0.002 (-0.24)	-0.003 (-0.43)
R^2	0.22	0.23	0.18	0.59	0.55	0.53
Breusch-Pagan test	1.92	2.05	1.99	1.87	1.79	1.92
White test	2.25	3.51	3.06	2.21	2.13	2.23

Table 2 yields the estimation results for the parameters a, b and c in the enforcement probability function, the R -squared, the Breusch-Pagan test and the White test for all three types of models for dockside inspections and boardings, respectively. The numbers in brackets under each estimate are the t -tests.

With respect to dock side inspections the Breuch-Pagan and White test shows that there is homoscedasticity. Thus, we can use OLS in the estimations. The variance inflation is, in all cases, below 10, therefore we have no problem with multi-collenarity.

From the t -tests it is seen that parameters are significant in all three models except from the dummy parameter c which is insignificant, but excluding the dummy variable would significant reduce R^2 . Therefore, D is included. R^2 is relatively low and R^2 does not vary much between the three models so the models perform equally well.

For model 3, we do, however, get positive b -values for both dock side inspections and boarding. Since we would expect to have increasing probabilities of apprehension with increasing enforcement effort, we eliminate this model for further analysis. We will thus work with all models 1 and 2 in the forthcoming analysis.

With respect to boardings the conclusions are almost the same. We have no problems with heteroscedasticity and multi-collenarity. Parameters a and b are significant and c is insignificant but D can not be excluded due to a significant drop in R^2 . R^2 is now reasonable high. However, there is not much variation in R^2 between models so again all three models are used in the analysis.

3. Enforcement cost function

In this section we calculate an enforcement cost function for the two different types of enforcement we operate with in this paper. In other words, we calibrate an average enforcement effort function for dock-side inspection (blanket 1) and boarding (blanket 2). With respect to costs of inspection we only have data for three years, see COBECOS deliverable WP2. This implies that we cannot rely on econometric methods when determining cost parameters. We, therefore, calculate cost parameters for one year based on The Danish Directorate of Fisheries (2006). Here we choose 2005 because for this year we also have data for enforcement effort as previously defined. We choose two specifications of the average cost function:

$$AC = sx \quad (\text{model 1}) \tag{10.1}$$

$$AC = sx^2 \quad (\text{model 2}) \tag{10.2}$$

Where

- AC are the average costs of enforcement
- x is the enforcement effort as defined previously
- s is a cost parameter.

Note that we have chosen a formulation without fixed cost. This is necessary to assume in order to calculate s but is also a reasonable assumption. It corresponds to the case where inspection inputs are also used for other purposes and the fixed cost is allocated to these purposes.

For dock side inspection and boarding we have data for the enforcement effort, x . This variable is calculated as the mean value of the enforcement effort defines above. We also have data for AC for dock-side inspection and boarding. AC is defined as the cost per inspection. Note that AC may be overestimated for boarding because other control exercises than boarding is included in the number. This problem is solved by making sensitivity analysis on s for boarding.

With information on the average costs and the enforcement effort level, x , we can calculate s in all three models, see Howitt (1995) and Jensen and Vestergaard (2002) for others applications of the same method for calculating parameters. The results are shown in table 3.

Table 3
Calculation of the cost parameter.

	Dock side inspection		Boarding	
	Model 1	Model 2	Model 1	Model 2
s	58403	1502782	1242012	30410903

4. The private benefit function

The private benefit function is basically determined by a standard bio-economic model involving fishermen maximizing a profit function not taking resource restrictions into consideration. It is assumed that the fisherman maximises net profit:

$$\begin{aligned} & \text{Max}(P_h h - P_t t - C(h, t, v_t) - \pi_h F_h(h - \underline{h}) - \pi_t F_t(t - \underline{t})) \\ & h, t \end{aligned} \tag{11}$$

where:

h is the catch of nephrops.

t is the catch of cod.

\underline{h} is the regulatory restriction on nephrops⁶

\underline{t} is the regulatory constraint on cod.

π_h is the probability of being detected when the nephrops restriction is exceeded.

π_t is the probability of being detected when the cod restriction is exceeded.

F_h is the penalty (fine) when violating nephrops restriction.

F_t is the penalty (fine) when violating the cod restriction.

P_h is the output price on nephrops.

P_t is the output price on cod.

v_t is the stock of cod.

$C(h, t, v_t)$ is the cost of harvest function.

The control variables for the fishermen in (11) are the catches of nephrops and cod. When defining the net profit function it is assumed that all of regulatory restrictions can be represented in a quota system. The main problems in the Norway lobster trawl fishery in Kattegat and Skagerrak are landings of undersized lobsters and illegal by-catch of particular cod. The regulatory measures included are therefore landings of undersized lobster and exceeding the quotas for cod. In the net-profit function it is assumed that landings of undersized nephrops also can be translated into a restriction on output. From the cost of harvest function introduced in the net-profit function in (11) it becomes clear the cost of harvest only depends on the stock size for cod and not for Norway lobster. Note, that we assume that there is no stock effect associated with nephrops. This assumption is justified by the fact that there is no binding output restriction for nephrops.

⁶ The names nephrops and Norway lobster will be used interchangeable.

The first-order conditions of (11) when fishermen violate the regulative measures are:⁷

$$P_h - \frac{\partial C}{\partial h} - \pi_h F_h = 0 \quad (12)$$

$$P_t - \frac{\partial C}{\partial t} - \pi_t F_t = 0 \quad (13)$$

where $\frac{\partial C}{\partial h}$ is the marginal production cost of nephrops and $\frac{\partial C}{\partial t}$ is the marginal production cost of cod. Equations (12) and (13) state that the marginal revenue equal the marginal expected costs under profit maximisation. The marginal expected costs consist of the marginal production costs and the marginal expected value of the penalty when violating regulative measures.

(12) and (13) may be re-written as:

$$y_h = \frac{\partial C}{\partial h} \quad (14)$$

$$y_t = \frac{\partial C}{\partial t} \quad (15)$$

where $y_h = P_h - \pi_h F_h$ and $y_t = P_t - \pi_t F_t$. Thus, y_h and y_t is the marginal net revenue of lobster and cod, respectively, including the expected fine but not the production costs. We have information about all variables in y_h and y_t from the deliverable in WP2. Thus, y_h and y_t may be identified. In addition, information is also available on harvest of cod, nephrops and the stock size of cod, h , t and x_t . This implies that $\frac{\partial C}{\partial h}$ and in (14) and (15) can be estimated using traditional econometric procedures. We do, however, not have information about the functional form of the cost function. We therefore estimated the marginal costs based on six possible functionalities. These six models are defined below:

Model 1:

$$C(h, t, x_t) = f + ch + d \frac{t}{x_t} \quad (16)$$

where:

- f is fixed costs
- c is variable cost of nephrops
- d is a cost parameter associated with cod.

This cost function corresponds to a case where there is no interaction in the cost function between the harvest of nephrops and the harvest of cod. Based on the cost function in (16), the functions to be estimated (equation (14) and (15)) may be written as:

⁷ The problem is only solved for violators since non-violators are irrelevant in this case.

$$y_h = c \quad (14.1)$$

$$y_t = \frac{d}{x_t} \quad (15.1)$$

Model 2:

$$C(h, t, x_t) = f + ch^2 + d \frac{t^2}{x_t} \quad (17)$$

Again there is no interaction in the cost function between harvests of cod and nephrops. With (17), (14) and (15) become:

$$y_h = 2ch \quad (14.2)$$

$$y_t = \frac{2dt}{x_t} \quad (15.2)$$

Model 3:

$$C(h, t, x_t) = f + ch + d \frac{t}{x_t} + eth \quad (18)$$

Now there is interaction in the cost function between the catches of cod and nephrops. From equation (17) equations (14) and (15) is given as:

$$y_h = c + et \quad (14.3)$$

$$y_t = \frac{2d}{x_t} + eh \quad (15.3)$$

Model 4:

$$C(h, t, x_t) = f + ch^2 + d \frac{t^2}{x_t} + eth \quad (19)$$

Again there is interaction in the cost function between the catches of cod and nephrops. (14) and (15) are calculated as:

$$y_h = 2ch + et \quad (14.4)$$

$$y_t = \frac{2dt}{x_t} + eh \quad (15.4)$$

Model 5:

$$C(h, t, x_t) = f + ch + d \frac{t}{x_t} + et^2 h^2 \quad (20)$$

And equations to be estimated are:

$$y_h = c + 2et^2 h \quad (14.5)$$

$$y_t = \frac{d}{x_t} + 2eh^2 t \quad (15.5)$$

Model 6:

$$C(h, t, x_t) = f + ch^2 + d \frac{t^2}{x_t} + et^2 h^2 \quad (21)$$

and (14) and (15) are given as:

$$y_h = 2ch + 2et^2 h \quad (14.6)$$

$$y_t = \frac{2dt}{x_t} + 2eh^2 t \quad (15.6)$$

The dataset for the case study, in particular for the enforcement effort and penalties for violations, are based on all landings from Kattegat and Skagerrak containing either nephrops or cod from 2005 and 2006. We thus have cross-sectional data over years. Since we would like to regard to differences in time we include a yearly dummy, A . The value of the dummy is zero in 2005 and one in 2006. In the equations for nephrops (14.x) fA is included and in the equations for cod (15.x) gA is included.

We apply the probability of being detected as defined in section 2. In the data set, which forms the basis for defining the probability of being detected, we also have information about the catches of nephrops and cod and the fines. The fines in the data set are, however, not directly allocated to violations of nephrops and cod regulative measures, respectively. Therefore we make an indirect allocation of the fines for different types of violation based on the catch composition. For the main part of the violators the catches consist of either cod or nephrops alone and in these cases it is easy to allocate the fines to different types of violations. When a violator catches both cod and nephrops we allocate with 50% of the fine to each type of regulative measure.

An overview over the estimation results of equations (14.x) and (15.x) is given in Table 4.

Table 4
Estimation results for cost parameters in the cost of harvest function.

Parameter estimates (<i>t</i> -value)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
<i>c</i>	23.54 (0.47)	- 0.003 (-0.04)	53.96 (0.8)	0.1 (0.63)	-50.05 (-0.32)	0.06 (0.47)
<i>d</i>	-883350 (-1.56)	-1617.5 (-2.23)	-830345 (-0.57)	4514 (0.76)	-174007 (-0.96)	6306.5 (1.27)
<i>e</i>			-0.11 (-0.72)	-0.65 (-0.96)	0.01 (0.56)	0.01 (0.45)
<i>f</i>	-81.93 (-1.18)	-212.79 (-2.01)	-33.92 (-0.39)	33.34 (0.05)	-377.4 (-1.24)	-413.94 (-1.42)
<i>g</i>	-41.2 (-0.6)	-40.66 (-0.52)	-84.08 (-0.56)	77.93 (0.13)	-301.93 (-1.24)	159.95 (0.33)
<i>R</i> ²	0.04 and 0.01	0.15 and 0.12	0.04 and 0.01	0.37 and 0.42	0.29 and 0.24	0.42 and 0.38
Breuch- Pagan test	2.56	4.17	2.13	3.14	4.13	5.14
White test	5.46	6.13	6.14	8.19	7.97	6.13

With respect to model 3-6 we have used simultaneous equation estimations so that a common value of *e* is generated for both first-order conditions. For all models the Breuch-Pagan and White tests are so low that there is no problem with heteroscedasticity. For all estimated parameters in all models the variance inflation is below 10, which implies absence of serious multi-collenarity problems. For model 1, 2, 3 and 5 the value of *d* becomes negative while the value of *d* is positive in model 4 and 6. A negative value of *d* means that costs will decrease when more cod is harvested, which is an unlikely situation. This implies that we prefer model 4 and 6 because a positive value of *d* is what we will expect according to theory. Model 4 and 6 also generate the largest *R*² and the highest *t*-values so based on these criteria they also perform best. Summarising the above estimation, then the two models for further application can be written as follows:

Model 4:

$$y_h = 2*0.1*h - 0.65t + 33.34*A \quad R^2 = 0.37 \quad R^2=0.37 \quad (22)$$

(0.63) (-0.96) (0.05)

$$y_t = 2*4514t/11795 - 0.65h + 77.93*A \quad R^2 = 0.42 \quad R^2=0.42 \quad (23)$$

(0.76) (-0.96) (0.13)

Model 6:

$$y_h = 2*0.06h - 2*0.010.596t^2h - 413.94A \quad R^2 = 0.42 \quad (24)$$

(0.43) (-0.45) (-1.42)

$$y_t = 2*6306.5t/11795 - 2*0.01h^2t + 159.95A \quad R^2 = 0.38 \quad (25)$$

(1.27) (0.45) (0.33)

5. Shadow value of biomass

The shadow values of the biomass or shadow prices are defined as the change in present value of future profits in the fishery from a one unit increase in catches. This means that it describes the value of leaving an additional unit of the stock behind, letting it grow and spawn to generate future profits. The shadow value of the biomass is necessary to describe the benefit function for the society since it reflects the value of having a stock. To generate shadow prices we apply a modified version of the NECESSITY model which was developed to make a cost-benefit analysis of improving selectivity by increasing mesh sizes. A short description of the NECESSITY is available in appendix for a more comprehensive description of the model see Frost *et al.* (2007). The NECESSITY model can, when used in a correct way, generate shadow prices. The shadow prices are calculated by increasing the catches by one unit (1 tonnes) in the first year and then evaluating the change in net present value of future profit over 10, 20 and 30 years, respectively. Since we are considering only cod and nephrops as species with binding regulatory measures, we are only interested in finding the shadow value of biomass for those two species. The shadow price for one unit increase in cod harvest alone⁸ is shown in table 5.

Table 5
Shadow value of biomass for cod (Euro pr. Kg).

Vessel length	Time (years of future profit included)		
	10	20	30
< 12 m	0	0	0
12-15m	-0.004	-0.125	-0.178
15-18m	-0.032	-0.102	-0.144
18-24m	-0.049	-0.154	-0.219
24-40m	-0.055	-0.173	-0.246
40 -	0	0	0

As seen from table 5 the shadow prices are all negative. The explanation for this is that in the first year the increase in catches implies an increase in profits. However, in future periods the increase in catches will have a negative effect on the stock. This implies decreased catches and negative future profits, which exceeds the benefit from increased catches in period 1. The effect becomes more visible the longer time period included in the net present value of future profit calculation. Therefore, shadow prices decreases the longer period included.

In table 6 the shadow vale of biomass for nephrops, with a one unit increase in the catches in the first period, is shown.

⁸ We assume by this that full selectivity is possible.

Table 6
Shadow value of biomass for nephrops (Euro pr. Kg).

Vessel length	Time (years of future profit included)		
	10	20	30
< 12 m	0	0	0
12-15m	0.003	0.003	0.003
15-18m	0.002	0.002	0.002
18-24m	0.002	0.002	0.002
24-40m	0.003	0.003	0.003
40 -	0	0	0

From table 6 it is seen that the shadow value of biomass for nephrops is very low, but positive. The reason for this is that there is hardly any stock effect for nephrops in the model. Thus, one unit increase in the catches of nephrops does not influence the stock size much. That the shadow value of biomass is positive, and constant no matter the time span included in the future profit, indicates that the one unit increase in the harvest in year one generates a positive profit in year one, but does not decrease the future profits.

It is important to recognise that the total allowable catch, TAC, for nephrops in Kattegat and Skagerrak is not binding. There is, however, a problem with discard of undersized catches in the fishery. For every tonnes of landed nephrops approximately one tonnes undersized nephrops are discarded (Nielsen *et al.* 2008). Whether some of the discarded nephrops will survive is very uncertain and subject for a large debate. This does not change the fact than an increment of one tonnes in landings has a larger effect than one tonnes reduction in the stock. In the above calculations of the shadow prices only landings and not total catches including discard are included. Therefore, the above table should be regarded as an upper limit for the shadow price.

The NECESSITY model allows us to determine the shadow value of biomass divided into different vessel length categories. In the COBECOS project we need one shadow price for all length categories. We, therefore, need weights for each length categories from the data collection in WP2. As weights we use the catch shares of each category. The catch shares are shown in table 7.

Table 7
Catch shares for length categories in percentage %.

Vessel length	Cod Catch share	Nephrops Catch share
> 12m	1.017	0.941
12-15 m	32.591	29.122
15-18m	38.605	32.713
18-24m	25.819	32.064
24-40m	1.969	5.160
40m-	0	0
Total	100	100

Source: Kronbak *et al.* (2007).

By applying the weights in table 6 and the calculated shadow values from table 4 and 5 we can calculate the total shadow value of biomass for each of the two species. The total shadow prices are shown in table 8.

Table 8
Shadow value of biomass for cod and nephrops (Euro pr. Kg.)

Species	Time (years of future profit included)		
	10	20	30
Cod	- 0.274	-0.1228	-0.1750
Nephrops	0.0023	0.0023	0.0023

The shadow values presented in table 8 are the shadow values of biomass applied for further analysis.

6. Social benefit function

Summarising the information from the above sections we are now able to define the social benefit function. This section sketches a private and social optimum and argues that there is sufficient information to solve these problems with the estimations in previous sections. It is important to notice; that the social benefit function is constructed with the aim of optimising the benefits to the society based using the enforcement effort as the control variable. The social benefit function is therefore a merger of the optimum from the private benefits from fishing, the costs of enforcement which should be maximized with respect to the two types of enforcement effort (dock side inspections and boardings) under the two response functions from the private benefit function.

In order to derive the social optimum we begin with the private profit maximisation problem in equation (11). Our aim is to find the harvest response functions for cod and nephrops:

$$\underset{h, t}{\text{Max}}(P_h h - P_t t - C(h, t, v_t) - \pi_h(x_h)F_h(h - \underline{h}) - \pi_t(x_t)F_t(t - \underline{t})) \quad (26)$$

The first-order conditions are:

$$P_h - \frac{\partial C}{\partial h} - \pi_h(x_h)F_h = 0 \quad (27)$$

$$P_t - \frac{\partial C}{\partial t} - \pi_t(x_t)F_t = 0 \quad (28)$$

In (27) and (28) we have information about P_h , P_t , F_h and F_t . In addition we know $\frac{\partial C}{\partial h}$ and $\frac{\partial C}{\partial t}$ from section 4 and $\pi_h(x_h)$ and $\pi_t(x_t)$ from section 2. Thus, we may specify the catches from a private response function:

$$t = T(x_t, F_t) \quad (\text{Cod response function}) \quad (29)$$

$$h = H(x_h, F_h) \quad (\text{Nephrops response function}) \quad (30)$$

These functions are obtained by solving (27) and (28) as two equations with two unknowns. The regulator assumes that the fishermen adopt optimal harvest behaviour and therefore follows the response functions as defined in (29) and (30). The regulator maximises the social welfare given as net-benefits from fishing minus the cost of applying enforcement and shadow costs subject to the fishermen's harvest response functions:

$$\begin{aligned} & \text{Max}(P_h h - P_t t - C(h, t, v_t) - TC(x_t, x_h) - \lambda_h h - \lambda_t t) \\ & x_t, x_h \end{aligned} \quad (31)$$

s.t.

$$t = T(x_t, F_t) \quad (32)$$

$$h = H(x_h, F_h) \quad (33)$$

Where:

$TC(x_t, x_h)$ are the total enforcement costs.

λ_h is the shadow price for lobster

λ_t is the shadow price for cod

Substituting (32) and (33) into (31), setting up an objective function and differentiating yields:

$$(P_h - \lambda_h) \frac{\partial H}{\partial x_h} = \frac{\partial TC}{\partial x_h} + \frac{\partial C}{\partial h} \frac{\partial H}{\partial x_h} = 0 \quad (34)$$

$$(P_t - \lambda_t) \frac{\partial T}{\partial x_t} = \frac{\partial TC}{\partial x_t} + \frac{\partial C}{\partial t} \frac{\partial T}{\partial x_t} = 0 \quad (35)$$

From above we know the response function and, therefore, $\frac{\partial H}{\partial x_h}$ and $\frac{\partial T}{\partial x_t}$. From section 4 we know the private cost function and prices and section 5 gives us information about λ_h and λ_t . Last, from section 3 we know the $AC(x_t, x_h)$ and can thereby solve for $TC(x_t, x_h)$. Therefore, based on (34) and (35) we may calculate x_h and x_t which is then the optimal mix of enforcement divided into enforcement on violations on the nephrops regulatory measure and violations on the cod regulatory measure. This holds for the various specifications of $C(h, t, v_t)$ and $TC(x_h, x_t)$ as described in section 4 and 3, respectively.

Equations (34) and (35) may also be interpreted as the marginal social benefit of different types of enforcement (dock side inspections and boardings). This would simply require the social benefit function in (34) maximized with respect to dock side enforcement effort (x_1) and boardings effort (x_2). In this case the fishermen's response functions would then depend upon probabilities of being apprehended if they exceed the nephrops and cod regulatory measures, respectively and are caught

by a dock side or a boarding inspection. Altogether this yields two probabilities in each response function. It would, however, again imply the marginal social benefit of each type of enforcement is zero, and we could solve for the optimal mix of enforcement effort between different types of enforcement. In our case it would be the optimal mix of dockside inspections and boardings.

7. Conclusion and discussion

This paper is a working paper within in the ongoing research project called “Costs and Benefits of Control Strategies” with the acronym COBECOS. It aims at presenting the first steps in the application of the theory on fishery enforcement from the COBECOS project to a specific case, namely the case of Norway lobster trawl fishery in Kattegat and Skagerrak. To apply the theory of fisheries enforcement we need to estimate and determine different functionalities relevant for the application of the COBECOS code. In this paper we start by defining how to convert data from our case into enforcement data between zero and one as necessary for the COBECOS code. We then estimate 1) the enforcement effort and the probability of apprehension function, 2) the enforcement effort and enforcement cost function, 3) the fishermen’s private benefit function, 4) the shadow value of the two biomasses cod and nephrops and finally 5) the social benefit function.

During our setup we recognize challenges that are general to the whole setting and some challenges that are related to our specific case and the available data. The general challenges are primarily connected to determining the enforcement probability. Among these challenges are

- The actual enforcement effort is not a random variable, but merely a targeted enforcement towards previous violators or based on biological sustainability issues. We have not found a way to overcome the non-randomization of the enforcement effort, and we therefore recognise that the problem is there, but we do not deal with it.
- In our data set the only information about violators available is that we only know violators that are also apprehended. Violators that are not apprehended are not represented in our data set. This leads to, together with the above-mentioned targeted enforcement that the information about violators may be biased.
- We found it difficult to define what enforcement effort is. It could be number of man hours, fuel costs, number of inspections, or others. We do need a link between the enforcement effort and probability of being apprehended and since we have only cross sectional data over 2005 and 2006 we are not able to make a time series analysis. We have, therefore, decided to settle on the number of inspections since this is the most accurate measure that we have on an individual level even though we are aware that not two inspections are similar.
- To be able to apply the Cobecos software in our next step we need to rescale the enforcement between zero and one. Now one is a measure of controlling each and every harvest.
- It is only a very little percentage of all landings that are actually controlled. Out of the controlled landings are even fewer violations. Therefore the enforcement effort relative to the number of landings is very low and similarly the probability of apprehension is very low. This means that data are concentrated for very low values of enforcement effort and for very low values of probability for apprehension. For estimating the enforcement probability function, we therefore use extrapolation.

We also experienced some more case specific data problems:

- As mentioned under the more general issues we have only cross sectional enforcement data for each landing from Kattegat and Skagerrak with cod or nephrops from the years 2005 and 2006. We were therefore forced to find the enforcement effort and the probabilities of

apprehension on an individual level. We added a dummy to identify the year. We are therefore not able to identify any development in the enforcement effort or the probability of apprehension over time.

- Our data set for enforcement cost had very limited information. We had only average enforcement cost over a 3 year period. We therefore had to rely on a positive mathematical programming method introduced by others (Howitt 1995, Jensen and Vestergaard 2002). We are aware that our cost of enforcement function is encumbered with a great deal of uncertainty, and sensitivity analysis on this function is of great importance.
- There exists no stock assessment of nephrops. We can therefore not include the nephrops stocks in the private cost of harvesting function. We have, however, been able to calculate the shadow value of biomass based on the NECESSITY model by finding the additional profit over a time horizon, by harvesting one additional unit in current time. By this the nephrops stock will still be represented in the social benefit function.
- The binding regulatory measure for nephrops is the minimum landing size. We have to redefine this regulatory measure in our benefit functions such that it is converted into a TAC.

The paper estimates the functional forms that are now ready to apply in the COBECOS software for finding the optimal mix of enforcement effort.

8. References

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APPENDIX: The NECESSITY model

Execution of a cost-benefit analysis (CBA) requires that different projects are compared with the aim of finding the best project. The most limited case is where one project continues as before and the other project comprises implemented changes. (A.1) is showing the model for the baseline case:

$$NPV_j^0 = \sum_{t=0}^T \frac{\sum_{i=1}^I H_{i,t}^0 p_{i,t}^0 - C_t^0 - G_t^0 + V_t^0 - U_t^0}{(1+d)^t} - I_j^0 \quad (\text{A.1})$$

where:

- i is species
- j is fleet segment
- t is time
- NPV is net present value in the baseline case
- H is landings
- p is price of fish
- C is variable costs
- G is fixed cost
- V is external effects
- U is management cost
- I is investment costs
- d is the discount rate

For a project with changes the formula looks like:

$$NPV_j^1 = \sum_{t=0}^T \frac{\sum_{i=1}^I H_{i,t}^1 p_{i,t}^1 - C_t^1 - G_t^1 + V_t^1 - U_t^1}{(1+d)^t} - I_j^1 \quad (\text{A.2})$$

The variables in (A.2) are the same as for (A.1) but different data inputs will be used for different projects. Therefore, the decision rules as to whether a new project should be accepted or rejected is the difference between NPV for the whole fleet compared for projects of the same duration as shown in (A.3) and (A.4):

$$\sum_{j=1}^J NPV_j^1 > NPV_j^0; \text{accept} \quad (\text{A.3})$$

$$\sum_{j=1}^J NPV_j^1 < NPV_j^0; \text{reject} \quad (\text{A.4})$$

Theses decision rules means that if a change in gear yields higher net present value for the whole fishery the project should be accepted. That means on the other hand that some fleet segments may be worse off by the gear change while others may become better of.

The calculations that is accomplished by using (A.1)-(A.4) requires information about all variables. Information about landings is derived from biological models in which catches (landings including discard) are estimated. In age structured models the number of fish at age 1 in year 1 is reduced to the number of fish at age 2 in year 2 and so forth. This decay is caused by natural mortality and total mortality (natural mortality and fishing). Furthermore, only the fish caught above minimum size are landed. The rest is either discarded or landed illegally and will, therefore, not appear in the recorded landings of a vessel. A change in gear specification is expected to lead to a change in selectivity which is the proportion of fish in each age group that is retained in the gear. If the selectivity is high the probability of escapement for small fish is high.

Formally, catches of each species as a function of age group can be expressed as in (A.5):

$$C_{a,t} = N_{a,t} (1 - \exp(-(M_a + F_a^0))) \frac{F_a^0}{M_a + F_a^0} \quad (\text{A.5})$$

where:

a is age group
 t is year
 C is catch
 N is the number of fish
 M is natural mortality
 F is fishing mortality.

The base line fishing mortality is denoted 0. This indicates the fishing mortality for the baseline mesh size. It is assumed that recruitment to the stock is constant over time.

The selectivity of the gear is implicitly captured by F in (A.5). The selection can be expressed as one of two forms:

$$S = \frac{1}{1 + \exp(-r - l_{50}l)} \text{ or } S = \frac{\exp(r + l_{50}l)}{1 + \exp(r + l_{50}l)} \quad (\text{A.6})$$

Where:

S is the probability of being retained
 l is the length of fish
 l_{50} is the length of fish that have a probability of being retained at 50%
 r is the distance between l_{75} and l_{25} .

The l and r are species and gear specific. In the second specification of the selection functions, S is explicitly a function of mesh size keeping the parameters l and r constant.

Given knowledge about the relationship between selectivity and length, (A.6), a new catch equation can be constructed for the new mesh size by scaling the baseline fishing mortality using new selectivity parameters. As the catch is specified as a function of fishing mortality on age groups,

(A.5), selectivity must be transformed in such a way that S also matches fishing mortality on age groups.

Often weight not length is recorded on age groups. The weight information can, however, be used to calculate length on age groups by use of the relationship in (A.7):

$$w = \alpha l^\beta \quad \text{or} \quad l = \frac{1}{\alpha} w^{1/\beta} \quad (\text{A.7})$$

where α and β are species specific parameters taken into account whether the parameters are specified for gutted or round fish and l is length while w is weight. If neither weight nor length information on age groups are available a possible method is to use a growth function, for example a von Bertalanffy function:

$$l = L_\infty (1 - \exp(-K(a - a_0))) \quad (\text{A.8})$$

where L_∞ is maximum length of a fish and K and a_0 are species specific parameters.

Combining information on age groups of F , w and l makes it possible to calculate S for age groups and, thereby, F_a . F is total fishing mortality while F_a is fishing mortality on age groups. By using the ratio between selectivity in the baseline case and the case of gear change to scale F for each age group, the modified equation will look like:

$$C_{a,t}^1 = N_{a,t} (1 - \exp(-(M_a + \frac{S_a^1}{S_a^0} F_a^0))) \frac{\frac{S_a^1}{S_a^0} F_a^0}{M_a + \frac{S_a^1}{S_a^0} F_a^0} \quad (\text{A.9})$$

While catches occur for all age groups, only fish from age groups over a certain minimum length are allowed to be landed. Therefore, the landings (or harvest) inserted in equation (A.2) are calculated as:

$$H_{i,t}^1 = \sum_{a=\text{min size}}^A C_{a,t}^1 \quad (\text{A.10})$$

The discard is then calculated as $\sum_{a=0}^{a=\text{min size}} C_{a,t}^1$. Discard is, however, omitted in the following analysis

In the present model future catches are determined by the fishing mortality rate, F , influenced only by the changes in selectivity. However, a more comprehensive approach as how changes in selectivity may impact profitability and, hence, future effort could be included.

Finally, when the calculation is carried out on fleet segment level the fishing mortality rate, F , must be adjusted appropriately. This is done by using the recorded landings of the pertinent species of the pertinent fleet segment in proportion to the total landings of all segments of the pertinent species:

$$h_{i,0,j}^0 = \frac{H_{i,0,j}^0}{\sum_{j=1}^J H_{i,0}^0} \quad (\text{A.11})$$

Hence on fleet segment level the equation using partial fishing mortality looks like:

$$C_{a,t}^1 = N_{a,t} (1 - \exp(-(M_a + \frac{S_a^1}{S_a^0} F_a^0 h_{i,0,j}^0))) \frac{\frac{S_a^1}{S_a^0} F_a^0 h_{i,0,j}^0}{M_a + \frac{S_a^1}{S_a^0} F_a^0 h_{i,0,j}^0} \quad (\text{A.12})$$