ISSN 1988-088X

Departamento de Fundamentos del Análisis Económico II

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University of the Basque Country
Avda. Lehendakari Aguirre 83
48015 Bilbao (SPAIN)
http://www.dfaeii.ehu.es

DFAE-II WP Series

2011-01

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Lessons from the northern hake long-term management plan: Could the economic assessment have accepted it?

Lessons from the northern hake long-term management plan: Could the economic assessment have accepted it?

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Abstract

An economic expert working group (STECF/SGBRE-07-05) was convened in 2007 for evaluating the potential economic consequences of a Long-Term Management Plan for the northern hake. Analyzing all the scenarios proposed by biological assessment, they found that keeping the *F* in the *status quo* level was the best policy in terms of net present values for both yield and profits. This result is counter intuitive because it may indicate that effort costs do no affect the economic reference points. However, it is well accepted that the inclusion of costs affects negatively the economic reference points. In this paper, applying a dynamic age-structured model to the northern hake, we show that the optimal fishing mortality that maximizes the net present value of profits is lower than $F_{max.}$.

JEL Classification: Q22, Q28, Q57

Keywords: northern hake, economic assessment, age-structured models, fishery management optimization, net present value of profits.

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Introduction

Economists have participated as consultants from fisheries management decisions for a long time (Wilen, 1999). However, biological and economical assessments are conduced independently. This means that the conclusions from the different models used by each discipline must be assembled by fishery agencies in order to reach their objectives. And this may become an unattainable aim when the analysis is based on different assumptions.

The use of unrelated methods of analysis in each area may lead to unexpected situations. For instance, an Expert Working Group (STECF/SGBRE-07-03) was convened in Lisbon from June 18th to June 22nd, 2007, for evaluating the potential biological consequences of a long-term management plan for the northern stock of hake. The working group found that current fishing mortality rate was close to $F_{pa}=0.25$. It also concluded that $F_{max}=0.17$ is a good proxy for the target reference point F_{msy}. The working group studied the impact of reducing the current fishing mortality rate, F_{pa}, to F_{max} assuming different convergence speed scenarios. Based on this analysis, STECF/SGBRE-07-03 concluded that maintaining F_{pa} as opposed to reducing F to F_{max}, would lead to increase in the short run the risk of returning to an unsafe situation (SEC(2007)).

In order to carry out bio-economic impact assessments for the long run stock management plan STECF also recommended scheduling an additional meeting, involving both biologists and economists. Therefore, a second Expert Working Group (STECF/SGBRE-07-05) was then convened in Brussels from 3-6 December 2007 for analyzing the socioeconomic impact of the scenarios proposed at the Lisbon meeting. The indicators chosen for evaluating this impact were the net present values of: landings (in value), crew share, gross cash flow, profits and gross added value. These indicators were calculated using the Economic Interpretation of ACFM Advice Model (EIAA, Annex 2 SEC(2004) 1710, Hoff and Frost (2008)).

Tables 1 and 2 show the results obtained by the expert group for all the economic indicators associated to the French and Spanish fleets, respectively, using a 5% discount rate and considering the period 2008-2016. Regardless the economic indicator used, the *status quo* was the scenario best ranked among all scenarios analyzed. Therefore the economic analysis concluded, contrary to Lisbon's proposal, that fishing mortality should be kept close to the *status quo* F_{pa} instead of reducing fishing mortality up to F_{max}.

Moreover, a close inspection of Tables 1 and 2 show that all the scenarios analyzed are equally ranked regardless of the economic indicator used, which is a counter intuitive result. It is well know that, in general, F associated to maximum profits is lower than F associated to maximum yield (Gordon (1954), Clark and Munro (1975), Christiansen (2010), Grafton *et al.* (2010)). Furthermore, this statement has been tested in empirical studies (Grafton, Kompas and Hilborn (2009), Dichmont *et al*. (2010) and Kompas *et al.* (2010)). Consequently, it is expected that when profits are considered, a scenario with F lower than F_{msy} be ranked higher than the scenario associated to F_{msy}.

In this paper, using a dynamic age-structured model, we show that the scenarios proposed by the biologists for the northern hake may be ranked in different manner depending on the economic indicator used. In order to do this, firstly, we solve for the optimal long run fishing mortality and the fishing mortalities trajectories that maximize net present values of the different indicators, using a generic basic age-structured model with constant recruitment, and specifying cost as a linear function of fishing mortality (see Gröguer *et al*. (2007), Kulmala, Laukkanen and Michielsens (2008), Tahvonen (2008, 2009) and Da Rocha, Cerviño and Gutiérrez (2010)).

Secondly, the economic indicators for the optimal trajectories are recalculated assuming a linear cost function on F. Our numerical simulations are quite intuitive from the theoretical point of view. Under reasonable prices by age, running costs per day, and discount rates, if net present values of profits are maximized, the scenarios associated with a long run fishing mortality lower than F_{max} will always be preferred, like in Grafton *et al*. (2009), Kompas *et al.* (2010) and Dichmont *et al*. (2010).

Dynamic management problem

An alternative to fisheries' economic assessment based on preselected fishing mortality trajectories is the optimal fishing mortality trajectory that maximizes the net present value of the fisheries economic indicator, taking into account the dynamics described by the standard age structured model.

In order to value the future we consider a given discount factor, $0 \leq \beta \leq 1$. Discount is frequently introduced in fisheries economics using the discount rate, r, instead of discount factor, β (Grafton *et al.* (2006). The former uses are applied in continuous time frameworks while the latter is more commonly used in discrete set up. The inverse relationship between both terms is given by $\beta = (1+r)^{-1}$.

Formally, let us assume that the fish stock is broken into A cohorts. The net present value of the a fishery economic indicator can be expressed as

$$\sum_{t=0}^{\infty} \beta^t \left(\sum_{a=1}^{A} pr^a Y_t^a - C(F_t) \right), \qquad (1)$$

where pr^a, Y_t^a and $C(F_t)$ are respectively the price and yield at age a^{th} and the total cost function which depends positively on fishing mortality.

The maximization problem consist of solving the objective function (1) taking into account the stock dynamics which are given by $N_{t+1}^{a+1} = e^{-z_t^a} N_t^a$, where z_t^a is the total annual mortality rate affecting the numbers N of age group a during year t.

The total mortality rate is decomposed into fishing mortality *F* and natural mortality *m*, which is assumed constant across ages. Formally, $z_t^a = p^a F_t^a + m^a$, where p^a represents the selectivity parameters for age *a*. We also assume that recruitment follows an Ockham rule and that the yield is determined by Baranov's equation (1918). Furthermore, we restrict the solution to satisfy the precautionary restriction given by $SSB_t \geq B_{pa} \; \forall t$.

Notice that the objective function can be interpreted in several ways. For instance, if pr^a is constant and the marginal cost is zero, the objective function represents the discounted yield in weight. When the marginal cost is zero and pr^a is not equal to one, the objective function coincides with the discounted yield in value. When pr^a is not constant and total cost equals the cost of fuel plus other running costs, the objective function is equal to the discounted value added. Finally, if the total cost includes also labor cost, then the objective function is the discounted profits of the fishery.

We show in Appendix 1 that the optimal management strategy that maximizes the net present value (1) for a given initial condition, is the fishing mortality trajectory $\{F_t, F_{t+1}, ...F_\infty\}$ that satisfies the following set of first order conditions (foc), $\forall t$

$$\sum_{a=1}^{A} pr^a \frac{\partial y^a(F_t)}{\partial F_t} \phi_t^a\left(F_{t-(a-1)},\ldots,F_{t-1}\right)N^1 - \frac{\partial C(F_t)}{\partial F_t} = \sum_{a=1}^{A-1} p^a \left[\sum_{j=1}^{A-a} \beta^j pr^j y^j\left(F_{t+j}\right)\phi_t^a\left(F_{t+j-(a-1)},\ldots,F_{t+j-1}\right)N^1\right], \quad (2)$$

where, $y^a(F_t)$ is the yield per recruit in period *t* when the fishing mortality is F_t and ϕ_t^a can be interpreted as the survival function that shows the probability of a recruit born in period *t-(a-1)* to reach age *a>1,* for a given *F* path $\{F_t, F_{t-1}, F_{t-2}, ...F_{t-(a-1)}\}$. It is given by

$$\phi_t^a = \begin{cases} \prod_{i=1}^{a-1} e^{-z_{t-i}^{a-1}(F_{t-i})} & \text{if} \quad a > 1, \\ 1 & \text{if} \quad a = 1. \end{cases} \qquad (3)$$

The fishing mortality trajectory that maximizes the net present value of yield per recruit is the balance, for any β, between the following two effects: *i)* the instantaneous effect on profits in period *t* of changes in the fishing mortality, when the age distribution population is constant across time and, *ii)* the future effect on yield, due to changes in future age distribution population induced by the changes in the F_t. Note that the discount factor, β, affects to the net present value of future effects. Considering the extreme case of $\beta = 1$ is equivalent to weight changes in the future as if they occur at the current period. By the contrary, considering $\beta = 0$ implies not to care about the future.

We also show in Appendix 1 that when F_t=F_{t+1}, the equation system (2) collapses to a steady state solution that defines the long term reference point that maximizes, for a given β , the net present value along the optimal fishing mortality trajectory. Notice that when pr^a is constant, the marginal cost is zero and β=1, the steady state solution is equal to F_{max}. By the contrary, when $\beta = 0$ the steady state solution coincides to the immediate maximum economic yield (F_{IMEY}), defined by Lleonart and Merino (2009).

In some frameworks, the optimal solution is not necessary a steady state but consists of pulse fishing (see Tahvonen, 2009).

Recalculating Economic Indicators

Four scenarios are solved for the optimal management problem: assuming *i)* marginal cost is zero and $pr^a = 1$; *ii)* marginal cost is zero and pr^a is not equal to one; *iii)* total cost is equal to the cost of fuel and other running costs and pr^a is not equal to one; and, *iv)* total cost includes also the labor cost and pr^a is not equal to one. It should be noted that the optimal trajectories have also been calculated under the restriction that mortality rate does not change more than a 15% per year.

In order to find the optimal trajectories, the model is calibrated for the northern hake. Appendix 2 shows in detail how the calibration has been prepared using data set reported for the working groups STECF/SGBRE-07-03 and SGBRE-07-05 and daily sales of the Spanish 300 fleet.

We assume that there exists uncertainty about the initial age distribution and recruitment process. In particular, log normal distributions are used to describe the initial conditions of the population distribution. So for each scenario 20,000 simulations are run.

Table 3 reports the net present value of the economic indicators calculated for the four scenarios using a discount factor of 0.95 and the age structured model and economic calibration described in Appendix 2. Each row shows information of net present value of yield in weight, yield in value, value added and profits, respectively. For any of them, the mean and the coefficient of variation (cv) associated to the 20,000 simulations run are displayed. Bold indicates the best economic indicator for each scenario. Notice that different economic indicators select different values of *F*. In particular, the optimal *F* is much lower when profits rather than yield (in weight or value) is used as the benchmark economic indicator.

It is worth highlighting that the economic indicators calculated represent the present value of the fishery for the whole future. Although the stationary fishery rate is reached in eight to ten periods, however, for each scenario, the value of the objective function (1) is calculated for the optimal trajectory taking into account infinity periods.

Discussion

Most fishery agencies base their advice about long-term plans on biological and economic analysis. However, in many occasions the analysis is done in steps: biological criteria determine the desired scenarios and subsequently economic criteria are applied to assess the impact of the proposed scenarios. This two-step procedure may lead to contradictory results. For instance, the latest advice for the Northern Stock of Hake long management plan consisted, in the first place, in proposing nine scenarios based on F_{max} as a good approximation of F_{msy}. However, posterior economic analysis of these nine scenarios proved that the $F=0.25>F_{max}$ is always preferred “under the economic point of view” to any of the alternative scenarios proposed.

Obviously, one of the causes of this undesired result was that the economic assessment did not consider the criteria used when designing the scenarios. When designing the long term management plan, the fishery was in a high risk situation. All the biological models unanimously concluded that if the fishing effort was not reduced, in a short period of time SSB would very likely fail bellow B_{pa}. In this sense, the economic analysis should have been done considering the restrictions necessary for recovering the stock (Da Rocha, Cerviño and Gutiérrez (2010)). In other words, the status quo scenario should have not been included among the set of scenarios to be evaluated for the economic assessment as it did not satisfy the precautionary criteria.

Nevertheless, a more important question is why the *status quo* scenario was selected by the economic assessment. Recently, Grafton *et al.* (2007), Kompas *et al.* (2010) and Dichmont *et al*. (2010) proved that, under the stock effect assumption, optimal fishing mortality rates (biomass) are much lower (higher) when profits rather than yield are used as the benchmark economic indicator. Similarly, we show that when a cost function that depends linearly on fishing mortality is introduced, the fishing mortality associated to maximization of discounted profits, F_{mey}, is lower than F_{max} .

Why does our analysis rank scenarios like Grafton *et al.* (2007), Kompas *et al.* (2010) and Dichmont *et al*. (2010) and the EIAA analysis did not? Our intuition is that the EIAA model calculated all the economic indicators as if they were monotonic transformations of landings because: a) pr^a was constant across ages, and b) it underestimated differences in effort cost between scenarios.

From the information that appears in the report from STECF/SGBRE-07-05 it is not possible to reproduce the cost indicators computed by EIAA model. Because of that we calculate the implicit costs used by the EIAA model computing

$$\sum_{t=2008}^{2016}\beta^t C(F_t) = \sum_{t=2008}^{2016}\beta^t \textit{value of landings}_t - \sum_{t=2008}^{2016}\beta^t \textit{net profits}_t .$$

Table 4 shows in the first and the second row, these implicit costs used by the EIAA model. The third and the fourth rows represent the same variables but indexed taken the status quo situation as 100.

We can observe that differences in effort cost between scenarios are much smaller than the differences in fishing mortality between scenarios. According to the EIAA model calculations, reductions over 15% in fishing mortality (from F_{SQ} to 1,20*F_{max}) imply reductions in the effort cost lesser than 1% for the French fleet segments and lesser than 2.5% for the Spanish ones. Therefore, the effort cost is quite constant which is equivalent to assuming a marginal cost close to zero.

Which will be the selected scenario when ranking according to the net present value of yield in weight? Figure 1 shows the fishing mortality associated to the optimal long term reference points that maximize net present value of yield in weight for different discount factors using the age structured model from Table 5. Notice that when yield in weight is the reference economic indicator $pr^a = 1$ and $C(F_t) = 0$. So the foc associated to the maximization problem, equation (2), can be expressed as

$$\sum_{a=1}^{A}\frac{\partial y^a(F_t)}{\partial F_t}\phi_t^a\left(F_{t-(a-1)},\ldots,F_{t-1}\right)N^1 = \sum_{a=1}^{A-1}p^a\left[\sum_{j=1}^{A-a}\beta^j y^j\left(F_{t+j}\right)\phi_t^a\left(F_{t+j-(a-1)},\ldots,F_{t+j-1}\right)N^1\right]. \quad (4)$$

The black line in Figure 1 represents how yield changes as F increases, whenever the cohort sizes are constant; that is, it sows the value of the left hand side of equation (4) for each F. Notice that this does not depend on the discount factor. This means that in a dynamic problem, this effect is instantaneous. It decreases because as F increases its relative weight increases less than proportionally (this is due by Baranov's assumption).

The grey lines in Figure 1 represent for $\beta = 1$, $\beta = 0.95$ and $\beta = 0.90$, how future yield varies as F increases due to the changes in the future cohort sizes; that is, it sows the value of the right hand side of equation (4) for each F. Notice that this effect has a bell shape. When the fishing rate is low, a marginal increase in F raise the future size cohorts due, for instance, to cannibalism. However, when the fishing rate is high, a marginal increase in F reduces future cohort size. Moreover, the empirical simulations show that when the discount factor decreases the bell shape shifts upwards.

In Figure 1, the optimal stationary fishing rate is determined by the intersection between the black line (left hand side of equation (4)) and the correspondent grey line (right hand side of equation (4)). So graphically, it is clear that the lower the discount factor is the higher the optimal F is. Nevertheless, it can be analytically proved that the optimal F that maximizes the net present value of yield in weight when future is discounted, $\beta<1$, is always greater than F_{max}. For instance, in our case when $\beta=1$, the optimal F is equal to $F_{max}=0.17$. However, when $\beta=0.95$ and $\beta=0.90$ the optimal F are 0.21 and 0.26 respectively.

Therefore, if our intuition is correct and the EIAA model economic indicators are monotonic transformations of net present value of yield in weight, the scenarios with F higher than F_{max} will be always preferred to those with F lower than F_{max}. This would imply that long term management plans designed to reach F_{max} will always be rejected.

Acknowledgements

Special thanks to participants in the Lisbon and Brussels 2007 North Hake Working Group Meetings. Financial aid from the Spanish Ministry of Education and Science (ECO2009-14697-C02-01 and 02) and the Basque Government (IT-241-07 and HM-2009-1-21) is gratefully acknowledged.

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Appendix 1: Charactering first order condition of the fishery maximization problem.

To solve the following maximization problem,

$$\max_{\{F_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left(\sum_{a=1}^{A} pr^a y^a (F_t) N_t^a - C(F_t) \right),$$

$$s.t. \begin{cases} N_{t+1}^{a+1} = e^{-p^a F_t - m^a} N_t^a , & \forall t, \forall a = 1,\dots, A-1, \\ N_t^1 = \overline{N}, & \forall t, \end{cases}$$

N_t^a is substituted by $N_t^a = \phi_t^a N_{t-(a-1)}^1 = \phi_t^a \overline{N},\ \forall a = 1,\dots, A$, where ϕ_t^a is the survival function that is given by the expression (3) in the main text.

Without loss of generality, we assume that $A = 3$. In this context, the function to be maximized can be expressed as

$$L = \sum_{t=0}^{\infty} \beta^t \left\{ pr^3 y^3 (F_t) \phi_t^3 \overline{N} + pr^2 y^2 (F_t) \phi_t^2 \overline{N} + pr^1 y^1 (F_t) \phi_t^1 \overline{N} - C(F_t) \right\},$$

where the survival functions are given by

$$\begin{aligned} \phi_t^1 &= \quad 1, \\ \phi_t^2 &= \phi(F_{t-1}) = \quad e^{-p^1 F_{t-1} - m^1}, \\ \phi_t^3 &= \phi(F_{t-1}, F_{t-2}) = \quad e^{-p^2 F_{t-1} - m^2} e^{-p^1 F_{t-2} - m^1}. \end{aligned}$$

Note that F_t appears only in three sums; in particular those multiplied by β^t, β^{t+1} and β^{t+2}. That is,

$$\begin{aligned} L = \dots &+ \beta^t \left\{ pr^3 y^3 (F_t) e^{-p^2 F_{t-1} - m^2} e^{-p^1 F_{t-2} - m^1} \overline{N} + pr^2 y^2 (F_t) e^{-p^1 F_{t-1} - m^1} \overline{N} + pr^1 y^1 (F_t) \overline{N} - C(F_t) \right\} \\ &+ \beta^{t+1} \left\{ pr^3 y^3 (F_{t+1}) e^{-p^2 F_t - m^2} e^{-p^1 F_{t-1} - m^1} \overline{N} + pr^2 y^2 (F_{t+1}) e^{-p^1 F_t - m^1} \overline{N} + pr^1 y^1 (F_{t+1}) \overline{N} - C(F_{t+1}) \right\} \\ &+ \beta^{t+2} \left\{ pr^3 y^3 (F_{t+2}) e^{-p^2 F_{t+1} - m^2} e^{-p^1 F_t - m^1} \overline{N} + pr^2 y^2 (F_{t+2}) e^{-p^1 F_{t+1} - m^1} \overline{N} + pr^1 y^1 (F_{t+2}) \overline{N} - C(F_{t+2}) \right\} + \dots \end{aligned}$$

Therefore, the first order condition (foc) of the maximization problem is given by

$$\begin{aligned} \frac{\partial L}{\partial F_t} = \beta^t &\left\{ pr^3 \frac{\partial y^3(F_t)}{\partial F_t} e^{-p^2 F_{t-1} - m^2} e^{-p^1 F_{t-2} - m^1} \overline{N} + pr^2 \frac{\partial y^2(F_t)}{\partial F_t} e^{-p^1 F_{t-1} - m^1} \overline{N} + pr^1 \frac{\partial y^1(F_t)}{\partial F_t}) \overline{N} - \frac{\partial C(F_t)}{\partial F_t} \right\} \\ &+ \beta^{t+1} \left\{ pr^3 y^3 (F_{t+1})(-p^2) e^{-p^2 F_t - m^2} e^{-p^1 F_{t-1} - m^1} \overline{N} + pr^2 y^2 (F_{t+1})(-p^1) e^{-p^1 F_t - m^1} \overline{N} \right\} \\ &+ \beta^{t+2} \left\{ pr^3 y^3 (F_{t+2})(-p^1) e^{-p^2 F_{t+1} - m^2} e^{-p^1 F_t - m^1} \overline{N} \right\} = 0 \end{aligned}$$

Using the survival function definition, ϕ_t^a, this foc can be expressed as

$$\frac{\partial L}{\partial F_t} = \beta^t \left\{ pr^3 \frac{\partial y^3(F_t)}{\partial F_t}\phi_t^3 \overline{N} + pr^2 \frac{\partial y^2(F_t)}{\partial F_t}\phi_t^2 \overline{N} + pr^1 \frac{\partial y^1(F_t)}{\partial F_t})\phi_t^1 \overline{N} - \frac{\partial C(F_t)}{\partial F_t} \right\}$$
$$+ \beta^{t+1}\left\{ pr^3 y^3(F_{t+1})(-p^2)\phi_{t+1}^3 \overline{N} + pr^2 y^2(F_{t+1})(-p^1)\phi_{t+1}^2 \overline{N} \right\}$$
$$+ \beta^{t+2}\left\{ pr^3 y^3(F_{t+2})(-p^1)\phi_{t+2}^3 \overline{N} \right\} = 0.$$

In a more compact way

$$\beta^t \left[\sum_{a=1}^{3} pr^a \frac{\partial y^a(F_t)}{\partial F_t}\phi_t^a N^1 - \frac{\partial C(F_t)}{\partial F_t} \right] = \sum_{a=1}^{2} p^a \left[\sum_{j=1}^{3-a} \beta^{t+j} pr^{a+j} y^{a+j}(F_{t+j})\phi_{t+j}^{a+j} \overline{N} \right].$$

A generalization of this example for any A implies

$$\beta^t \left[\sum_{a=1}^{A} pr^a \frac{\partial y^a(F_t)}{\partial F_t}\phi_t^a \overline{N} - \frac{\partial C(F_t)}{\partial F_t} \right] = \sum_{a=1}^{A-1} p^a \left[\sum_{j=1}^{A-a} \beta^{t+j} pr^{a+j} y^{a+j}(F_{t+j})\phi_{t+j}^{a+j} \overline{N} \right].$$

If $\beta = 1$, $pr^a = 1$ and $\frac{\partial C(F_t)}{\partial F_t} = 0$, then the above equation can be written as,

$$\sum_{a=1}^{A} \frac{\partial y^a(F_t)}{\partial F_t}\phi^a(F_t) = \sum_{a=1}^{A-1} p^a \left[\sum_{j=1}^{A-a} y^{a+j}(F_t)\phi^{a+j}(F_t) \right].$$

After some manipulation and assuming an steady state solution, $F=F_t=F_{t+1}$, this expression becomes

$$\sum_{a=1}^{A} \frac{\partial y^a(F)}{\partial F}\phi^a(F) = \sum_{a=1}^{A-1} y^a(F)\phi^a(F)\left(\sum_{i=1}^{a-1} p^i \right).$$

Since

$$\frac{\partial \phi^a(F_{ss})}{\partial F_t} = \begin{cases} 0, & \text{if } \quad a = 1, \\ \sum_{i=1}^{a-1} p^i, & \text{if } \quad a > 1, \end{cases}$$

the above expression can be written as

$$\sum_{a=1}^{A} \frac{\partial y^a(F)}{\partial F}\phi^a(F) + \sum_{a=1}^{A} y^a(F)\frac{\partial \phi^a(F)}{\partial F} = 0.$$

Observe that this equation represents the f.o.c. of the maximization problem $\max_F \sum_{a=1}^{A} y^a(F)\phi^a(F)$, that characterizes $F_{\max}$. Therefore, it is clear that if $\beta = 1$, $pr^a = 1$ and $\frac{\partial C(F_t)}{\partial F_t} = 0$, then $F = F_{max}$.

Appendix 2: Calibration of the economic model

We use the Age Structured model reported in Table 5. The data set reported for the working groups (STECF/SGBRE-07-03 and SGBRE-07-05) do not include any information about prices. Since the Spanish fleet accounts for the main part of the hake landings with 59% of the total in 2006 (ICES(2007)), we have decided to use 2007 daily sales of the Spanish 300 fleet. These data are also shown in Table 5. Taking into account these prices and the catches generated by the model, 54,889 MT with a fishing mortality rate of F_{sq}=0.25, we calculate a value of yield equal to 322.36 million of Euros. This means that the average price of hake is 5.87 Euros per kilo.

For calibrating the cost function, we assume $C(F)=c_{mg}F$. This assumption is equivalent to assume constant catchability which is the assumption used by the XSA analysis to calibrate the age-structured model. Since TACs quotas are equal among the fisheries units (FU), we have decided to calibrate c_{mg} as the average cost for all FUs. We use data about the cost structure and the dependency degree of hake for the different FUs for the Spanish fleet in 2004 and for the French fleet in 2006 (See Tables 6 and 7).

For determining, the running costs per day, we calculate fuel costs, other costs, depreciation and interest divided by the days at the sea of each segment. Secondly, we calculate the average costs weighted by the sea days for each segment. Finally, we use the hake average dependency (0,47) to calculate the percentage of imputed costs. This implies an average costs for fuel equal to 294 Euros, and other costs equal to 438 Euros per day.

Taking into account that fuel costs rose during 2007, we decided to increase the fuel costs in the same proportion. In particular, we multiply fuel costs by 1,625. This proportion is the result from dividing the price of fuel during the first days on 2008, 0.52 Euros, by the price of the fuel during the last days on 2006, 0.32 Euros. The final costs for the fuel are 477 Euros. Adding this amount to the other costs implies a total cost of 915,87 euro per day.

The days at the sea are originally calculated with data from 2004 and 2006. However, since these amounts are overestimated, we reduce them by a 5%. The result is 80,335 days at the sea.

Therefore, we assume that 915.87 Euros and 80,335 days are good proxy's of the average running cost and total effort, respectively. Then, the total cost can be considered equal to 73.57 millions of Euros. The valued added of a fishery is defined as the difference between the value of yield and the total running cost. As a result, the valued added of the hake fishery can be considered equal to 248.78 million of Euros. For calculating the labor costs we assume a crew share equal to 37% of the yield. This implies labor costs equal to 120.62 million of Euros. Finally, the fishery profits, 128.16 million Euros, are equal to added value less wages.

For obtaining the optimal paths that maximize the added value of yield, c_{mg} is calculated taking into account the total operating costs of 73,576 Euros. This number is divided by the current mortality rate, $F_{sq}=0.25$, to calculate the marginal cost. When maximizing profits, c_{mg} is calculated assuming a value of cost equal to the sum of operating cost and labor cost (73,576 plus 120,62 Euros), which is divided by the current mortality rate, $F_{sq}=0.25$.

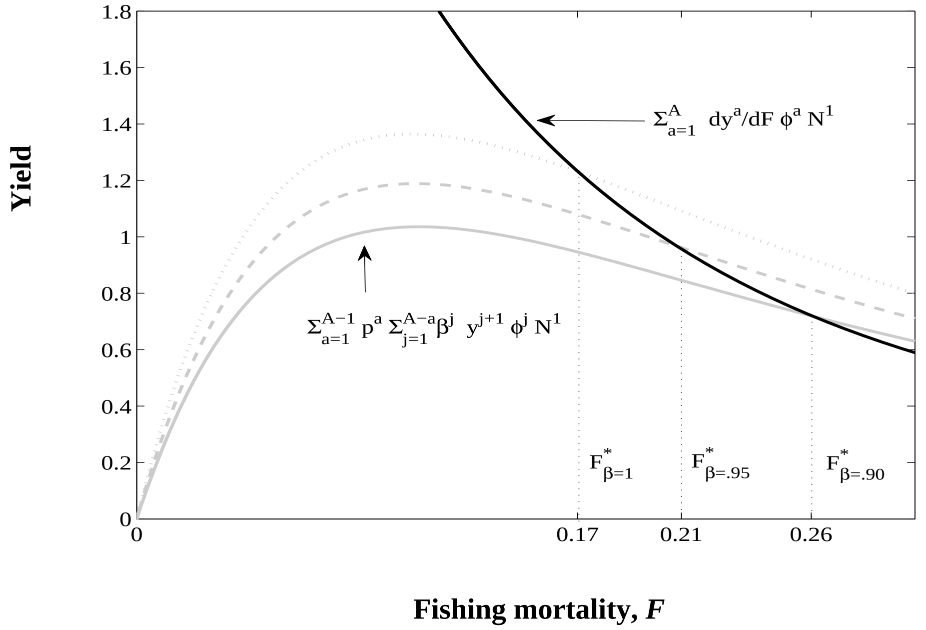

Figure 1: Optimal *F* for different values of β using the age-structured model reported in Table 5. The black line represents yield for constant cohort sizes are constant (the left hand side of equation (2)). It decreases because as *F* increases its relative weight increases less than proportionally (this is due by Baranov's assumption). The grey lines represent for $\beta=1$, $\beta=0.95$ and $\beta=0.90$, yield for a constant weight of fishing mortality on total mortality. It shows that if the discount rate, β, is lower than one then the optimal *F* is higher than F_{max}.

Table 1: French fleet segments

Net present value at 5%	SQ	1,2 F_{max} 5	1,2 F_{max} 10	1,2 F_{max} 15	F_{max} 5	F_{max} 10	F_{max} 15	0,8 F_{max} 5	0,8 F_{max} 10	0,8 F_{max} 15
Value of landings	**2077**	2054	2057	2059	2032	2027	2029	2026	1994	1989
Crew share	**699**	693	694	695	686	685	686	684	674	673
Gross cash flow	**394**	391	393	**394**	383	385	387	381	373	374
Net profit	**207**	203	205	**207**	196	197	199	194	186	187
Gross value added	**1093**	1084	1087	1089	1069	1070	1073	1065	1047	1047

Source: Table 7.3.1, STEFC, SEC(2007b). In bold the best scenario in terms of net present value.

Table 2: Spanish fleet segments

Net present value at 5%	SQ	1,2 F_{max} 5	1,2 F_{max} 10	1,2 F_{max} 15	F_{max} 5	F_{max} 10	F_{max} 15	0,8 F_{max} 5	0,8 F_{max} 10	0,8 F_{max} 15
Value of landings	**1823**	1783	1779	1778	1759	1735	1731	1757	1696	1677
Crew share	**837**	818	817	817	807	797	795	806	778	769
Gross cash flow	**372**	365	366	366	360	356	357	359	345	343
Net profit	**181**	174	174	175	168	164	165	167	154	151
Gross value added	**1210**	1183	1183	1184	1167	1153	1152	1165	1123	1112

Source: Table 7.4.1, STEFC, SEC(2007b). In bold the best scenario in terms of net present value.

Table 3: Economic indicators

	Status Quo	Maximizing Yield (weight)	Maximizing Yield (value)	Maximizing Value Added	Maximizing Profits
Reference points	0.25	0.21	0.17	0.14	0.10
Net present value with $\beta = 0.95$					
- Yield (t)	1136	**1144**	1133	1095	1024
(c.v.)	(3.29)	(3.32)	(3.36)	(3.38)	(3.36)
- Yield (million €)	6041	6236	**6310**	6208	5892
(c.v.)	(3.26)	(3.31)	(3.36)	(3.40)	(3.40)
- Value Added (million €)	4570	5020	5307	**5387**	5221
(c.v.)	(4.31)	(4.11)	(4.00)	(3.92)	(3.84)
- Profits (million €)	2157	3027	3664	4042	**4120**
(c.v.)	(9.13)	(6.81)	(5.79)	(5.22)	(4.86)

Source: Own calculations. Bold means the best scenario for each economic indicator.

Table 4: Implicit cost (2008-2016)

		$1,2\ F_{max}$			F_{max}			$0,8\ F_{max}$		
	SQ	5	10	15	5	10	15	5	10	15
Net Present Value at 5%										
French fleet segments	1870	1851	1852	1852	1836	1830	1830	1832	1808	1802
Spanish fleet segments	1642	1609	1605	1603	1591	1571	1566	1590	1542	1526
SQ=100										
French fleet segments	100,00	98,99	99,04	99,04	98,18	97,86	97,86	97,97	96,68	96,36
Spanish fleet segments	100,00	97,99	97,75	97,62	96,89	95,68	95,37	96,83	93,91	92,94

Source: Own calculations

o

Table 5 Age structured model

Initial	conditions										
Age	0	1	2	3	4	5	6	7	8	9	10
N	186213	152458	123457	100213	67409	35551	19674	10206	9147	4078	1819
Population	dynamics										
Age	0	1	2	3	4	5	6	7	8	9	10
pa	0.00	0.06	0.05	1.15	1.03	1.52	2.09	2.43	2.43	2.43	2.43
!a	0.06	0.13	0.22	0.34	0.60	0.98	1.44	1.83	2.68	2.68	2.68
ケa	0.00	0.00	0.00	0.23	0.60	0.90	1.00	1.00	1.00	1.00	1.00
Stochastic	shocks										
Age	0	1	2	3	4	5	6	7	8	9	10
sigmalogN	0.200	0.200	0.166	0.086	0.061	0.063	0.076	0.084	0.084	0.084	0.084
Prices											
Age	0	1	2	3	4	5	6	7	8	9	10
euros per kilo	2.36	2.93	3.42	3.85	4.55	5.22	5.81	6.22	6.92	6.92	6.92

Source. Meeting on Northern Hake Long-Term Management Plans (STECF/SGBRE-07-03), ICES Report-2007 and Spanish 300 fleet.

Table 6 *Economic indicators for segment*

Economic Indicators for segment	*S1(2004)*	*S2(2004)*	*S3(2004)*	*F1(2006)*	*F2(2006)*	*F3(2006)*	*F4(2006)*	*F5(2006)*	*F6(2006)*
Value of landings	101.914.422	19.172.000	90.970.320	98,1	77,6	67,5	3,9	37,9	18,3
Fuel costs	21.182.889	3.141.640	7.300.860	20,2	15,9	15,4	0,5	3,0	1,7
Other running costs	12.071.121	3.867.258	20.030.640	9,7	7,7	7,1	0,4	3,1	1,5
Depreciation	12.938.904	2.551.888	10.711.260	8,8	7,0	8,1	0,3	2,8	1,4
Interest	879.594	194.053	859.236	1,6	1,3	1,6	0,2	0,6	0,4
Days at the sea	25.389	4.112	21.924	32.300,0	21.500,0	14.500,0	1.100,0	10.300,0	4.500,0
Crew share	40.876.476	7.221.568	44.804.508	32,1	25,4	20,1	1,5	15,0	7,3

S1= Demersal trawlers (24-40m); S2= Pair demersal trawlers (24-40m); S3= Longliners (24-40m); F1=DTS - Targeting Nephrops, (12-24m); F2= DTS, - Targeting Fish, (12-24m); F3=DTS (24-40m); F4= Hook (24-40m); F5= Netters (12-24m) and F6=Netters (24-40m).

Source: Tables 6.1.7-6.1.9, 6.2.8-6.2.13 and 7-2-3, (SEC 2007b).

Table 7 *Costs per day and FU*

data per day	*S1(2004)*	*S2(2004)*	*S3(2004)*	*F1(2006)*	*F2(2006)*	*F3(2006)*	*F4(2006)*	*F5(2006)*	*F6(2006)*	mean
fuel per day	834,3	764,0	333,0	625,4	739,5	1062,1	454,5	291,3	377,8	651
other costs per day	475,4	940,5	913,6	300,3	358,1	489,7	363,6	301,0	333,3	483
depreciation/day	509,6	620,6	488,6	272,4	325,6	558,6	272,7	271,8	311,1	403
interest/day	34,6	47,2	39,2	49,5	60,5	110,3	181,8	58,3	88,9	56
Total cost per day	1854,1	2372,3	1774,4	1247,7	1483,7	2220,7	1272,7	922,3	1111,1	1.593
Hake dependency % value of landings	24%	36%	98%	4%	2%	6%	77%	20%	84%	0,47
Crew share /y	0,40	0,38	0,49	0,33	0,33	0,30	0,38	0,40	0,40	0,37

S1= Demersal trawlers (24-40m); S2= Pair demersal trawlers (24-40m); S3= Longliners (24-40m); F1=DTS - Targeting Nephrops, (12-24m); F2= DTS, - Targeting Fish, (12-24m); F3=DTS - Targeting Nephrops or Fish, (24-40m); F4= Hook (24-40m); F5= Netters (12-24m) and F6=Netters (24-40m).

Source:Own calculation from Table 6.