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Why Economists Reject Long-Term Fisheries Management Plans?

Why Economists Reject Long-Term Fisheries Management Plans?*

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ABSTRACT: Most fisheries agencies conduct biological and economic assessments independently. This independent conduct may lead to situations in which economists reject management plans proposed by biologists. The objective of this study is to show how to find optimal strategies that may satisfy biologists and economists' conditions. In particular we characterize optimal fishing trajectories that maximize the present value of a discounted economic indicator taking into account the age-structure of the population as in stock assessment methodologies. This approach is applied to the Northern Stock of Hake. Our main empirical findings are: *i)* Optimal policy may be far away from any of the classical scenarios proposed by biologists, *ii)* The more the future is discounted, the higher the likelihood of finding contradictions among scenarios proposed by biologists and conclusions from economic analysis, *iii)* Optimal management reduces the risk of the stock falling under precautionary levels, especially if the future is not discounted to much, and *iv)* Optimal stationary fishing rate may be very different depending on the economic indicator used as reference.

Key Words: fisheries management, age-structured models, discounting, F_{msy}, $F_{\max}$, Northern Stock of Hake.

JEL Classification: Q22.

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1 Introduction

Economists have participated in fisheries management decisions for a long time. Gordon (1954) and Scott (1955) were the pioneers of the bioeconomic theory that establish the economic basis of fisheries management. Economic concepts such as maximum sustainable yield (MSY), total allowable catches (TAC) or individual transferrable quotas (ITQ) have been included into fisheries legislation over the years to improve economic efficiency. As a result, most of the current legislations conforms to the principles of modern bioeconomics[1].

In spite of this, since Ward (2000) points out "*Economics, biology, and sociology remain separate sciences in the fishery management process. That is, when an analysis of a proposed fishery management regulation is conducted, the economic, biological, and sociological assessments are conducted independently*". This means that conclusions from the different disciplines must be assembled by fisheries agencies in order to reach their objectives. And this may become an unattainable aim because most of the analyses are based on different assumptions.

This independent conduct between areas may lead to unexpected situations. For instance, in advising the European Commission on the Northern Stock of Hake, the STECF biological analysis concluded that maintaining current fishery effort would lead the stock close to the precautionary levels; so their proposal consisted of reducing that level to $F_{\max}$ in order to move away from the unsafe allocation. However, the posterior economic analysis considered that fishing effort should be kept on current levels because that policy maximized the discounted profits. In this article we argue that the reason why the economic analysis may not support the biologists' proposals is the different objectives that both group of experts may have considered. While the biological analysis generally consists of looking for scenarios where yield is maximized in the long run and spawning biomass maintain safe values. However the economic analysis is based on the calculation of the net present value of yield and profits that maintain those scenarios characteristics in the longer term.

The connection between maximum yield and maximum discounted profits has been already studied empirically for the Western and Central Pacific Big Eye Tuna and Yellowfin Tuna, the Australian Northern Prawn Fishery and the Australian Orange Roughy Fishery by Grafton, Kompas and Hilborn

[1] The MSY appears for the first time in the legislation in the United Nations Convention of the Law of the Sea (UN 1983). TACs are the cornerstone of the Common Fisheries Policy of the European Union (Frost and Andersen (2000)). ITQs have been successfully implemented in Icelandic fisheries(Arnason (1955)) or New Zealand (Gibbs (2007)).

(2007). Their main conclusion is that the stock associated with the maximization of yield is always lower than the stock derived from the maximization of discounted profits. This result is quite intuitive from the theoretical point of view. When discounted profits are considered, optimal behavior always takes into account not only the value of the yield but also the discounted value of future costs; so in the long run optimal effort associated to discounted profits is lower than the one associated to just (the value of) yield.

The aim of this article is to show how to find optimal fishing management trajectories that guarantee that the present value of some particular economic indicator is maximized taking into account the biological properties of the resources. Basically this procedure compresses the biological and economic analysis to one step in which fishery effort trajectories are determined in such way that the present value of a particular economic indicator is maximized for a certain period of time, subject to as many biological and/or economic restrictions as desired.

This optimal management approach has been analyzed mainly in fishery economics using simple biomass models that abstract from other non economic restrictions affecting the fishery population. Martinet, Thébauda and Doyen (2007) can be considered an exception among the biomass models. They develops a formal analysis of the recovery process for a fishery using viable control framework to take into account a combination of biological, economic and social constraints which need to be met for a viable fishery to exist. However, they do not consider neither the age structure of the population nor the uncertainty in the recruitment which, as they point out, limits the usefulness of their model for policy recommendations.[2]

Only recently some articles as Kulmala, Laukkanen and Michielsens (2008) and Tahvonen (2009, 2008) have addressed different issues integrating age-structured models in optimal harvesting problems. Kulmala, Laukkanen and Michielsens (2008) solve numerically the optimal harvesting for the age-structure population of the Atlantic salmon fishery in the Baltic Sea using Bellman's (1957) principle of optimality. However, Tahvonen (2009,20008) characterizes analytically optimal harvesting in a generic age-structured model.

Our work extend the research line opened by these authors. Unlike Tahvonen (2009, 2008) we include the basic age-structured model used in stock assessment as restrictions of the optimal harvesting model. This allows us to compare optimal management in a discounted economic context with standard reference targets used for long term management plans (e.g. $F_{\max}$ or

[2] In their words: "*(The model) ignores certain important characteristics of the fishery, in particular the age structure of the population and the uncertainty in recruitment, which limits the usefulness of the model for policy recommendations*" (Martinet, Thébauda and Doyen (2007, page 413)).

F_{msy}). In particular, we are able to characterize analytically the optimal harvest path using control theory. This optimal path can be numerically implemented for a number of cohorts relatively high. So, as in Kulmala, Laukkanen and Michielsens (2008), our results also can be interpreted as a reconcilation between economic and biological modeling of fsh stocks.

The paper proceeds as follows. In the next section the issue addressed is focussed by describing the biological and economic analysis developed by STECF to advice the European Commission about the management of the Northern Stock of Hake. Section 3 shows how to find optimal harvesting strategies in a discounted utility framework assuming the age-structured population used by STECF. In section 4 the optimal stationary solution is characterized. Section 5 presents the results of this alternative approach when it is applied to the Northern Stock of Hake. Finally, Section 6 concludes the paper with a policy recommendation discussion.

2 The Northern Stock of Hake Long Term Management Plan

After the collapse of the spawning stock of biomass in the 1990s, an emergency plan was implemented for the Northern Stock of Hake (EC Reg. No 1162/2001, EC Reg. No 2602/2001 and EC Reg. No 494/2002). This emergency plan was followed by a recovery plan in 2004 (EC Reg. No 811/2004). Its objective was to increase mature fish to values greater than 140,000 t by limiting fishing mortality to 0.25 and by allowing a maximum 15% change in TACs between consecutive years.

Article 3 of EC Reg. No 811/2004 points out that the recovery plan should be replaced by a management plan when, in two consecutive years, the target size level for the stock has been reached. Scientific assessments by ICES and STECF indicate that this objective was achieved in 2004, 2005 and 2006[3]. So, in 2007 the European Commission asked STECF to provide scientific advice for a future long-term management plan based on optimal yield considerations and regarding several possible scenarios.

In order to advise the Commission on the potential impact of the proposed management plan for Northern hake, an Expert Working Group (STECF/ SGBRE-07-03) was convened in Lisbon from 18-22 June 2007 to evaluate the potential biological consequences of the plan. The working group found

[3]Except in 1995, landings decreased steadily from 66,500 t in 1989 to 35,000 t in 1998. Up to 2003, landings fluctuated around 40,000 t. In 2004 and 2005, an important increase in landings was observed with 47,123 t and 46,300 t of hake landed respectively. In 2006, the total landings decreased to 41,810 t . (See Table 2.2.2, SGBRE-07-03)

that current fishing rate was close to $F_{pa} = 0.25$. Also it concludes that $F_{\max} = 0.17$ is well defined for this stock and it is considered a good proxy for the target reference point F_{msy}[4]. From this *status quo*, the biological impact of reducing the current fishing rate, $F_{sq} \simeq F_{pa}$, to the $F_{\max}$ assuming different scenarios about the convergence speed to the target was studied.

Nine scenarios were analyzed considering $1.20F_{\max}$, $F_{\max}$ and $0.80F_{\max}$ as final possible targets and gradual changes of the fishing rate in steps of 5% per year, 10% per year and 15% per year. Based on this analysis STECF main conclusions regarding the biological consequences were[5]: *i)* There was little difference, in terms of long-term yields, between $F_{\max}$ and F_{pa} scenarios; *ii)* Reducing F to $F_{\max}$ as opposed to F_{pa} would lead to higher SSB and thus provide the stock with greather stability, reducing the risk of returning to an unsafe situation; *iii)* A 5% decrease in F would lead to $F_{\max}$ before 2015 without significant loss in yields in the short term.

STECF also recommended scheduling an additional meeting, involving both biologists and economists in order to carry out bioeconomic impact assessments for the alternative management plans for this stock. So, a second Expert Working Group (STECF/SGBRE-07-05) was then convened in Brussels from 3-6 December 2007 with the aim of analyzing the socioeconomic impact of the nine scenarios proposed at the Lisbon meeting.

The Economic Interpretation of ACFM Advice Model (EIAA)[6] was used to calculate the net present value of five economic indicators for the nine proposed scenarios, i.e. value of landings, crew share, gross cash flow, net profits and gross value added. The EIAA model is an input based model that has been developed to calculate changes in fixed costs and vessel numbers on the basis of long-run stock changes. This means that output is the independent variable in the EIAA model while fishing effort and costs are dependent variables. Therefore, all the economic indicators calculated become monotonic transformations of landings. In practice, this implies that any pattern observed when the different scenarios are ranked according to a particular indicator, is repeated for any other indicator.

This fact can be observed in Table 1 where the results for the net present value of landings for the French and Spanish fleets using a 5% discount rate and considering the period 2008-2016 are summarized. We can observe that if the scenarios are ranked considering this indicator, the *status quo* is the best scenario; approaching to the $1.20F_{\max}$ target is the second one and $F_{\max}$

[4]The working group based its decision on two facts. First, the stock-recruitment relationship is not accuratellyl estimated for this stock. Second, the determination of $F_{\max}$ does not require the use of the stock-recruitment relationship.

[5]See STEFC Comments and Conclusions (SEC(2007), page 4 and 5).

[6]See Anex 2 SEC(2004) 1720 for a description of the EIAA Model.

Table 1: Net Present Value of Landings for the French and Spanish Fleet (m. euros) under Different Target Scenarios.

		To 120% of $F_{\max}$			To $F_{\max}$			To 80% of $F_{\max}$		
	Status quo	5%	10%	15%	5%	10%	15%	5%	10%	15%
Target (F)	0.25	0.17	0.17	0.17	0.14	0.14	0.14	0.12	0.12	0.12
French fleet	2077	2054	2057	2059	2032	2027	2029	2026	1994	1989
Spanish fleet	1823	1782	1779	1778	1759	1735	1731	1757	1696	1677

Source: From Tables 7.3.1 y 7.4.1 (SEC(2008), pages 57 to 62)

and $0.80F_{\max}$ scenarios are the third and fourth, respectively. Moreover, this ranking does not depend upon the speed of approaching to the targets related to $F_{\max}$. Results are qualitatively equal for any other indicator (see Tables 7.3.1 and 7.4.1 (SEC(2008)).

At first glance this result may be seen as contradictory. On the one hand $F_{\max}$ is a good proxy for F_{msy} and F_{msy} can be understood as the fishing mortality rate that generates the largest average yield that can be continuously caught . On the other hand, the results shown in Table 1 indicate that at least the fishing rate associated to the *status quo* ($F_{sq} = 0.25$) generates a higher yield, in net present value, than that associated to the MSY.

This contradiction appears because while the biological analysis are based on looking for scenarios where yield is maximized in the long run, however the economic analysis is based on the calculation of the net present value of yield associated to those scenarios.

In this context, a logical issue is to analyze how fishery management advice changes when the fishing targets are selected taking into account the present value of discounted indicators rather than the stationary annual ones. The aim of the rest of the article is to show how to find optimal fishing management trajectories that guarantee the present value of some particular economic indicator being maximized whilst taking into account the age-structured considered by XSA methodology.

3 Model features

We use a standard age-structured model. Lets assume that the fish stock is broken into A cohorts. That is in each period t, there are $A-1$ initial old cohorts and a new cohort is born. Let z_t^a be the mortality rate that affects to the population of fish in the a^{th} age during the t^{th} period. This mortality rate can be decomposed into fishing mortality, F_t^a, and natural mortality, m^a,

$$z_t^a = F_t^a + m^a.$$

While the fishing mortality rate may vary between periods and ages, natural mortality is constant among periods. Moreover, it is assumed that the fishing mortality over each age is given by stationary selection patterns, p^a, that is

$$F_t^a = p^a F_t.$$

The stock dynamics is determined by

$$N_{t+1}^{a+1} = e^{-z_t^a} N_t^a, \tag{1}$$

$$N_{t+1}^1 = \overline{N^1}, \tag{2}$$

where N_t^a is the number of fish in the a^{th} age at the beginning of the t^{th} period and $\overline{N^1}$ is the recruitment at any period. Note that the size of a new cohort (recruitment) is given by the Ockham rule. Finally, the oldest age group is assumed to be a true age group, i.e. $N_{t+1}^{A+1} = 0, \quad \forall t$.

A stationary path of fishing mortality, $F = F_t = F_{t-1}$, generates an **stationary age structured population** characterized by

$$N^a = \overline{N^1}\phi^a(F),$$

where

$$\phi^a(F) = \begin{cases} 1 & \text{for } a = 1, \\ \Pi_{i=1}^{a-1} e^{-p^i F - m^i} & \text{for } a = 2, ...A, \end{cases}$$

can be interpreted as the the accumulated probability of a recruit to reach age a for that stationary fishing mortality rate F.

Among all the fishing mortality stationary paths, $F_{\max}$ is used as a reference point for fisheries management whenever the S-R relationship is not well estimated. Formally, F_{max} is the stationary mortality rate that maximizes equilibrium yield per recruit, that is

$$\max_{\{F_{max}\}} \sum_{a=1}^{A} y^a(F)\phi^a(F),$$

where

$$y^a(F_t) = \omega^a \frac{F_t}{p^a F_t + m}\left(1 - e^{-p^a F_t - m}\right).$$

and ω^a stands for weight distribution of age a.

An alternative to fisheries management based on F_{max} as a references point is to find for a given discount factor[7], β, the optimal path of fishing mortality, $\{F_t\}_{t=0}^{\infty}$, that maximizes the present value of discounted profits of the fishery, taking into account the dynamics described by equations (1) to (2).

Formally, the **optimal management path** is the solution of the following maximization problem

$$\max_{\{F_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left\{ \sum_{a=1}^{A} pr^a y^a(F_t) N_t^a - TC(F_t) \right\},$$
$$s.t. \begin{cases} N_{t+1}^{a+1} = e^{-z^a(F_t)} N_t^a \quad \forall t \quad \forall a = 1, ...A-1, \\ N_{t+1}^1 = \overline{N^1} \quad \forall t, \end{cases} \tag{3}$$

where pr and TF represent the price and the total cost function which depends positively on fishery mortality, respectively.

Notice that the objective function maximized in problem (3) can be interpreted in several ways. For instance, if $pr = 1$ and the marginal cost is zero, the objective function represents the present value of yield. When the marginal cost is zero and $pr \neq 1$, the objective function coincides with the revenues of the fishery. In the case of $pr \neq 1$, marginal cost different from zero and total cost equal to the cost of fuel and other running costs, the objective function is equal to the added value of the yield. Finally, if the total cost includes also the labor cost, then the objective function can be understood as the profits of the fishery.

By backwards substitution in the first restriction, the size of cohort age $a > 1$ in period t, N_t^a, can be expressed as a function of the past mortality rates and initial recruitment,

$$N_t^a = e^{-z_{t-1}^{a-1}(F_{t-1})} N_{t-1}^{a-1} = e^{-z_{t-1}^{a-1}(F_{t-1})} e^{-z_{t-2}^{a-2}(F_{t-2})} N_{t-2}^{a-2} = ... = \Pi_{i=1}^{a-1} e^{-z_{t-i}^{a-i}(F_{t-i})} N_{t-(a-1)}^1.$$

Therefore, we can express N_t^a as

$$N_t^a = \phi_t^a N_{t-(a-1)}^1 = \phi_t^a \overline{N^1}, \qquad \text{for } a = 1, ...A, \tag{4}$$

[7] Discount is frequently introduced in fisheries economics using the discount rate, r, instead of discount factor, β. 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 $\beta = (1+r)^{-1}$.

where

$$\phi_t^a = \phi(F_{t-1}, F_{t-2}, ...F_{t-(a-1)}) = \begin{cases} 1 & \text{for } a = 1, \\ \Pi_{i=1}^{a-1} e^{-z_{t-i}^{a-i}(F_{t-i})} & \text{for } a = 2, ...A, \end{cases}$$

can be understood 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 fishing mortality path $\left\{F_{t-1}, F_{t-2}, ...F_{t-(a-1)}\right\}$. Notice that the survival function in any period depends upon the $a-2$ next past mortality rates.

After substituting the survival function, (4), the maximization problem (3) can be rewritten as

$$\max_{\{F_t\}_t^\infty} \quad \sum_t^\infty \beta^t \left\{ pr^1 y^a(F_t)\phi_t^a \overline{N^1} + \sum_{a=2}^{A} pr^a y^a(F_t)\phi_t^a \overline{N^1} - TC(F_t) \right\}.$$

The optimal fishery rate path can be summarized in the following dynamic equation,

$$\sum_{a=1}^{A} pr^a \frac{\partial y^a(F_t)}{\partial F_t} \phi_t^a \overline{N^1} - \frac{\partial TC_t}{\partial F_t} = \sum_{a=1}^{A-1} p^a \left\{ \sum_{j=1}^{A-a} \beta^j pr^a y^{a+j}(F_{t+j})\phi_{t+j}^a \overline{N^1} \right\}. \quad (5)$$

Appendix shows how these optimal conditions are obtained.

Optimal condition (5) shows how the mortality rate, F_t, is selected and its significance is the following. In the optimal path, an increase of current mortality rate leads to an increase of current fishery profits (left hand side) that is compensated by the decrease of future profits derived from reductions on the future size of the alive cohorts, $t+1$ to $t+A-1$ (right hand side). This can be visualized also looking at age structure in Table 2. The left hand side represents the effects of F_t on the structure of the fishery in period t (column t). The the right hand side shows the effects of F_t on the structure of the future size of alive cohorts (lower triangle matrix).

4 Optimal Stationary Solution

The optimal stationary solution is defined as a an optimal solution characterized by a vector $\left(F_{ss}, N_{ss}^1, N_{ss}^2, ...N_{ss}^A\right)$ such that for any future period t

$$\begin{aligned} F_{ss} &= F_t = F_{t+1}, \\ N_{ss}^a &= N_t^a = N_{t+1}^a, \qquad \forall a = 1, .., A. \end{aligned}$$

Table 2: Age Structure and the Intertemporal Maximization Problem

	t	t+1	t+2	...	t+A-2	t+A-1	t+A
a=1	$\overline{N^1}$			...			
a=2	N_t^2	N_{t+1}^2		...			
...	...	...	...	...		...	...
a=A-1	N_t^{A-1}	N_{t+1}^{A-1}	N_{t+2}^{A-1}	...	N_{t+A-2}^{A-1}		
a=A	N_t^A	N_{t+1}^A	N_{t+2}^A	...	N_{t+A-2}^A	N_{t+A-1}^A	

The first order condition, (5), valued at the steady sate can be reduced to the following equation to solve for F_{ss},

$$\sum_{a=1}^{A} pr^a \frac{\partial y^a(F_t)}{\partial F_t}\phi^a(F_{ss})\overline{N^1} - \frac{\partial TC_t}{\partial F_t} = \sum_{a=1}^{A-1} p^a \left\{ \sum_{j=1}^{A-a} \beta^j pr^a y^{a+j}(F_{ss})\phi^{a+j}(F_{ss})\overline{N^1} \right\}. \tag{6}$$

Once F_{ss} is known the stationary cohort size of any age, N_{ss}^a, can be calculated using the survival function (4).

We can prove that the optimal stationary mortality rate, F_{ss}, is just a generalization of $F_{\max}$. In particular, we show that $F_{\max}$ coincides with F_{ss} for the case of in where the objective function is to maximize the present value of yield and the future is not discounted and all periods are treated equally. The following proposition formalizes this result.

Proposition 1 *If* $\beta = 1$, $pr^a = 1$ *and* $\partial TC/\partial F = 0$, *then* $F_{ss} = F_{\max}$.

Proof. See Appendix.■

5 Results

In order to calibrate the age structured model for this fishery two data sources have been used. First, the information about the biological parameters of the fishery was provided by the expert working group meeting on Northern Hake Long-Term Management Plans (STECF/SGBRE-07-03) held in Lisbon, June 4-8 2007. Second, the economic data of the fishery emanate from the expert working group meeting on Northern Hake Long-Term Management Plan Impact Assessment (STECF/SGBRE-07-05) held in Brussels, December 3-6 2007.

Table 7 in the Appendix shows, for each age, the number of fishes at the initial conditions, the parameters of the population dynamics (selection pattern, weight and maturity), the stochastic structure of the initial conditions and the prices[8]. Following Pontual, Groison, Piñeiro and Bertignac (2006) we consider that $A = 11$. The 8(plus) age-group is disaggregated assuming that the sum of the abundance of the new age-groups $(8- > 11)$ is equal to the 8 (plus) age-group. Recruitment is considered fixed and equal to N^1 in Table 7.

Table 8 illustrates the cost structure and the variables related to the output for the Northern Stock of Hake[9]. In the numerical simulations we assume that the effort cost is proportional to the mortality rate, $TC = qF$, where $q = TC/F$ represents the marginal cost. It is worth mentioning that the valuation of total costs has to be consistent with the variable that is considered as output in the objective function. For instance, to obtain the optimal paths that maximize the added value of yield we use as value of cost the total operating costs of 73,576 Euros. This value is divided by the current mortality rate, $F_{sq} = 0.25$, to calculate the marginal cost. When the variable to maximize correspond to the profits, the value of cost used is the sum of operating cost and labor cost (73,576 plus 120,620 Euros), which is divided by the current mortality rate, $F_{sq} = 0.25$.

We assume that there exists uncertainty about the initial age distribution and recruitment process. In particular, the following log normal distributions are used to describe the initial conditions of the population distribution,

$$\tilde{N}_0^a = e^{\sigma_a \varepsilon_a} N_0^a, \quad \forall a,$$

where ε_a is a random variable affecting the initial size of cohort of age a that follows a normal distribution with a mean of 0 and standard deviation σ_a. This implies that the mean of the initial distribution is given by N_0^a. Information about this stochastic structure is also found in Table 7.

Finally, the model is based on the fact that catches were equal to 54,889 t. in 2007 with a fishing mortality rate of $F_{sq} = 0.25$. This situation represents the so called *status quo*.

Once the model is calibrated, Monte Carlo simulations are carried out

[8] To calculate prices as a function of ages we have used data on 2007 daily sales for the trawl, gill nets and long line Galician fleets.

[9] To calculate the costs associated to each fleet we only consider the proportion of hake relative to the total revenues.

Table 3: Long term targets, F_{ss}, for different discount factors

	Yield	Income	VA	Profits
$\beta = 0.95$	0.21	0.17	0.14	0.10
$\beta = 0.90$	0.26	0.21	0.16	0.12

using 20,000 replications of the fishery for 28 periods. This calibration of the model is able to reproduce the SGBRE-07-03 long-run target, $F_{\max} = 0.17$.

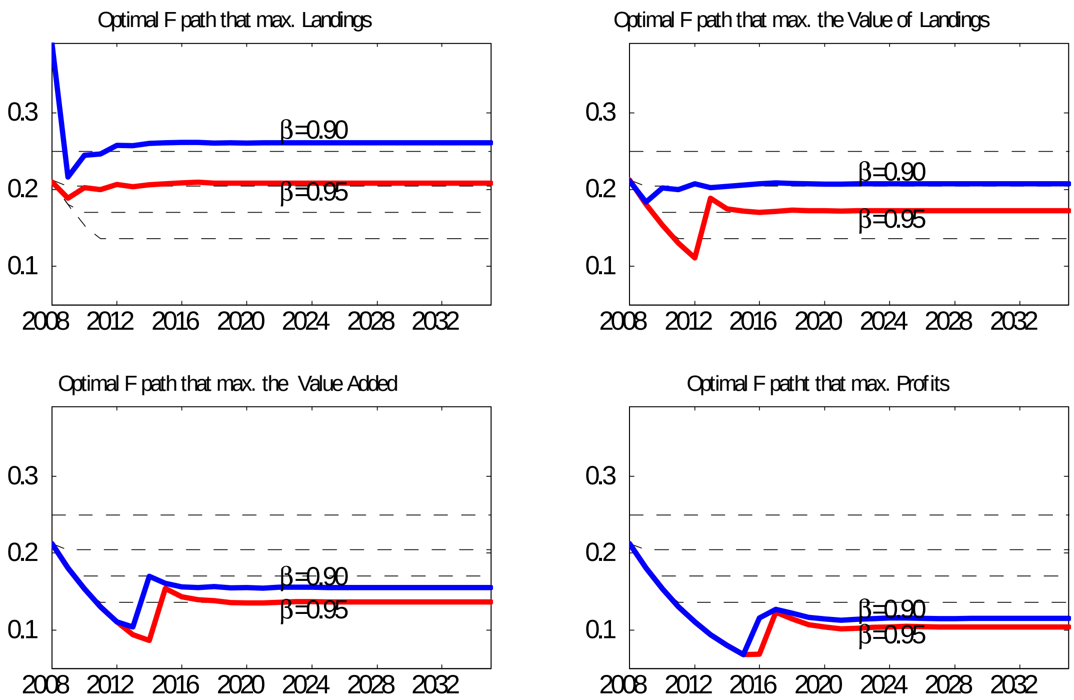
Table 3 displays the optimal stationary F targets when the economic indicator to be maximized is the present value of discounted yield, revenues, value added and profits. Simulation results are displayed for two different discount factors. Notice that when the economic indicator to be maximized is the present value of the yield, with $\beta = 0.90$, the simulation generates an optimal stationary target $F_{ss} = 0.26$ which is close to the *status quo,* $F_{sq} = 0.25$[10]. On the contrary, optimal stationary fishing rate, F_{ss} is equal to $F_{\max} = 0.17$ when the present value of revenues are maximized and $\beta = 0.95$.

Notice that our results support Grafton, Kompas and Hilborn (2007) conclusions. They analyze the biomass associated to yield maximization and discounted profit maximization for the Western and Central Pacific Big Eye Tuna and Yellowfin Tuna, the Australian Northern Prawn Fishery and the Australian Orange Roughy Fishery. Their main conclusion is that the stock associated to the maximization of yield is always lower than the stock derived from the maximization of discounted profits. This also applies to the Northern Stock of Hake. Long-run fishing mortality for present value of profits maximization runs from 0.10 for $\beta = 0.95$ to 0.12 for $\beta = 0.90$, whereas fishing mortality for discounted yield maximization goes up to 0.21 for $\beta = 0.95$ to 0.26 for $\beta = 0.90$. This also implies that for the Northern Stock of Hake, in the long run the stock associated to the maximization of yield will be lower than the stock derived from the maximization of discounted profits.

Figure 1 shows not only the long-run fishing targets but the whole optimal paths that maximize the present value of discounted yield, revenues, value added and profits. The solid blue and red lines display the optimal paths assuming a discount factor of 0.90 and 0.95, respectively. These optimal paths are compared with the four scenarios used by STECF for advice on this fishery: *i)* The *status quo*, i.e. stay on the current fishing mortality,

[10] Notice that this optimal solution would never be a solution in an optimization problem that had take into account the biological restriction that fishing mortality should be above the precautionary level ($F_{pa} = 0.25$). We have not taken this restriction into account because the neither did the economic analysis developed by the SGBRE-07-05

Figure 1: Optimal paths comparing with the STEFC scenarios



$F = F_{pa} = 0.25$; *ii)* Approaching to a $1.2 \times F_{\max} = 1.2 \times 0.17 = 0.2$ in steps of reductions of a maximum of 15% per year; *iii)* Approaching to a $F_{\max} = 0.17$ in steps of a maximum of 15% per year; *iv)* Approaching to a $0.8 \times F_{\max} = 0.8 \times 0.17 = 0.14$ in steps of a maximum of 15% per year. The four scenarios are shown in Figure 1 in shaded lines. It should be noted that the optimal paths have also been calculated under the restriction that the mortality rate does not change more than a 15% per year.

The main results we have observed are the following. First, in most of the scenarios the optimal paths consist of drastically reducing current mortality ($F_{sq} = 0.25$) to values even lower than 0.10 in the short run. After this, fishing mortality recovers until it reaches the stationary values in the long run. Second, the level of the optimal stationary fishing mortality depends on which economic indicator we are interested in. For instance, when the aim is to maximize landings the stationary fishing rate fluctuates between 0.20 and above 0.25, depending on the discount rate. In fact, when the discount factor is $\beta = 0.90$, the stationary fishing mortality is even higher than the one in the *status quo*. For the value of landing the stationary fishing rate goes into the range of 0.17 and 0.20. However, when valued added is the objective, the

Table 4: Main statistics under $\beta = 0.95$

					F_{ss} ($\beta = 0.95$)			
	SQ	1.2 F_{max}	F_{max}	.8 F_{max}	Yield	Income	VA	Profits
target	0.25	0.20	0.17	0.14	0.21	0.17	0.14	0.10
$\sum_{t=1}^{\infty} \beta^{t-1} \sum_{a=1}^{A} y_t^a$								
mean	1136	1144	1134	1100	1144	1133	1095	1024
cv	3.29	3.32	3.34	3.36	3.32	3.36	3.38	3.36
$\sum_{t=1}^{\infty} \beta^{t-1} \sum_{a=1}^{A} p^a y_t^a$								
mean	6041	6243	6304	6223	6236	6310	6208	5892
cv	3.26	3.31	3.35	3.38	3.31	3.36	3.40	3.40
$\sum_{t=1}^{\infty} \beta^{t-1} VA_t$								
mean	4570	5038	5287	5381	5020	5307	5387	5221
cv	4.31	4.10	3.99	3.91	4.11	4.00	3.92	3.84
$\sum_{t=1}^{\infty} \beta^{t-1} \pi_t$								
mean	2157	3062	3619	4002	3027	3664	4042	4120
cv	9.13	6.74	5.83	5.26	6.81	5.79	5.22	4.86

stationary fishing mortality fluctuates around 0.15 which can be identified with the classical reference target of $0.8 \times F_{\max}$. The optimal fishing mortality falls even more when we focus on maximizing profits, dropping to 0.11 in the steady state. In this case the stationary state is even below the classical target of $0.8 \times F_{\max}$.

Tables 4 and 5 report the present value of all economic indicators under optimal behavior compared to those obtained under STECF scenarios for a discounted factor $\beta = 0.95$ and $\beta = 0.90$, respectively. Each rows shows information on discounted yield, revenues, value added and profits. For any of them, the mean and the coefficient of variation (cv) associated to the 20,000 simulations run are displayed. Columns 2 to 5 display data under the four STECF scenarios described above. Columns 6 to 9 show the results of optimal management for the cases in which yield, revenues, value added and profits are used as an objective function, respectively.

In light of these results we may highlight the following findings. For both discount factors analyzed, the *status quo* policy is better than the $F_{\max}$ policy when present value of discounted yield is considered as the aim of the policymaker. This result supports the STECF advice based in the EIAA model of keeping fishing rate on current terms for the long term management of the Northern Stock of Hake. However, if the objective of the managers is maximizing the present value of revenues, valued added or profits, the $F_{\max}$

Table 5: Main statistics under $\beta = 0.90$

	SQ	1.2 F_{max}	F_{max}	.8 F_{max}	F_{ss} ($\beta = 0.90$) Yield	Income	VA	Profits
target	0.25	0.20	0.17	0.14	0.26	0.21	0.16	0.12
$\sum_{t=1}^{\infty} \beta^{t-1} \sum_{a=1}^{A} y_t^a$								
mean	573	565	552	530	575	565	539	502
cv	3.25	3.28	3.30	3.29	3.24	3.29	3.32	3.24
$\sum_{t=1}^{\infty} \beta^{t-1} \sum_{a=1}^{A} p^a y_t^a$								
mean	3056	3082	3058	2974	3045	3081	3012	2846
cv	3.14	3.19	3.22	3.22	3.13	3.20	3.26	3.19
$\sum_{t=1}^{\infty} \beta^{t-1} VA_t$								
mean	2320	2478	2541	2535	2259	2480	2551	2463
cv	4.13	3.96	3.87	3.78	4.22	3.97	3.85	3.68
$\sum_{t=1}^{\infty} \beta^{t-1} \pi_t$								
mean	1114	1488	1695	1815	971	1495	1796	1835
cv	8.60	6.60	5.80	5.28	9.82	6.59	5.47	4.94

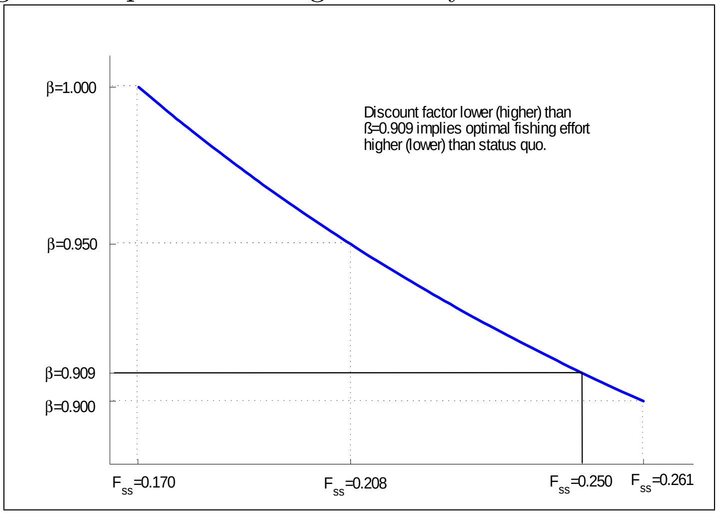
policy is better than the *status quo* policy. This result clearly differs from the EIAA model results that ranks all scenarios in the same way regardless of the indicator used to make comparisons.

On the other hand, it should be noticed that optimal policy may be far away from any of the four scenarios analyzed by STECF. For instance, when yield is maximized, for $\beta = 0.95$, optimal policy consist of selecting $F_{ss} = 0.21$ which is in between the *status quo,* $F_{sq} = 0.25$, and the $F_{\max} = 0.17$. However, for $\beta = 0.90$, the optimal policy implies even increasing the current fishing mortality by up to $F_{ss} = 0.26$.

In general, higher discount factors imply that we care more about the future so the discount is less important. So higher discount factors lead to lower optimal stationary fishing mortality rates. Figure 2 shows the relationship between optimal stationary fishing mortality rate and the discount factor when the present value of landings is aimed. We can observe that for discount factors lower than $\beta^* = 0.909$, optimal policy implies current fishing mortality raises. However, for discount factors higher than $\beta^* = 0.909$, the optimal policy is in between the *status quo* policy and the $F_{\max}$ policy. Finally, as we prove in Proposition 1, only if the future is not discounted at all such that $\beta = 1$, optimal policy consist of selecting $F_{\max} = 0.17$.

Finally, we also investigate the likelihood that the stock spawning biomass, SSB, falls in to unsafe situations under the different proposals. The

Figure 2: Optimal Fishing Mortality and Discount Factor



SSB is calculated in each simulation as $SSB = \sum_{a=1}^{A} \mu^a \omega^a \phi_t^a N_t^a$, where μ stand for maturity fraction of each age. Maturity parameters used are displayed in Table 7 in the Appendix. Moreover, following STECF biologists recommendations, the SSB is considered at risk if it is bellow $SSB_{pa} = 140,000$ t.

Table 6 illustrates the annual probability of the SSB is under SSB_{pa} for the *status quo* scenario and for the case in which discounted yield and profits are maximized. Probability of period t for a particular scenario is calculated as the ratio of number of simulations where SSB falls under SSB_{pa} in period t over 20,000 which is the total number of simulation run. We highlight the following results. First, the worst case scenario from the point of view of biomass safety is the optimal trajectory when yield is the objective and the discount factor used is $\beta = 0.90$. For all the periods, SSB is under safe values in more than 90 out of 100 simulations. This result is very intuitive. The discounted maximization problem solved, (3), is not taking into account the biological restriction that fishing mortality should be above the precautionary level ($F_{pa} = 0.25$) and offers an optimal fishing rate that is above the precautionary level, $F_{ss} = 0.26$. This result clearly indicates that any kind of biological restrictions should be included as restrictions of the discounted maximization problem in order to satisfy both, biologists and economists' principles. Second, when the future is not discounted so much, optimal behavior reduces enormously the probability of putting the stock at risk, even in the case that yield is the indicator considered. This finding highlights again the relevance of the discount rate used in calculating net present val-

Table 6: Annual Risk of SBB falling under SSB_{pa}

	SQ	F_{ss} (yield)		F_{ss} (profits)	
		$\beta = 0.95$	$\beta = 0.90$	$\beta = 0.95$	$\beta = 0.90$
target	0.25	0.21	0.26	0.10	0.12
$t = 1$	0.00	0.00	0.00	0.00	0.00
$t = 2$	0.40	0.01	1.00	0.01	0.01
$t = 3$	0.82	0.00	1.00	0.00	0.00
$t = 4$	0.92	0.03	0.99	0.00	0.03
$t = 5$	0.92	0.05	0.96	0.00	0.05
$t = 6$	0.91	0.08	0.94	0.00	0.08
$t = 7$	0.88	0.08	0.93	0.00	0.08
$t = 8$	0.85	0.07	0.91	0.00	0.07
$t = 9$	0.83	0.07	0.92	0.00	0.07
$t = 10$	0.82	0.07	0.92	0.00	0.07

ues. Finally, the *status quo* policy which consist of keeping current fishing rate forever also leads to a high probability of puttin the stock at risk.

6 Discussion

Most fisheries agencies base their advice about long-term plans on biological and economic analysis. On the one hand, biological advice consists of looking for scenarios where yield is maximized in the long run. On the other hand, posterior economic analysis model conclusions are based on net present value of discounted yield or profits associated to those scenarios. These two-step procedure may lead to contradictory results. For instance, the lastest STECF advice to the European Commission on the Northern Stock of Hake long management plan consisted, in first place, of 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 current policy lead a higher present value of discounting yield and profits than any of the alternative scenarios proposed by biologists.

At first glance this may be seen as contradictory. On the one hand, $F_{\max}$ is a good proxy for F_{msy} and F_{msy} can be understood as the fishing mortality rate that generates the largest average yield that can be continoulsy caught. On the other hand, current policy generates a higher yield, in net present value, than that associated to the MSY. This contradiction is inherent to the procedure. While biological analysis consists of looking up scenarios where stationary yield is maximized in the long run, however the economic conclusions are based on the comparison of the net present value of yield associated to those scenarios.

In this context, a logical issue is to analyze how fishery management advice changes when the fishing targets are selected taking into account the present value of discounted indicators rather than the stationary annual ones. The question is not enterilly new. For instance, Grafton, Kompas and Hilborn (2007) study empirically the connection among maximum yield and maximum discounted profits for some fisheries. Their main conclusion was that the stock associated to the maximization of yield is always lower than the stock derived from the maximization of discounted profits.

The objective of this study is to show how to find optimal fishing management trajectories that guarantee that the present value of some particular economic indicator is maximized. Basically, this procedure may compress the ICES practice to one step in which fishery effort trajectories are determined in such way that the present value of a particular economic indicator is maximized for certain period of time, subject to as many biological and/or economic restrictions as desired. In particular, we characterize optimal management trajectories that account for the age-structure such as the ones considered in assessment methodologies.

From a theoretical point of view, our results show that optimal steady state coincides with the traditional target $F_{\max}$ whenever the yield is maximized and the discount rate is zero. This means that if economists care about the future as much as present, no contradictions should be observed among biological scenarios proposed by STECF and conclusions from economic analysis. Furthermore, optimal trajectories that maximized several economic indicators, in present value terms, are found for the Northern Stock of Hake. Based on our empirical findings we may highlight some policy recommendations.

It will be recommended that biologists and economists agree on fishing efforts paths to satisfy the conditions on both sides. If the management scenarios proposed by biologists only take into account long-run targets rather than the optimal paths, the optimal policy from an economic point of view may be far from those proposals. On the other hand, if only economists' advice is taken into account we may find that the stock enters unsafe situations where the biomass falls below safe levels.

The discount rate plays a relevant role in the economic analysis. In general, the less we care about the future, the larger is the distance between optimal trajectories and scenarios proposed by biologists. Therefore the more economists discount the future, the higher the likelihood of finding contradictions among biological scenarios proposed and conclusions from economic analysis.

Finally, it is important to mention that optimal management policies are very dependent upon the economic indicator used as a reference. In general optimal fishing rates (biomass) are much lower (higher) when profits rather than yield is used as benchmark economic indicator. In this context, as Grafton, Kompas and Hilborn (2007) point out, if current biomass were compared with the biomass produced by optimal policies maximizing discounted profits, many more stocks would be considered overexploited.

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A Appendix

Obtaining First Order Condition (5):
The Lagrangian associated to the maximization problem (**??**) is given by

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} pr^1 y^a(F_t)\overline{N^1} + \sum_{a=2}^{A} pr^a y^a(F_t)\phi_t^a \overline{N^1} - TC(F_t) \\ +\theta_t \left[\mu^1\omega^1\overline{N^1} + \sum_{a=2}^{A} \mu^a\omega^a\phi_t^a\overline{N^1} - SSB_{pa}\right] \end{array} \right\}.$$

At any period t, $\overline{N^1}$ is given and the variables to solve are F_t. Notice that $\phi_t^a = \phi(F_{t-1}, F_{t-2}, ...F_{t-(a-1)}) = \Pi_{i=1}^{a-1} e^{-p^{a-i}F_{t-i}-m^a}$. This means that

$$\frac{\partial \phi_{t+j}^a}{\partial F_t} = \begin{cases} 0 & \text{for } j = 0, \\ -p^a\phi_{t+j}^a & \text{for } j = 1, ..., A-1. \end{cases}$$

Taking into account this fact it is easy to calculate first order conditions from $\partial\mathcal{L}/\partial F_t = 0$ as

$$\beta^t \left[\sum_{a=1}^{A} pr^a \frac{\partial y^a(F_t)}{\partial F_t}\phi^a(F)\overline{N^1} - \frac{\partial TC_t}{\partial F_t}\right] = \sum_{a=1}^{A-1} p^a \left\{\sum_{j=1}^{A-a} \beta^{t+j}\left[pr^a y^{a+j}(F_{t+j}) + \theta_{t+j}\mu^{a+j}\omega^{a+j}\right]\phi_{t+j}^{a+j}\overline{N^1}\right\},$$

which is completed with the restriction of the maximization problem. ■

Proof of Proposition 1
If $\beta = 1$, $pr^a = 1$ and $\partial TC/\partial F = 0$, the equation that determines F_{ss}, (6) can be written as,

$$\sum_{a=1}^{A} \frac{\partial y^a(F_{ss})}{\partial F}\phi^a(F_{ss}) = \sum_{a=1}^{A-1} p^a \sum_{j=1}^{A-a} y^{a+j}(F_{ss})\phi^{a+j}(F_{ss})$$

After some manipulation this expression becomes

$$\sum_{a=1}^{A} \frac{\partial y^a(F_{ss})}{\partial F}\phi^a(F_{ss}) = \sum_{a=1}^{A} y^a(F_{ss})\phi^a(F_{ss})\left(\sum_{i=1}^{a-1} p^i\right). \tag{7}$$

Since

$$\phi^a(F_{ss}) = \begin{cases} 1 & \text{for } a = 1, \\ \Pi_{i=1}^{a-1} e^{-p^{a-i}F_{ss}-m^a} & \text{for } a = 2, ...A, \end{cases}$$

then,

$$\frac{\partial \phi^a(F_{ss})}{\partial F_{ss}} = \begin{cases} 0 & \text{for } a = 1, \\ \phi^a(F)\sum_{i=1}^{a-1}(-p^i), & \text{for } a = 2, ...A. \end{cases}$$

Taking this into account, expression (7) can be written as

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

Comparing this expression with the equation that determines F_{MSY}, (6), it is clear that $F_{ss} = F_{\max}$.■

Table 7: Parameters by age

	Initial conditions										
	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10
N^a (1)	186213	152458	123457	100213	67409	35551	19674	10206	9147	4078	1819
	Population dynamics										
	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10
p^a	0.00	0.06	0.05	1.15	1.03	1.52	2.09	2.43	2.43	2.43	2.43
ω^a (2)	0.06	0.13	0.22	0.34	0.60	0.98	1.44	1.83	2.68	2.68	2.68
μ^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	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10
$\sigma logN$	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	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10
pr^a	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) and ICES Report (2007)
(1) Thousand;(2) kg ; (3) €/kg

Table 8: Economic Parameters Calibration

Cost structure		Macro magnitudes		
	Data per vessel		Data	Model
Fuel per day (€)	471.39	Landings (t)	54,889	54,889
Other costs per day (€)	444.48	Income (thousand €)	301,551	301,560
Total cost per day (€)	915.87	Total cost (thousand €)	73,576	73,576
Total days	80,335	Value Added (thousand €)	227,975	227,984
Total cost (thousand €)	73,576	Wages (thousand €)	120,620	120,624
Wages (thousand €)	120,620	Profits (thousand €)	107,355	107,360

Own calculations from the Spanish fleet data (2006) and French fleet data (2004)