Fundación BBVA

Documentos de Trabajo

6

2005

José María Da-Rocha Álvarez
María-José Gutiérrez Huerta

A Dynamic Stochastic Approach to Fisheries Management Assessment

An Application to some European Fisheries

Fundación BBVA

A Dynamic Stochastic Approach to Fisheries Management Assessment:

An Application to some European Fisheries

[1] José María Da-Rocha Álvarez
[2] María-José Gutiérrez Huerta

[1] *UNIVERSITY OF VIGO*
[2] *UNIVERSITY OF THE BASQUE COUNTRY*

Abstract

Most existing studies assessing the management of fisheries fail to check the accuracy of the parameters estimated in reproducing the observed dynamics of the resource. We present an alternative approach: assuming that the stock growth path is affected by productivity shocks that follow a Markov process, we calibrate the growth path of the resource so that the observed dynamics of resource are matched. In this context, an efficient policy consists of applying a different exploitation rule depending on the state of the resource whereas the constant-escapement rule is not the efficient policy. This approach is applied to three different fishing grounds: the European Anchovy (Division VIII), the Southern Stock of Hake (Divisions VIIIc and IXa) and the Northern Stock of Hake (mainly Divisions VII and VIII).

Key words

Fisheries management, renewable resources, biomass dynamics, European fisheries.

Resumen

La mayoría de los estudios que analizan la gestión de pesquerías no comprueban la capacidad de los parámetros estimados para reproducir las dinámicas del recurso observada en los datos. En este documento de trabajo presentamos una aproximación alternativa: calibramos la senda de crecimiento del recurso de manera que se reproduzca la senda observada del *stock,* asumiendo que el *stock* se ve afectado por *shocks* de productividad que siguen un proceso de Markov. En este contexto estocástico, una política eficiente consiste en aplicar diferentes reglas de explotación dependiendo del estado del recurso. Además, la regla de escape constante no es eficiente. Esta aproximación se aplicada a tres pesquerías diferentes: La Anchoa Europea (División VIII), el Caladero Sur de Merluza (Divisiones VIIIc y IXa) y el Caladero Norte de Merluza (Divisiones VII y VIII, principalmente).

Palabras clave

Gestión de pesquerías, recursos renovables, dinámica de la biomasa, pesquerías europeas.

A Dynamic Stochastic Approach to Fisheries Management Assessment: An Application to some European Fisheries

edita
© Fundación BBVA. Plaza de San Nicolás, 4. 48005 Bilbao

diseño de cubierta
Roberto Turégano

depósito legal: M-52.517-2005
imprime: Rógar, S. A.

La serie Documentos de Trabajo de la Fundación BBVA están elaborados con papel 100% reciclado, fabricado a partir de fibras celulósicas recuperadas (papel usado) y no de celulosa virgen, cumpliendo los estándares medioambientales exigidos por la actual legislación.

El proceso de producción de este papel se ha realizado conforme a las regulaciones y leyes medioambientales europeas y ha merecido los distintivos Nordic Swan y Ángel Azul.

C O N T E N T S

1. Introduction

EFFICIENCY in managing the explotation of fishery resources has been widely analyzed in resource literature. Most of the existing studies analyze the behavior of fisheries without checking the reliability of the parameters estimated in reproducing the observed dynamics of the resource (among others, Garza-Gil *et al.*, 2003; Del Valle *et al.*, 2001; Grafton *et al.*, 2000; Garza-Gil, 1998; Flaaten and Stollery, 1996; Amundsen *et al.*, 1995. In general terms, these studies use deterministic models that consider that an efficient policy consists of maintaining the exploitation levels of the fishing ground at steady state values.

However, the traditional approach used to estimate the parameters cannot reproduce the observed biomass dynamic. For instance, the biomass path generated from the estimated parameters and observed catches is far from the biomass path used to estimate the parameters. In short, since most articles only focus on steady states, the accurate of the parameters in reproducing the observed dynamics of the resource is never checked. However, we consider that accurate reproduction of the observed data is a minimum condition that any fishery management study must satisfy. In particular, we believe that the more accurately the parameters reproduce the observed evolution of the biomass the more reliable the assessment of the exploitation is.

In this paper we present an alternative approach that allows a better reproduction of the stylized facts of the fishing ground. This is a stochastic approach in which we assume that the stock growth path is affected by stochastic productivity shocks that follow a Markov process [1]. We calibrate the growth path of the resource to match the observed dynamics of the resource and captures.

With this kind of approach, we do not limit our work to comparing the observed paths of catches and biomass to the stationary values from a deterministic model. Our analysis goes further into the calculations of the optimal exploitation rules associated with both the size and the productivity

1. Productivity shocks can reflect that the biomass may be affected by biological cycles (Larrañeta and Vázquez [1982]) or any other ecological uncertainty element.

of the biomass to summarize, with productivity shocks affecting the growth of the biomass, an efficient policy consists of applying a different exploitation rule depending on the state of the resource, and given that the stock is always in transition, jumping from one steady state to another.

This stochastic approach is applied to three different fishing grounds: the European Anchovy fishery (Division VIII), the Southern Stock of Hake (Divisions VIIIc and IXa) and the Northern Stock of Hake (mainly Divisions VII and VIII). We study these fishing grounds for three reasons. Firstly, all of them are considered as individual administrative units by the International Council for the Exploitation of the Sea (ICES), which advises the European Commission on their management. secondly, the three are fishing grounds that have been analyzed previously with the traditional approach (Del Valle *et al.*, 2001; Garza-Gil, 1998; Da-Rocha and Gutiérrez, 2004, respectively). Those papers allow us to focus on the calibration of the growth resource because they show (partial) information about capturability functions, prices of catches and costs of effort. Thirdly, biomass evolution is quite different in the three fishing grounds. While in the European Anchovy fishery the biomass shows high variability over the period analyzed, in the Southern and Northern Stock of Hake the stock shows a monotonic (dramatically) descending trend.

Our results show that in aggregate terms, catches in the European Anchovy fishery and in the Southern Stock of Hake have been even lower than would correspond to efficient exploitation. However, the timing of catches has not been appropriate and the exploitation has not been able to protect the resource. This inefficiency has meant a reduction of potential profits by 17% in European Anchovy and by 35% in the Southern Stock of Hake. Moreover the Southern Stock of Hake is in a dangerous situation; in particular, our results show that an efficient exploitation policy would bring the stock up to ICES recommended levels. We also illustrate how catches should be shared between the two existing fleets once the fishing ground is recovered. Our results indicate that efficient exploitation will require a larger proportion of the total catches to go to the artisanal fleet than is currently the case. With respect to the Northern Stock of Hake, the finding is that, given the *quota* system imposed by European regulation, an efficient exploitation would have generated more than 111,000 Tn of profits (about 670 millions euro). Furthermore, a European policy regulation that would have allowed side-payments between fleets from different countries would have increased the profits of the fishing ground by 26%.

Other authors have introduced uncertainty into the dynamics of the resource. Androkovich and Stollery (1989) simulate a stochastic dynamic program to quantify the relative merits of different policies for regulating the Pacific halibut fishery. More recently, Danielsson (2002) and Weitzman (2002) analyze the relative performance of different methods of fisheries management when some risks are involved. Both include *ecological* or *environmental* uncertainty in the biological dynamics of the fish stock. Sethi, Costello, Fisher, Hanemann and Karp (2005) develop a theoretical model that incorporates uncertainty about, among others, variability in fish dynamics assuming Markovian transitions. Our work is on the same line as these studies; in particular we assume that the current state of productivity may depend on past productivity.

The article proceeds as follows. In the next section the traditional approach to the evaluation of fisheries management is presented. In particular, two examples show how poorly this approach may reproduce the observed dynamics of the biomass. In Section 3 an alternative stochastic approach is proposed. Firstly, a multifleet fishery model with stochastic biomass dynamics is developed, and then, a method for calibrating the growth path of the resource is proposed. The model is adapted to characterize the European Anchovy fishery in Section 4. Subsection 4.1 presents the calibration of the fishing ground and in Subsection 4.2 the assessment of the fishery is analyzed. Section 5 applies the analysis to the Southern Stock of Hake and reports what would have happened if side payments between fleets been allowed. In Section 6 the analysis is applied to the Northern Stock of Hake [2]. Firstly, a multifishery model is developed to include political discrimination and heterogeneous productivity. Second, the model is calibrated not only to reproduce catches and biomass evolution but regulated *quotas*, relative catches per unit of effort and target stock announced by the European recovery plan. Thirdly, we report how far the observed behavior is from the efficient management of the fishery and what would have happened if side-payments between countries had been allowed. Section 7 concludes the article with a policy recommendation discussion.

2. The main contents of this section have been accepted to be published in the *Spanish Economic Review* (see Da-Rocha and Gutierrez, 2005).

2. The Traditional Approach

THE literature of fishery efficiency assessment has traditionally followed a deterministic steady state approach that considers an efficient policy consists of maintaining the exploitation levels of the fishing ground at steady state values. In this section we show the effects that this approach may have on the expected evolution of the resource.

Let us consider that the stock of the fishing ground we want to evaluate, X_t is characterized by the following dynamics

$$X_{t+1} = F(X_t) - Y_t \qquad (2.1)$$

where Y_t is total catches and F is the gross growth of the biomass, which depends upon the stock of resource, X_t.

The traditional approach consists of the following steps: *i)* The dynamics of the resource are estimated using data on stock and catches, *ii)* An appropriate parametric form for the gross growth of the stock, *F*, is selected based on this estimation, *iii)* The complete theoretical problem is solved [3], and *iv)* Parameters estimated in steps *i)* and *ii)* are used to assess the fishery according to the solution of the theoretical model. The problem of this procedure is that the estimated dynamics of the resource (step *i)*) are never checked against the data used to estimate them. That means that we may be using an inappropriate estimation for evaluation. We show two examples of this effect.

Let us consider the European Anchovy (Division VIII) and the Southern Stock of Hake (Divisions VIIIc and IXa) for the periods 1987-2002 and 1982-2002, respectively [4]. Our estimation results point to Gompertz as being the functional form that best fits the data of the European Anchovy ground

3. Other functional forms such as capturability and profit functions are usually involved in the theoretical problem.

4. Data used are shown in Tables 13 and 14 in Appendix A.

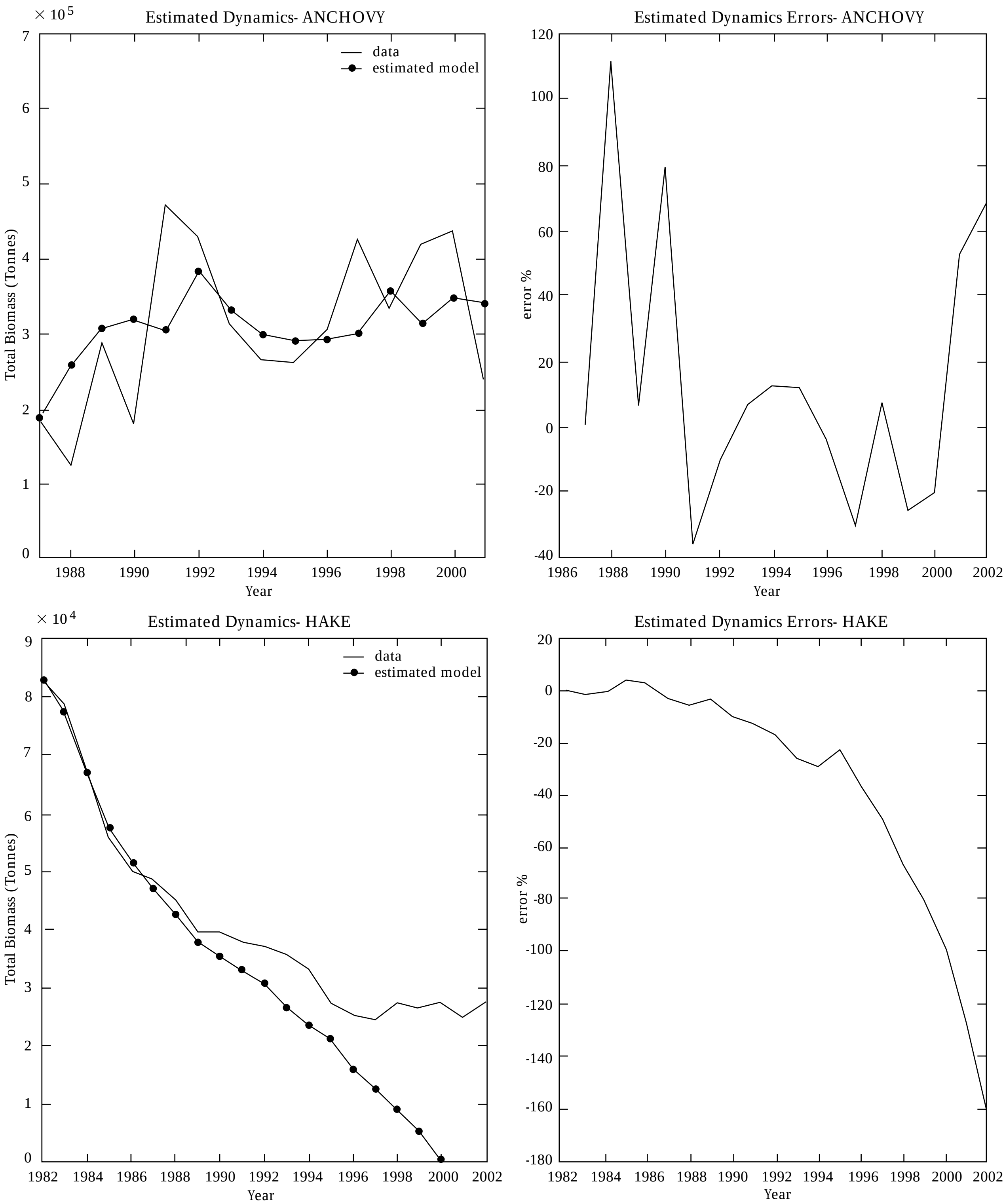
fishery, and Ricker for the Southern Stock of Hake [5]. The traditional approach would use the estimation of the parameters of these functional forms to evaluate the efficiency of the fishing ground without checking the accuracy of these estimated parameters in reproducing the observed dynamics of the resource. However, this is very simple to do. Thus given X_0, the dynamics of the resource imply $\hat{X}_1 = \hat{F}(X_0) - Y_0$ where $\hat{F}$ is the estimated gross growth function. Then $\hat{X}_2 = \hat{F}(\hat{X}_1) - Y_1$ and so on.

Graphic 2.1 reproduces the resource evolution of European Anchovy and the Southern Stock of Hake implied by the traditional approach using the above mentioned estimated gross growth functions and taking the initial stocks as given. We can observe two different points. In the case of anchovy (upper panels), the traditional approach implies a much lower variability of the resource dynamics than shown by the actual data. For some periods the estimated stock deviates from the observed stock by more than 60%. For southern hake (lower panels), the traditional estimation reproduces the observed evolution of the stock very poorly. In particular from 1989 on the estimated stock is lower than the observed stock and the estimated errors increase with time (in absolute terms). Notice that the traditional estimation would imply the disappearance of the hake stock in 2000.

We propose that using an approach that more accurately reproduces the evolution of the dynamic resource leads to more reliable results in assessing the efficiency of resource management.

5. We show how this selection is made in sections 3.1 and 4.1.

GRAPHIC 2.1: Estimated Dynamics. (upper) European Anchovy; (lower) Southern Stock of Hake



3. A Stochastic Approach

IN this section a new stochastic approach is presented to evaluate the efficiency of fishing resource management. Firstly, we present a multifleet bioeconomic model in which the resource is affected by stochastic productivity shocks. Secondly, since the model has to be simulated, we describe how to calibrate it, i.e. how to choose values for the parameters that reproduce the main stylized facts of the fishing ground.

3.1. The Model

Let us consider a fishing ground in which the dynamic of the stock, X_t, is given by

$$X_{t+1} = F(X_t, z_t) - Y_t \tag{3.1}$$

where Y_t represents total catches and F is the gross growth of the biomass, which depends upon the stock of resource, X_t, and a productivity random shock, z_t. In particular we assume

$$F(X_t, z_t) = e^{z_t} f(X_t) \tag{3.2}$$

where z_t is a random variable with mean zero which follows a Markov process with a transition matrix, $\pi(z_t, z_{t+1})$. We assume that the realization of z_t is known at the beginning of the period t.

We consider that n heterogeneous fleets operate in the fishing ground. Catches of fleet i, $y_{i,t}(\xi_{i,t}, X_t)$, depend on its own effort, ξ_i, and on the stock of fish. Therefore, total catches are a function of all individual efforts and of stock,

$$Y_t = \sum_{i=1}^{n} y_{i,t}(\xi_{i,t}, X_t) \tag{3.3}$$

Let us assume that the common fishery is managed by a benevolent regulator who maximizes the expected present discount value of the future profits of the fleets,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\Pi_{1,t} + \Pi_{2,t} + \ldots + \Pi_{n,t}\right)$$

where E_t represents the expectation taken at time t and β is the discount factor. $\Pi_{i,t}$ represents the profit of fleet i in period t, defined as the difference between its revenues, $p_{i,t} y_{i,t}$, and the effort cost, $\omega_{i,t} \xi_{i,t}$. Moreover, the regulator may place constraints on total captures by fleets, i.e. $Y \in \{Y_{min}, Y_{max}\}$. Y_{max} can be understood as the maximum amount of fish that can physically be captured by the fleets at their current size. Y_{min} can be interpreted as the minimum amount of catches that the fleet must make in order to maintain minimum revenues for current fleets given their fishing capacity. Formally the benevolent regulator problem is given by the following Bellman's equation

$$V(X, z, Y_{min}, Y_{max}) = \max_{(X', \{\xi_i\}_{i=1}^n)} \sum_{i=1}^{n} \Pi_i (z, X, X', \xi_i) + \beta E_{z'} [V(X' z', Y_{min}, Y_{max})/z], \quad (3.4)$$

$$s.t. \begin{cases} \Pi_i = p_i y_i (\xi_i, X_i) - \omega_i \xi_i \\ Y = \Sigma_{i=1}^n y_i (\xi_i, X) \\ X' = e^z f(X) - Y \\ z \in [z_1, \ldots\ldots, z_m], \pi \\ Y \in \{Y_{min}, Y_{max}\} \end{cases}$$

where a prime on a variable indicates its value for the next period and the notation $E_{z'}$ means that the expectations are over the distribution of z'.

A solution of this problem is a value function $V(z, X, Y_{min}, Y_{max})$, policy functions $\{\xi_i (X, z, Y_{min}, Y_{max})\}_{i=1}^n$ and $g(X, z, Y_{min}, Y_{max})$ such that:

1. Given X, z, Y_{min} and Y_{max}, $V(z, X, Y_{min}, Y_{max})$ is the value function that solves the benevolent regulator problem, and $\{\xi_i (X, z, Y_{min}, Y_{max})\}_{i=1}^n$ are the maximizing effort choices.
2. Total catches $\Sigma_{i=1}^n y(\xi_i (X, z, Y_{min}, Y_{max}), X)$ are within the interval (Y_{min}, Y_{max}).
3. Individual effort and stock target are compatible, i.e. $X' = g(X, z, Y_{min}, Y_{max}) = e^z f(X) - \Sigma_{i=1}^n y_i (\xi_i (X, z, Y_{min}, Y_{max}), X)$.

In other words, given the current stock, X, the benevolent regulator chooses an optimal effort rule and a stock target for which the total catches in each period, $Y = \Sigma_{i=1}^{n} y_i (\xi_i, X)$, are within the allowed range of catches, $Y \in \{Y_{min}, Y_{max}\}$, and the stock target is sustainable, that is $X' = e^z f(X) - Y$.

3.2. Calibration Procedure

In order to simulate the model we need to calibrate it, i.e. to choose values for the parameters that reproduce the main stylized facts of the fishing ground analyzed. Since we have introduced stochastic productivity shocks into the gross growth function, we focus on illustrating how to choose the parameters in the dynamic resource equation, (3.1) [6].

The first step in calibration consists of selecting an appropriate parametric form for the gross growth function, $f(X_t)$. Suppose that a potential functional form depends on a parameter set $(k_1, \ldots k_r)$ [7]. Then, if data on stock and catches are available, we can estimate those parameters from the dynamic resource equation, (3.1), which in logarithm terms can be expressed as

$$\ln (X_{t+1} + Y_t) = \ln f(X_t \mid k_1, \ldots, k_r) + z_t \tag{3.5}$$

After examining the results of the estimations for different functional forms, we choose the most appropriate according to the usual econometric criteria.

Once the parameters have been estimated, the stochastic process, z_t, is calibrated in such a way that the sequence of productivity shocks reproduces the stock and total catches for the observed period. In order to do this, we have to choose m equidistant values for the state of the productivity shock, that is $(z_1, z_2, \ldots z_m)$. Given these values for the states of z, the transition matrix, π, for the Markov chain that discretes a continuum process in m states is calculated following the method proposed by Tauchen (1986) [8]. The number of states of nature and the values that they take are chosen so that deviations of the observed paths for the stock and catches from those implied by the model are minimal.

6. The parameters that appear in the capturability functions can be calibrated with traditional procedures.

7. In practice, we can use the traditional functional forms for the growth function, i.e. logistic, Cushing, Ricker, Gompertz and others.

8. Implementing Tauchen's method requieres the estimation of the first order autocorrelation coefficient from the estimated errors, $\hat{z}_t$.

Once the model has been calibrated, the Bellman equation that represents the regulator problem, equation (3.4), is solved numerically. In Appendix B, we outline how this is done.

In sections 4 and 5 this procedure is applied to calibrate the dynamic resource equation in two different fishing grounds. First we analyze the European Anchovy fishery (Division VIII) in which the fleet can be considered homogeneous in the sense that all ships fish with the same technology. Secondly, we analyze the Southern Stock of Hake. In this fishing ground two different fleets operate (the trawler and the artisanal fleets). Subsequently, in section 6, this approach is applied to the Northern Stock of Hake which is a fishing ground regulated by the European Union and fished by two heterogeneous fleets from different countries. In this case, the stochastic approach is extended to fit not only the observed data on biomass and catches but also the relative catches per unit of effort and the *quotas* assigned by the European regulation to each fleet.

4. The Case of the European Anchovy Fishery

EUROPEAN Anchovy Division VIII is a fishing ground in the Bay of Biscay [9]. Anchovy *(engraulis encrasicholus)* is a short-lived species that is fully mature at one year old in the Spring following its hatching.

Two fleets fish anchovy in the Bay of Biscay and the pattern of each fishery has not changed in recent years: purse seines and pelagic trawlers. The purse seines are mainly Spanish and operate in Spring in Divisions VIIIb-c [10]. There are also French purse seines located in the Basque Country and in the southern part of Brittany, which have recently increased in number. They fish mainly in Spring in VIIIb, and some of them in Autumn in the north of the Bay of Biscay. The pelagic trawlers are french and operate in Summer, Autumn and Winter in Divisions VIIIa-b. Most fish have spawned at least once before being caught. Due to a bilateral agreement between France and Spain, the pelagic trawlers fish outside the spawning season (Spring) and the purse seines fish outside the spawning area (Division VIIIc). The purse seine fleet represents 80% of the boats fishing anchovy in Division VIII. This percentage has remained stable since 1990. However, while Spanish vessels accounted for 90% of the purse seine fleet in 1990, it represented just 73% in 2002 [11].

Like the other main stocks of the EU, the Bay of Biscay anchovy stock has been managed since 1979, with fixed annual total allowable catches (TAC)

---

9. The anchovy is one of the most important species in European Atlantic waters from the central part of the Bay of Biscay to the West of Galicia. However, the ICES considers that for biological and management purposes the anchovy population has to be divided into two different stocks: the South-east corner of the Bay of Biscay (Division VIII) and the Atlantic Iberian Coast (Division IXa). See ICES CM 2004/ACFM:08, section 10.1.

10. Most of the fleet goes tuna fishing in summer time and small anchovies are used as live bait for this fishing.

11. In 1990 there were 266 Spanish purse seines, 30 French purse seines and 80 pelagic trawlers. In 2002, there were 215, 81 and 71, respectively (see Table 11.5.1 in ICES CM 2004/ACFM:08).

being established under the Principle of Relative Stability. There is however no biological background behind this, apart from fixing catches at the historical average, at least up to 2000. This is due to the difficulties of managing this short-lived species properly and the strong and short-term fluctuations in biomass linked to variability in recruitment strongly influenced by environmental factors.

Based on the most recent estimations of the biomass, the ICES classifies the anchovy stock as being outside safe biological limits. Accordingly, the ICES recommended a provisional TAC for 2004 of 11,000 Tn, to be re-evaluated in the middle of the year (see ICES 2003, ACFM Annual Report, section 3.11.8.a.) [12]. The Scientific Technical and Economic Committee on Fisheries (STECF) agreed with the ICES assessment and suggested that the preliminary TAC for 2004 should be restricted to below 10,000 Tn (see STECF Review of Scientific Advice for 2004, section 2.1). Finally the European Commission decided to set the annual TAC at the traditional level of 33,000 Tn for 2004, a figure which will be reviewed during the year in the light of new scientific advice (Council Regulation of 19 December 2003).

For more details about biological and technical characteristics of this fishery see Lucio *et al.* (1989), AZTI's Assessment (2004) and the reports issued by the ICES Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine, and Anchovy (WGMHSA). Del Valle *et al.* (2001) also analyze the role that resource users (through fishermen's guilds) play inside the institutional regime management of this fishery.

4.1. Calibration

To evaluate the optimal exploitation policy for the Bay of Biscay anchovy, we calibrate the model assuming stochastic productivity shocks. First the parameters from the dynamics resource equation are calibrated following the procedure developed in Subsection 3.2.

An appropriate functional form for the gross growth of the biomass, $F = e^{z_t} f(X_t)$, is chosen from among different candidates analyzed. Table 4.1 shows the estimation results of the dynamic resource equation considering five alternative gross functions: Cushing, logistic, logistic with minimum via-

12. Since 1999 the ICES has suggested setting a preliminary TAC at the beginning of the year based on analytic assessment in the Autumn, and reviewing it midway through half of the year when the results from egg and acoustic surveys became available (ICES 2002, ACFM Annual Report).

ble population size (MVPS), Ricker and Gompertz. We use data on the stock and total catches from 1987-2002 in European Anchovy (Division VIII). These data were compiled by the ICES WGMHSA and are shown in Table A.1 in Appendix A. Given the high level of non linearity of the gross growth functions, the dynamic resource equation expressed in logarithms, equation (3.5), has been estimated using non linear least squares.

TABLE 4.1: Estimations for European Anchovy (Division VIII)

Estimation	*t*-statistics	Sum Square Error
Cushing Function $f(X_t) = AX_t^{\alpha}$		
MSY = 138,176 X_{MSY} = 59,710 MCC = 332,109		
A 7166.25	0.32869516	1.766838
α 0.3017	1.2483737	
Logistic Function $f(X_t) = rX_t\left(1-\frac{X_t}{K}\right) + X_t$		
MSY = 77,565 X_{MSY} = 181,915 MCC = 363,830		
r 0.8528	2.2557307*	1.988025
K 363,830	8.3957264*	
Logistic with MVP $f(X_t) = rX_t\left(\frac{X_t}{k_0}-1\right)\left(1-\frac{X_t}{K}\right) + X_t$		
MSY = 77,565 X_{MSY} = 181,915 MCC = 363,830		
r –0.8528	–0.75037476	1.988025
K 363,830	5.8169770*	
K_0 –1.11E13	–1.88E-8	
Ricker Function $f(X_t) = X_t e^{r(1-X_t/K)}$		
MSY = 90,058 X_{MSY} = 155,946 MCC = 350,127		
r 0.8219	2.7565286*	1.909892
K 350,127	8.0717812*	
Gompertz Function $f(X_t) = rX_t \ln\left(\frac{K}{X_t}\right) + X_t$		
MSY = 95,097 X_{MSY} = 127,455 MCC = 346,457		
r 0.7461	2.4418437*	1.852062
K 346,457	7.6560014*	

* Statistics significant at the 5% level.

Following Meade and Islam (1995) a functional form is deemed to be suitable for use if all the parameter estimates are significantly different from zero. Among the suitable functional forms we choose the one with the lowest sum of square errors, i.e. in accordance with the Akaike criterion [13], provided the estimated biological aggregates are sensible [14]. As Table 4.1 illustrates, the Gompertz is the functional form that best fits the data. The Gompertz function defines the gross growth function as $f(X_t) = [1 + rLn(K / X_t)]\, X_t$, where $r > 0$ is the intrinsic growth rate and K represents environmental carrying capacity. The results of this estimation imply $\hat{r} = 0.7461$ and $\hat{K} = 34{,}645$. Both estimates are significantly different from zero at the 5% level with t statistics of 2.44188771 and 7.65601 for r and K, respectively. With these estimations of the parameters r and K, the Maximum Sustainable Yield (MSY) is 95,097 Tn, the biomass required for the MSY is 127,455 Tn and the Maximum Carrying Capacity (MCC) is 346,457 Tn [15]. This means that actual catches, at about 17,507 Tn in 2002, are far below the MSY level.

Once these parameters are estimated, the stochastic process is calibrated in such a way that the sequence of productivity shocks reproduces the stock and total catches observed from 1987 to 2002. In order to do this, we take nine equidistant values for the state of the productivity shock, that is

$$z \in \{-0.6742, -0.5056, -0.3371, -0.1685, 0.0000, 0.1685, 0.3371, 0.5056, 0.6742\}.$$

Given the information from the estimated errors, $\hat{z}$, and the values for the states of z, we calculate the transition matrix, π, for the Markov chain that discretes a continuum process in nine states following Tauchen (1986). The calibrated values are

13. The suitable functional forms in the case analysed have the same number of parameters.

14. The P-test of Davidson and MacKinnon (1981) was also calculated to select among the suitable functional forms. However, the test was inconclusive, probably due to the small sample size (15 observations).

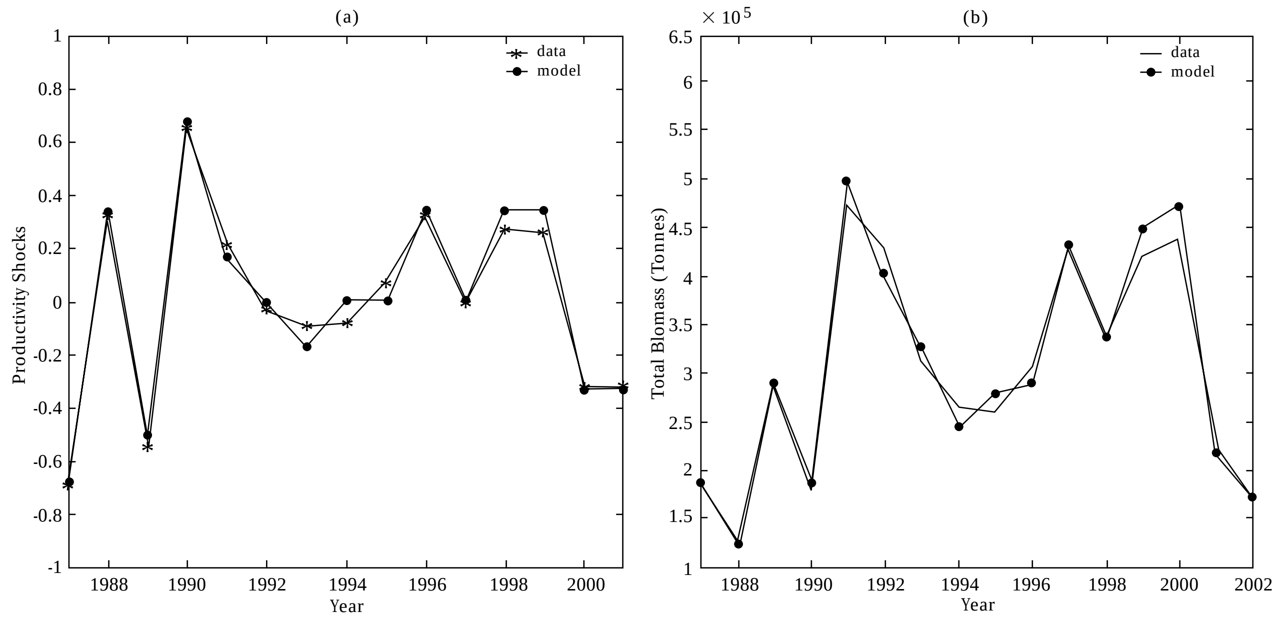
15. The *MSY* is the maximum net growth of the biomass. In other words, the value of the net growth for a stock level such that $\partial(F(X_t) - X_t) / \partial X_t = 0$. Recently, the National Marine Fisheries Service of the USA has started to call this yield *long-term potential yield*. The *MCC* is the maximum stock compatible with a null net growth of the resource, i.e. X_t such that $F(X_t) = 0$.

$$\pi\ (z, z') = \begin{pmatrix} 0.0001 & 0.0014 & 0.0133 & 0.0682 & 0.1928 & 0.3013 & 0.2604 & 0.1245 & 0.0381 \\ 0.0002 & 0.0031 & 0.0237 & 0.1007 & 0.2364 & 0.3068 & 0.2202 & 0.0874 & 0.0216 \\ 0.0005 & 0.0062 & 0.0397 & 0.1402 & 0.2734 & 0.2947 & 0.1757 & 0.0579 & 0.0117 \\ 0.0013 & 0.0118 & 0.0629 & 0.1843 & 0.2983 & 0.2671 & 0.1323 & 0.0362 & 0.0060 \\ 0.0028 & 0.0213 & 0.0939 & 0.2284 & 0.3071 & 0.2284 & 0.0939 & 0.0213 & 0.0029 \\ 0.0059 & 0.0362 & 0.1323 & 0.2671 & 0.2983 & 0.1843 & 0.0629 & 0.0118 & 0.0013 \\ 0.0116 & 0.0579 & 0.1757 & 0.2947 & 0.2734 & 0.1402 & 0.0397 & 0.0062 & 0.0006 \\ 0.0216 & 0.0874 & 0.2202 & 0.3068 & 0.2364 & 0.1007 & 0.0237 & 0.0031 & 0.0003 \\ 0.0380 & 0.1245 & 0.2604 & 0.3013 & 0.1928 & 0.0682 & 0.0133 & 0.0014 & 0.0001 \end{pmatrix}$$

where $\pi_{i,j} = Pr\ [z = z_i \mid z' = z_j]$.

Graphic 4.1 shows the observed and calibrated productivity shocks and stock in panels (a) and (b), respectively, from 1987 on. Notice that the productivity shocks estimated reproduce the path of the observed stock (panel b) quite accurately.

GRAPHIC 4.1: Anchovy Dynamics (a) productivity shocks *(z_t)*; (b) biomass dynamics *(X_t)*



Following Del Valle *et al.* (2001) we use a homogeneous Cobb-Douglas production function in which total catches are a function of total number of vessels, E, and the stock of the resource, X_t,

$$Y_t(\xi_t, X_t) = B\xi_t^{\theta} X_t^{\lambda},$$

where θ and λ are the elasticity of the catches with respect to the effort and stock, respectively [16]. Table 4.2 shows the parameters used for our analysis.

TABLE 4.2: European Anchovy Fleet

Value	Parameters
$\theta = 0.66562$	Elasticity of effort (number boats)
$\lambda = 0.68226$	Elasticity of Stock
$B = 0.31991$	Total factor productivity
$w/p \in [40,100]$	Tn

Source: Del Valle *et al.* (2001).

4.2. Evaluation of European Anchovy Stock Management

To generate the dynamic transition from the initial situation to the stochastic steady state we solve the following dynamic program,

$$V(z, X, Y_{min}, Y_{max}) = \max_{X'} \sum_{i=1}^{n} \Pi_i(z, X, X') + \beta E_{z'}\left[V(z', X', Y_{min}, Y_{max}) \;/\; z\right]$$

$$s.t. \begin{cases} Y = e^z\,[1 + rLn\,(K/X)]\,X - X' \geq 0 \\ z \in [z_1, z_2, z_3, z_4, z_5, z_6, z_7, z_8, z_9], \pi(z, z') \\ Y \in \{Y_{min}, Y_{max}\} \end{cases}$$

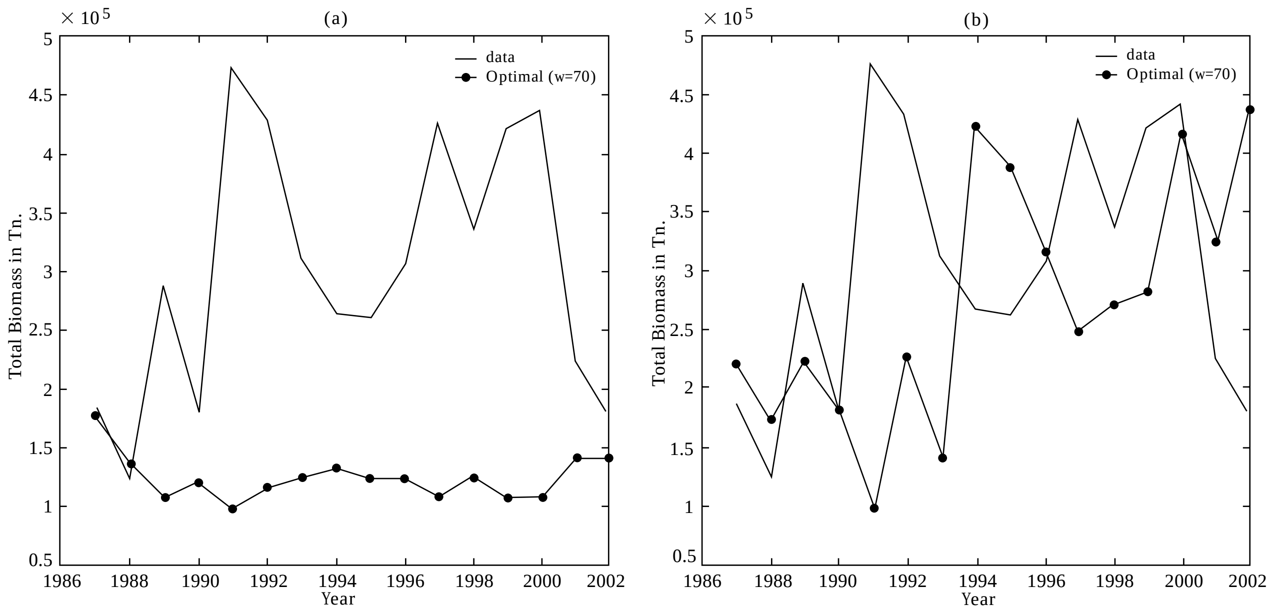
where the profits, in real terms, are given by

$$\Pi_i(z, X, X') = e^z\,[1 + rLn\,(K/X)]\,X - X' - \omega\left(\frac{e^z\,[1 + rLn\,(K/X)]\,X - X'}{BX^{\lambda}}\right)^{1/\theta}$$

and the real cost of effort is $\omega = w/p$.

16. We do not change the productivity functions used in Del Valle *et al.* (2001) because we want to focus on how the assessment of resource management varies when we are able to improve the reproduction of the evolution of the dynamic resource. In spite of the fact that two different types of technology are used in the fishery, Del Valle *et al.* (2001) defend the use of a homogeneous production function because of the lack of reliable estimations for the pelagic trawler fleet.

GRAPHIC 4.2: **Optimal Stock vs data (a) without maximum; (b) with maximum catches of to 40,000 Tn**



We solve the dynamic program without restriction (Y_{min} = 0) and with an upper bound on catches (Y_{max} = 40,000 Tn). This upper bound on catches is selected taking into account that the maximum captures of the fleet in 1987-2002 correspond to catches in 1993 of 40,293 Tn. Optimal paths for the stock in the two cases are illustrated in Graphic 4.2, panel (a) and panel (b), respectively. Notice that the efficient stock in the absence of an upper bound on catches is fairly constant and varies between 100,000 and 200,000 Tn [17]. However, the efficient path when an upper bound on catches is imposed is much higher and more volatile. That is, when unconstrained catches are not allowed stock becomes more volatile. Since the number of vessels is (almost) fixed, we consider it more appropriate to use the efficient path imposing the upper level of captures as our benchmark [18].

Table 4.3 shows the deviations of the observed exploitation paths from the optimal ones with maximum catches of 40,000 Tn. Aggregate catches are 184,000 Tn less than optimal for the period analyzed. This means that effective exploitation has deviated, in aggregate terms, by more than

17. We have checked that this path is associated with a high and very volatile level of catches.

18. The number of boats was 327 in 1987 and 367 in 2002 (see Table 11.5.1 in the ICES 2004, ACFM:08 Report).

29% from the efficient policy. However, this underexploitation has not been able to protect the stock. In 2002 biomass was about 173,000 Tn. while optimal exploitation would have required a lower resource stock of 435,000 Tn. This is consistent with the fact that the stock is outside the safe biological limits according with the ICES studies.

TABLE 4.3: Optimal Stock and Catches. European Anchovy

Catches and Stock [1]	Data	Optimal
$\Sigma_{t=1987}^{2002} Y_t$	448,984	632,623
X_{2002}	173,484	435,000

1. Tn of Anchovy.

Table 4.4 quantifies aggregate discounted profits for the whole period analyzed under the two scenarios, effective exploitation and efficient exploitation ($\Sigma_{t=1987}^{2002} \beta^{t-1987} \Pi_t$ and $\Sigma_{t=1987}^{2002} \beta^{t-1987} \Pi_t^*$, respectively). These profits are shown for different values of the real effort cost. As expected, the higher the real cost of effort is, the lower the profit of the fishery, regardless of the degree of management efficiency. We can see that for a medium real cost of effort (w/p = 70), optimal exploitation would have entailed an increase in profits of 17%. In the same line, Graphic 4.3, panel (a), illustrates in percentage terms how much profits would have increased if exploitation had been efficient with a constant TAC of 40,000 tons. Results show that profits would have increased by between 13% and 40%.

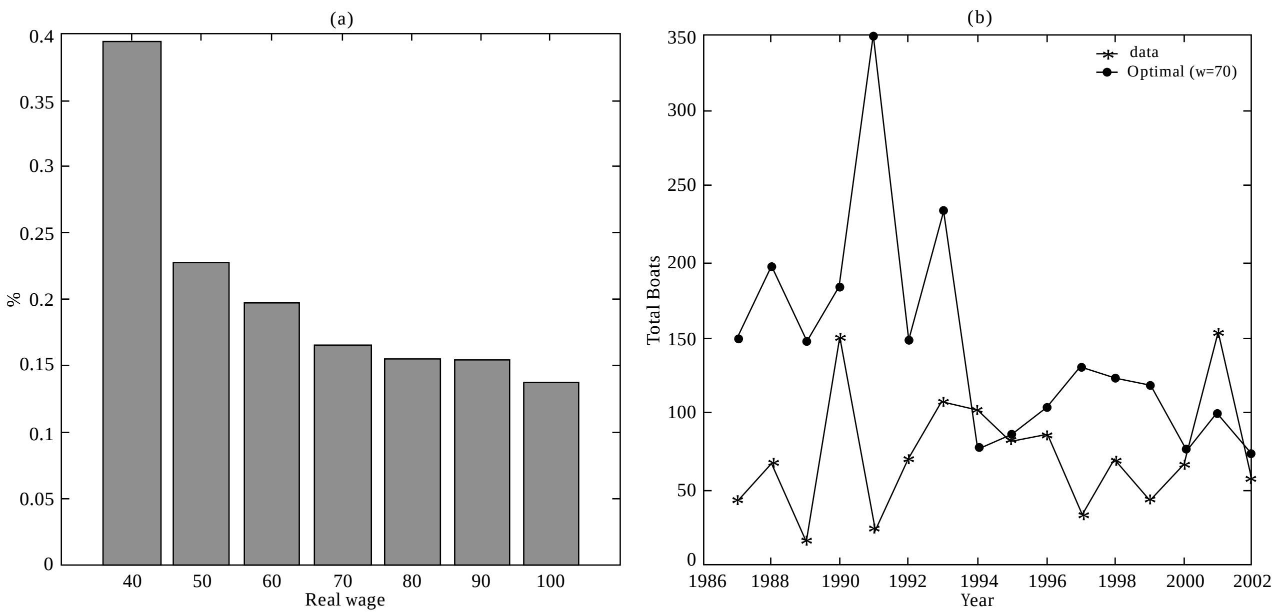
TABLE 4.4: Optimal and Observed Profits. European Anchovy

Profits [1]	Real cost						
	40	50	60	70	80	90	100
$\Sigma_{t=1987}^{2002} \beta^{t-1987} \Pi_t$	257,240	249,630	242,030	234,420	226,820	219,210	211,610
$\Sigma_{t=1987}^{2002} \beta^{t-1987} \Pi_t^*$	358,430	306,410	289,830	273,320	261,740	252,850	240,570

1. Tn of Anchovy.

Graphic 4.3, panel (b), illustrates the evolution of the optimal and observed number of boats operating in the fishery under the maximum catch restrictions. We can see that the effective number of boats has varied from between 20 and 150 while efficient exploitation would have required more than 300 boats in some periods. This divergence is specially relevant for the periods 1989-1993 and 1996-2000. These periods correspond to the timing in which the effective stock was lower than that implied by efficient exploitation (see panel b) in Graphic 4.3).

GRAPHIC 4.3: **European Anchovy. Maximum catches of 40,000 Tn. (a) Increase in Profits; (b) Optimal number of boats**



To summarize, the exploitation of the European Anchovy stock in 1987-2002 was far from efficient. In aggregate terms, catches were lower than they would have been with efficient exploitation. However, the timing of the captures has not been appropriate. It would have been better, from the efficiency point of view, to catch more in the good years with high stock and less in the bad years, with lower stock. This inefficiency has meant a reduction of between 13% and 40% in the profits of the fishery.

5. The Southern Stock of Hake

THE Southern Stock of Hake is a fishing ground allocated around the Atlantic coast of the Iberian Peninsula (Divisions VIIIc and IXa) [19]. Hake *(merluccius merluccius)* is a late maturing fish. Males mature at 3-4 years old (27-35 cm) and females at 5-7 years old (50-70 cm).

Two fleets fish on hake in the Southern Stock: the Spanish and Portuguese trawl and artisanal fleets. The trawler fleet is fairly homogeneous and uses two kinds of gears: bottom trawl and pair trawl. This fleet has shown a general downward trend in effort over the last decade. The artisanal fleet is very heterogeneous and uses a wide variety of gears: traps, nets, longlines, etc. Hake is caught throughout the year, though sea conditions may produce some fluctuations. Most of the catches are used for human consumption.

Hake is managed by annual TAC with associated technical measures in the Southern Stock. The agreed TAC was 8,000 Tn in 2002, 7,000 Tn in 2003 and 5,950 Tn in 2004. However the catches in most years did not reach the TACs. In order to protect juveniles, fishing is prohibited in some areas during part of the year and the minimum landing size is 27 cm [20].

Biomass dropped from about 84,000 Tn in the early 1980s to 27,000 Tn in 2002 (see Table A.2 in Appendix A). This reduction is reflected in catches, which dropped from 22,000 Tn to 6,000 Tn in the same period. The ICES Advisory Committee for Fisheries Management considers that the stock is outside safe biological limits and recommends a recovery plan to ensure safe and rapid rebuilding. Such a recovery plan must include a provision for zero catches for 2004 until strong evidence of rebuilding is obser-

19. Hake is one of the most important species in European Atlantic waters. The ICES considers that for biological and management purposes the hake population must be divided into two different stocks: the Northern Stock (Ireland and the Bay of Biscay) and the Southern Stock (Atlantic coast of the Iberian Peninsula).

20. The minimum landing size was introduced into regulations in 1989. This has produced a structural break in the length distribution series: before 1989 half of the individuals were below 27 cm, but since 1989 the proportion of these individuals in the landing has decreased sharply.

ved (ICES Annual Report 2003). However, STECF considers that more investigations are needed to define appropriate biological points, although it agrees with the ICES advice that a recovery plan should be applied (STECF Review of Scientific Advice for 2004, section 2.33).

For more details about biological and technical characteristics of this fishery see the report by the ICES Working Group on the Assessment of Southern Stock of Hake, Monk and Megrim (WGHMM). Garza-Gil (1998) uses this fishery to illustrate how individual transferable *quotas* may help to achieve efficient exploitation in a multifleet setting. Garza-Gil *et al.* (2003) show with this fishery how a tax on effort can obtain socially optimum operating results [21].

5.1. Calibration

As in the European Anchovy stock, we choose the functional form for the gross growth function by estimating the dynamic resource equation for six alternative gross functions: Cushing, logistic, logistic with minimum viable population size (MVPS), extended logistic, Ricker and Gompertz. Given the non-linear character of these gross growth functions, the dynamic resource equation expressed in logarithms, equation (3.5), is estimated using non linear least squares. Data for the stock and total catches from 1982-2002 in the Southern Stock of Hake are used. These data were drawn up by the ICES WGHMM and are shown in Table A.2 in Appendix A. Table 5.1 shows the estimation results.

The estimation results in Table 5.1 point to the Ricker as being the functional form that best fits the data [22]. The Ricker function defines the gross growth function as $f(X_t) = X_t e^{r(1-X_t/K)}$, where $r > 0$ is the intrinsic growth rate and K represents environmental carrying capacity. The results of this estimation imply $\hat{r} = 0.3234$ and $\hat{K} = 138{,}448$. Both estimates are signif-

21. Our paper addresses the problem of efficient exploitation in a different manner than Garza-Gil (1998) and Garza-Gil *et al.* (2003). While she considers exploitation in the steady state, we analyze the transition from the initial situation to the steady state in the presence of productivity shocks.

22. Logistic function with MVPS and the extended logistic function are not considered suitable because the parameter estimates are not significantly different from zero. Cushing, Logistic and Gompertz functions fit the data well, but according to the Akaike criterion, the Cushing function was chosen because it presents the lowest sum of squared errors in the parameters and the estimated biological aggregates are sensitive. The P-test of Davidson and MacKinnon (1981) was unhelpful in this context.

TABLE 5.1: Estimations for the Southern Stock of Hake

Estimation		t-statistics	Sum Square Error
Cushing Function $f(X_t) = AX_t^{\alpha}$			
MSY = 13,326 X_{MSY} = 111,293 MCC = 320,468			
A	3.8793	28.134676*	0.052878
α	0.8931	2.9820643*	
Logistic Function $f(X_t) = rX_t\left(1 - \frac{X_t}{K}\right) + X_t$			
MSY = 12,219 X_{MSY} = 65,374 MCC = 130,748			
r	0.3738	9.8149288*	0.052428
K	130,749	5.0834094*	
Logistic with MVP $f(X_t) = rX_t\left(\frac{X_t}{K_0} - 1\right)\left(1 - \frac{X_t}{K}\right) + X_t$			
MSY = –110,335 X_{MSY} = 453,612 MCC = 638,286			
r	–0.3836	–3.1926058*	0.052408
K	638,286	0.079101568	
K_0	142,126	0.768117981	
Extended Logistic $f(X_t) = rX_t^{\alpha}\left(1 - \frac{X_t}{K}\right) + X_t$			
MSY = 12,168 X_{MSY} = 69,334 MCC = 146,516			
r	1.0347	0.21310542	0.052303
α	0.8983	1.91120203	
K	146,516	1.5106097	
Ricker Function $f(X_t) = X_t e^{r(1 - X_t/K)}$			
MSY = 12,172 X_{MSY} = 66,352 *MCC* = 138,448			
r	0.3234	10.529445*	0.052407
K	138,448	4.7900225*	
Gompertz Function $f(X_t) = rX_t \ln\left(\frac{K}{X_t}\right) + X_t$			
MSY = 12,851 X_{MSY} = 96,665 MCC = 262,762			
r	0.1329	3.4292341*	0.052754
K	262,762	1.7779578*	

* Statistics significant at the 5% level.

icantly different from zero at the 5% level with *t* statistics of 10.5294 and 4.7900 for *r* and *K*, respectively. With these estimations of the parameters *r* and *K*, the MSY is 12,172 Tn, the biomass required for the MSY is 66,352 Tn and the MCC is 138,448 Tn. We can observe that current stock, at about 27,074 Tn in 2002, is far below that required to maintain MSY. This supports the ICES prediction of current stock being outside safe biological limits and the recommendation for zero captures in order to rebuild the stock.

Once these parameters are estimated, the stochastic process is calibrated in such a way that the sequence of productivity shocks reproduces the stock and total catches observed from 1982 to 2002. In order to do this, we take seven equidistant values for the state of the productivity shock, that is

$$z \in \{-0.0988, -0.0659, -0.0329, 0.0000, 0.0329, 0.0659, 0.0988\}$$

Given the information from the estimated errors, $\hat{z}$ and the values for the states of *z*, we calculate the transition matrix, π, for the Markov chain that discretes a continuum process in seven states following Tauchen (1986). The calibrated values are

$$\pi\ (z, z') = \begin{pmatrix} 0.0001 & 0.0205 & 0.1356 & 0.3460 & 0.3433 & 0.1325 & 0.0220 \\ 0.0010 & 0.0299 & 0.1687 & 0.3686 & 0.3134 & 0.1035 & 0.01496 \\ 0.0024 & 0.0424 & 0.2046 & 0.3829 & 0.2789 & 0.0789 & 0.01006 \\ 0.0045 & 0.0585 & 0.2419 & 0.3877 & 0.2419 & 0.0585 & 0.00676 \\ 0.0079 & 0.0789 & 0.2789 & 0.3829 & 0.2046 & 0.0424 & 0.00456 \\ 0.0128 & 0.1035 & 0.3134 & 0.3686 & 0.1687 & 0.0299 & 0.00326 \\ 0.0198 & 0.1325 & 0.3433 & 0.3460 & 0.1356 & 0.0205 & 0.00236 \end{pmatrix}$$

where $\pi_{i,j} = Pr\ [z = z_i \mid z' = z_j]$.

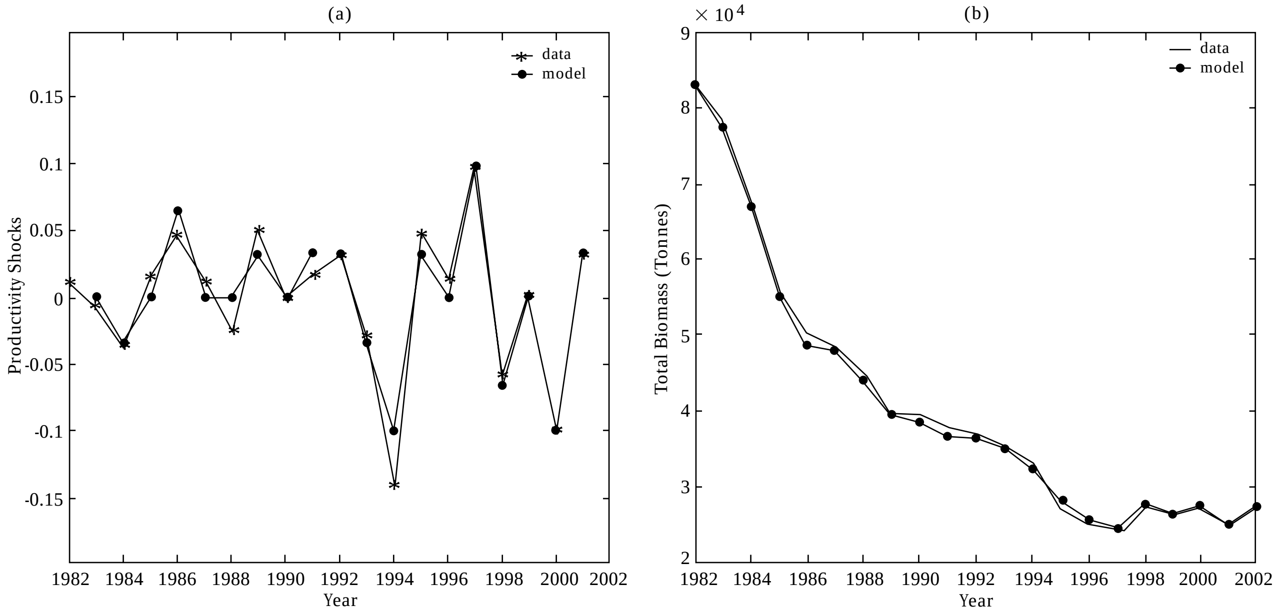
Graphic 5.1 illustrates the observed and calibrated productivity shocks and stock, in panels (a) and (b) respectively, from 1982 on. For the data from this fishery, deviations in the observed paths for stock and catches from those implied for the model are minimal.

In calibrating the capturability function we follow Garza-Gil (1998), who considers there to be two different fleets operating in this fishery. Each fleet, $i = 1,2$, fishes with the following production function,

$$y_{i,t} = \xi_{i,t}^{\theta_i}\ X_t^{\lambda i}$$

where ξ_i is the effort applied by fleet *i* and θ_i and λ_i are the elasticity of fleet *i*'s captures with respect to effort and stock, respectively. The two fleets are

GRAPHIC 5.1: Southern Hake Dynamics (a) productivity shocks *(z_t)*; (b) biomass dynamics *(X_t)*



heterogeneous in the sense that the inputs behind the effort are different for the two fleets. In particular, effort is given by

$$\xi_{1,t} = d_{1,t}^{\gamma_1} T_t^{\gamma_2} \quad (5.1)$$
$$\xi_{2,t} = d_{2,t} \quad (5.2)$$

where d and T represent days operating in the fishery and vessel capacity, respectively. Fleets 1 and 2 represent the trawler and the artisanal fleet, respectively. Parameters γ_1 and γ_2 represent the elasticity of the trawler fleet's effort with respect to the number of days fishing and the capacity of its vessels, respectively. Observe that with these production functions and the sharing rule we can express effort in fishery 2 as a function of effort in fishery 1,

$$p_1 - \frac{w_1 \xi_{1,t}}{\theta_1 y_{1,t}(\xi_{1,t}, X_t)} = p_2 - \frac{w_2 \xi_{2,t}}{\theta_2 y_{2,t}(\xi_{2,t}, X_t)} \Rightarrow \xi_2 = \xi_2(\xi_{1,t}, X_t)$$

Table 5.2 indicates the capturability and market parameters used for our analysis. The parameters come from Garza-Gil (1998), where it can be seen how they are obtained along with their statistical properties. Note that the estimated parameters show that the larger the stock is, the lower the share of the trawl fleet in total catches will be [23].

TABLE 5.2: Southern Hake Fleets

Trawler (Fleet 1)	
Value	**Parameters**
$\theta_1 = 0.64313$	Elasticity of trawl effort (days per GRT)
$\lambda_1 = 0.18324$	Elasticity of Stock (Tn)
$p_1 = 4{,}346.2$	Euros per Tn
$w_1 = 205.507$	Euros per day and GRT
$\gamma_1 = 0.16729$	Trawl Effort function
$\gamma_2 = 0.83271$	Trawl Effort function
Artisanal (longline and fixed gillnet) (Fleet 2)	
Value	**Parameters**
$\theta_2 = 0.18874$	Elasticity of trawl effort (days per GRT)
$\lambda_2 = 0.68537$	Elasticity of Stock (Tn)
$p_2 = 6{,}568.3$	Euros per Tn
$w_2 = 370.342$	Euros per day

Source: Garza-Gil (1998).

5.2. Evaluation of the Management of the Southern Stock of Hake

Now we can investigate whether the observed exploitation paths for 1982-2002 in the Southern Stock of Hake can be considered efficient given the initial conditions of the stock, $X_0 = X_{1982}$. To generate the dynamic transition from the initial situation to the stochastic steady state we solve the following dynamic programming,

$$V(z, X, Y_{min}, Y_{max}) = \max_{X', \xi_1, \xi_2} \sum_{i=1}^{2} \pi_i(z, X, X', \xi_i) + \beta E_{z'} \left[V(z', X', Y_{min}, Y_{max}) / z \right]$$

23. It is easy to prove that the relative share of fleet i in total captures is given by $(\lambda_i - \lambda_j) \xi_1^{\theta_1} \xi_2^{\theta_2} X^{\lambda_1 + \lambda_2 - 1}$, $\forall i \neq j$, which is negative provided $\lambda_i < \lambda_j$.

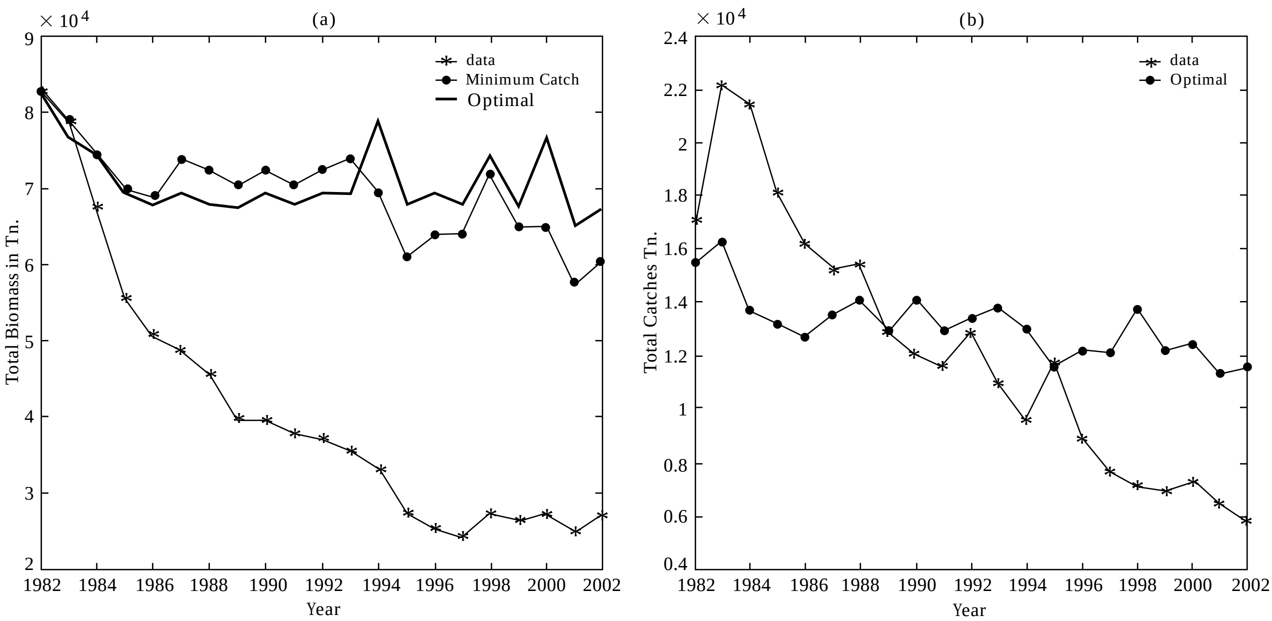
$$s.t. \begin{cases} \Sigma_{i=1}^{2} \xi_i^{\theta_i} X^{\lambda_i} = e^z e^{r\,(1-X/K)}\, X - X' \geq 0 \\ Y = \Sigma_{i=1}^{2}\, \xi_i^{\theta_i} X^{\lambda_i} \\ z \in \, [z_1, z_2, z_3, z_4, z_5, z_6, z_7],\, \pi\ (z, z') \\ Y \in \{Y_{min}, Y_{max}\} \end{cases}$$

where the profits are given by

$$\Pi_i\ (z, X, X', \xi_i) = p_i \xi_i^{\theta_i} X^{\lambda_i} - w_i \xi_i$$

We solve the dynamic program without restriction (Y_{min} = 0) and with a lower bound on catches (Y_{min} = 5,000 Tn). Optimal paths for the stock in both cases and real data are shown in Graphic 5.2, panel (a). We can see that optimal exploitation would have maintained the stock fairly constant with oscillations between 80,000 Tn and 60,000 Tn. These oscillations are smaller if the minimum catch bound is not considered. Comparing the optimal stock paths with the data we can conclude that the Southern Stock of Hake has been managed in a very inefficient way. This is consistent with the ICES position that the stock is outside safe biological limits and that it should be rebuilt. Since the optimal path associated with a minimum catch of 5,000 Tn is consistent with the current ICES objective, we decided to use it as our benchmark for the rest of our simulations.

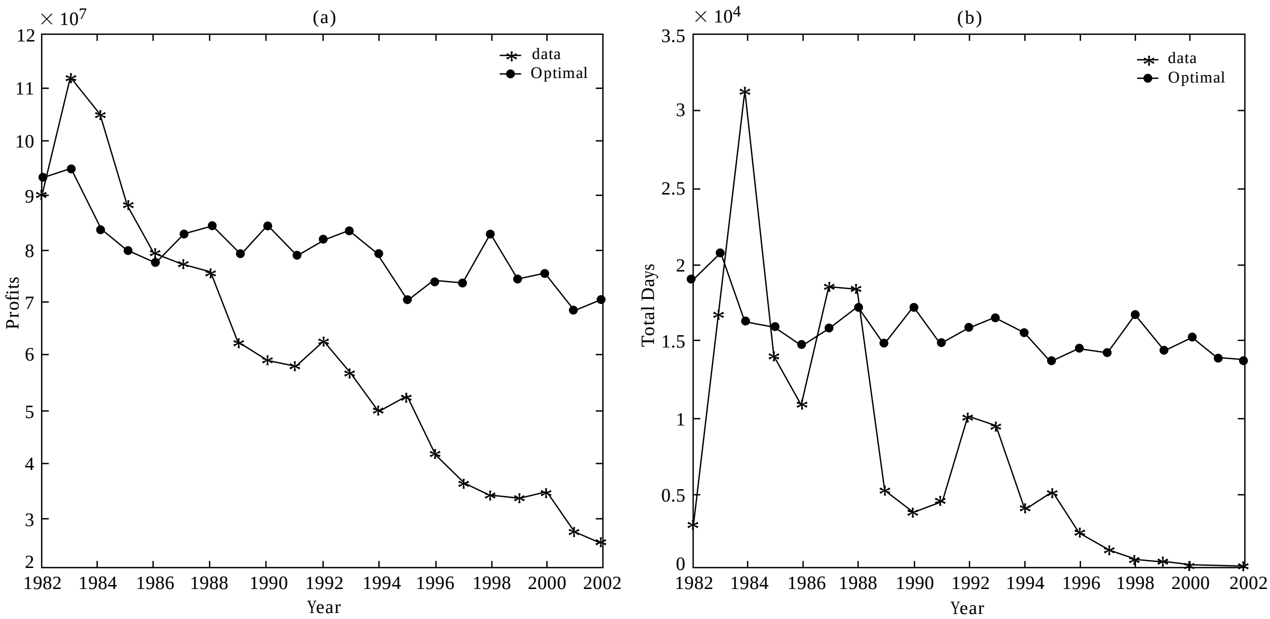
GRAPHIC 5.2: **Southern Stock of Hake: (a) Optimal Stock vs data, (b) Optimal Catches vs data with minimum catches of 5,000 Tn**



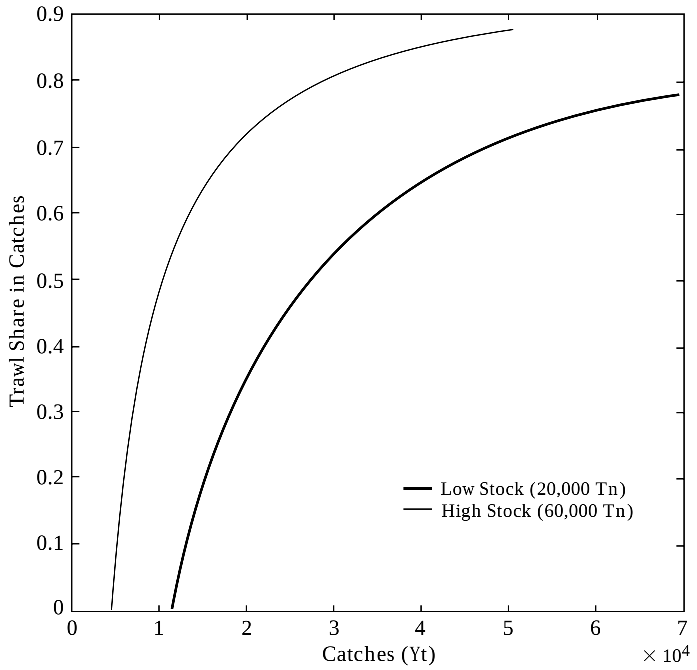
Graphic 5.2, panel (b), illustrates the optimal evolution of catches in the benchmark case and actual catches. Results show that until 1989 catches were greater than they should have been for optimal exploitation. In particular, in 1983 catches were about 23,000 Tn when optimal exploitation called for 16,000 Tn. This excess of catches during the 1980's resulted in the depletion of stock. In 2002 biomass was about 27,000 Tn while optimal exploitation would have led to a resource stock of 60,000 Tn.

Graphic 5.3 in panel (a) illustrates the path of aggregate profits associated with optimal exploitation, with catch restrictions and with the observed data. Results show that optimal exploitation would have implied low variability in aggregate profits over the period analyzed. By contrast, observed profits dropped drastically in the fishery due to the overexploitation of the stock in the early 1980s. In particular, we see that if the fleets had fished efficiently profit in 2002 would have been almost 2.8 times the observed level. A similar pattern appears in panel (b), where the effort of the artisanal fleet is shown. We see that the artisanal fleet has reduced its effort enormously; however, optimal management of the fishery would have enabled the initial level of effort to be maintained with no great variation.

GRAPHIC 5.3: Southern Stock of Hake: (a) Profits with minimum catches of 5,000 Tn, (b) Total Effort of Artisanal fleet (days) vs data with minimum catches of 5,000 Tn



GRAPHIC 5.4: Southern Stock of Hake: Capturability functions



Graphic 5.4 illustrates the efficient sharing of total catches between the two fleets. This illustration is presented for two different levels of the resource stock: a low stock (20,000 Tn) which represents a level close to current stock, and a high stock (60,000 Tn) which is close to the optimal level. We observe several points. Firstly, the larger the total catches are the larger the share for the trawler fleet is (i.e. the capturability function is increasing). The intuition for this result is clear. When catches are low the more efficient (artisanal) fleet fishes most of them; however, as catches increase, the trawler fleet increases its catches by a greater proportion because the artisanal fleet reaches its maximum capacity. Secondly, the higher the resource stock is, the lower the participation of the trawler fleet is in total catches. This is because an increase in stock implies more catches and, therefore, a more than proportional increase in the catches of the less productive fleet (trawlers). And third, for levels of stock and catches close to the optimal levels (i.e. stock close to 60,000 Tn and catches about 12,000 Tn), the optimal sharing of catches implies that only the artisanal fleet would operate in the fishery.

Table 5.3 quantifies the deviations of the observed catches and stock from the efficient ones in aggregate discounted terms. Aggregate catches are 18,000 Tn less than optimal when restrictions in catches are considered. This means that aggregate catches have deviated by no more than 6% from optimal ones. However, Graphic 5.2 shows the timing of the fishing was not appropriate. Overexploitation of the resource in the early 1980s reduced the stock enormously and this led to the reduction of catches in the 1990s. This process has led to stock being less than half the optimal level. In terms of aggregate profits, the fishery has lost more than 317 million euros, which represents 35% of the current profits. However, this loss has not been shared out evenly among fleets. While the trawler fleet has increased its profits by more than 214 million euros (93%), the artisanal fleet has lost more than 531 million euros (80%). To summarize, we can see that the Southern Stock of Hake has been overexploited. This has dissipated profits but has also reduced artisanal participation.

TABLE 5.3: Optimal Stock, Catches and Profits for the Southern Stock of Hake

	Data	Optimal	Min. Catch
Catches and Stock [1]			
$\sum_{t=1982}^{2002} Y_t$	257,438	258,639	275,759
$\sum_{t=1982}^{2002} y_t^{trw}$	107,828	11,960	4,852
$\sum_{t=1982}^{2002} y_t^{art}$	246,610	246,679	270,907
X_{2001}	27,074	67,500	60,500
Profits [2]			
$\sum_{t=1982}^{2002} \beta^{t-1982} \Pi_t$	889.61	1176.30	1206.14
$\sum_{t=1982}^{2002} \beta^{t-1982} \pi_t^{trw}$	229.17	33.38	14.19
$\sum_{t=1982}^{2002} \beta^{t-1982} \pi_t^{art}$	660.44	1142.92	1191.95

[1] Tons of Hake.
[2] Million Euros.

6. The Northern Stock of Hake

THE objective of this section is to quantify the losses associated with the exploitation of the Common Fisheries Policy (CFP) in regard to the Northern Stock of Hake from 1986 to 2001. This is a common fishing ground regulated by the CFP which is formed mainly by ICES zones VII and VIII [24] and is exploited by the Spanish and French fleets.

Hake has been the main species supporting trawling fleets off the Atlantic coasts of France and Spain since the 1930s, and it is present in the catches of nearly all fisheries in sub-areas ICES VII and VIII. In 2000, Spain took 61% of the catches, France 22%, the UK about 6% and Ireland 4% [25]. Hake is caught throughout the year, though the peak landings are made in the spring-summer months. The three main gear types used by vessels fishing for hake as a target species are lines (Spain), fixed-nets and other trawls (all countries). Hake spawn from March to July at depths of 120-160 m, mainly to the south and west of Ireland. They move to shallower water by September. The two major nursery areas are the Bay of Biscay and off southern Ireland. As they become mature, they disperse to offshore regions of the Bay of Biscay and the Celtic Sea. Male hake mature at 3-4 years old (27-35 cm) and females at 5-7 years old (50-70 cm).

Like all the main stocks of the European Union, the Northern Stock of Hake is managed by TAC and *quotas* with associated technical measures. During the period analyzed the Commission allocated an average of 55% of the TAC to France, 30% to Spain, 11% to the UK and 3% to Ireland (see Da Rocha and Gutiérrez, 2004). The minimum legal sizes for fish caught in this area is 27cm total length.

Biomass dropped from about 290,000 Tn in the early 1980s to 170,000 Tn in 2001 (see Table A.3 in Appendix A). This reduction was re-

---

24. The Northern Stock of Hake is formed by ICES areas IIa, IIIa,b,c,d, IV, Vb, VI, VII and VIIIa,b,d,e. However catches from areas VII and VIII represent more than 90% of total catches of the whole stock.

25. Data from Table 5.1.1. in Report ICES CM 2002/ACFM:05.

flected in catches, which dropped from 60,000 Tn to 37,000 Tn in the same period. In October 2000, the ICES Advisory Committee for Fisheries Management considered that the stock was outside safe biological limits. In the light of ICES recommendations, an Emergency Plan was implemented by the Commission in June 2001 to recover the Northern Stock of Hake [26]. The objective is to reduce catches of small hake occurring in fisheries located in hake nursery areas. Nevertheless, these emergency measures do not apply to vessels less than 12 m in length which return to port within 24 hours of their most recent departure (Council Regulations 1162/2001, 2602/2001 and 494/2002). For more detailed information see the last report drawn up by the Working Group on the Assessment of Southern Stocks of Hake, Monk and Megrim (WGHMM) (Report ICES CM 2003/ACMF:01).

6.1. An Heterogeneous Multi-fleet Model

Section 3 shows how the stochastic approach can be implemented using a very simple model where the regulator considers all fleets equally. Since we want to introduce the possibility of political discrimination to analyze the optimality of the CFP, this model is extended. Moreover, we consider that the fleets are heterogenous in terms of productivity.

Assume that the dynamics of the aggregate level of catches in period t, $Y_t(L_t, X_t)$, depend upon the total effective effort, L_t, and the level of fish stock in this period, X_t. To introduce heterogeneity we make two assumptions. Firsty, we assume that the effective effort of each fleet is a function of its productivity, in particular we define the effective effort of country i as $l_i^{\theta_i}$ where θ_i represents the productivity parameter of fleet i. Therefore, the total effort of the fishery can be expressed as

$$L_t = \sum_{k=1}^{n} l_{k,t}^{\theta_k}$$

where n is the number of fleets fishing in the area. Secondly, each country i obtains a share of the total catches, a *quota* $s_{i,t}$, which is proportional to its share in the total effective effort. Formally,

$$s_{i,t} = \frac{y_{i,t}}{Y_t} = \frac{l_{i,t}^{\theta_i}}{L_t}\ ,\forall i = 1, ..., n$$

26. The proposal for the Recovery Plan was presented in June 2001 (COM(2001) 326 final), and in December 2002 was amended (COM(2002) 773 final).

These two assumptions allow us to express the production function of each country as a function of its own effort and that of the rest of the fleets, i.e. for each country $i = 1, ..., n$,

$$y_{i,t}(l_{1,t}, ..., l_{n,t}, X_t) = \frac{l_{i,t}^{\theta_i}}{\sum_{k=1}^{n} l_{k,t}^{\theta_k}} Y_t(L_t, X_t), \forall i = 1, ..., n$$

Notice that this expression implies two different externality effects of the effort of one of the fleets over the catches of the other fleets. On the one hand a rise in the current effort of any fleet produces an increase in total current catches which reduces future stock and therefore future individual catches. So this intertemporal effect is negative provided $\partial Y_t / \partial X_t > 0$. On the other hand an increase in the effort of fleet j reduces the *quota* of any fleet $i \neq j$ but at the same time increases total catches. This is an intratemporal effect which is ambiguous whenever $\partial Y_t / \partial L_t > 0$ [27].

Let us suppose that the common fishery is managed by a benevolent regulator who maximizes the expected present discount value of the weighted future profits of the fleets,

$$E_0 \sum_{t=0}^{\infty} \beta^t (\gamma_1 \Pi_{1,t} + \gamma_2 \Pi_{2,t} + ... + \gamma_n \Pi_{n,t})$$

where E_t represents the expectation taken at time t and β is the discount factor. $\Pi_{i,t}$ represents the profit of fleet i in period t, defined as the difference between its catches, $y_{i,t}$, and the real effort cost (measured in units of fish), $\omega_i l_{i,t}$. γ_i is the exogenous weight of country i in the regulator's objective function. These weights can be interpreted as the political power of country i within the regulatory agency. A similar interpretation for the case of international environmental agreements can be found in Escapa and Gutiérrez (1997) [28].

An optimal policy for managing the resource, OCFP, is a path for stock and efforts $\{X_{t+1}, \{l_{i,t}\}_{i=1}^{n}\}_{t=0}^{\infty}$ that solves the following problem:

27. This assumption implies that, at any time, catches by one fleet depend on the effort of the other fleets. We consider that this is an acceptable approach in an aggregate analysis of the fleets but it may be difficult to approve in a micro-level study. In any case, we are aware that this model includes an extra externality that may overestimate the welfare gains from cooperation.

28. The need to introduce of political elements into fishery regulation was acknowledged by Emma Bonino, ex-Commissioner for Fisheries (see point 4 in the Memorandum on Questions raised by the preparation of the MAGP IV, 1997).

$$[OCFP] \equiv \begin{cases} \max_{\{X_{t+1},\, \{l_{i,t}\}_{i=1}^{n}\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t (\gamma_1 \Pi_{1,t} + \gamma_2 \Pi_{2,t} + \dots + \gamma_n \Pi_{n,t}) \\ s.t. \begin{cases} \Pi_{i,t} = y_{i,t}(l_{1,t}, \dots, l_{n,t}, X_t) - \omega l_{i,t} \\ y_{i,t}(l_{1,t}, \dots, l_{n,t}, X_t) = \dfrac{l_{i,t}^{\theta_i}}{\sum_{k=1}^{n} l_{k,t}^{\theta_k}} Y(L_t, X_t) \qquad \forall i = 1, \dots, n \\ X_{t+1} = F(X_t) - \sum_{i=1}^{n} y_{i,t}(l_{1,t}, \dots, l_{n,t}, X_t) \\ L_t = \sum_{i=1}^{n} l_{i,t}^{\theta_i} \end{cases} \end{cases}$$

The solution of this problem is a vector of effort $\{l^*_{i,t}\}_{i=1}^{n}$, and stock target X_{t+1}, such that, for each period t:

1. Given the current stock, X_t, total catches will be $Y_t(\Sigma_{i=1}^{n}(l^*_{i,t})^{\theta_i}, X_t)$.
2. In the next period, $t+1$, the stock target is sustainable. That is:
   $X_{t+1} = F(X_t) - Y_t(\Sigma_{i=1}^{n}(l^*_{i,t})^{\theta_i}, X_t)$.

The solution of the regulator's problem can be written in terms of *quotas*. Let us define $L^*_t(\gamma_1, \dots, \gamma_n, X_t) = \Sigma_{k=1}^{n}(l^*_{k,t})^{\theta_k}(\gamma_1, \dots, \gamma_n, X_t)$. Then the optimal *quotas* are given by

$$s^*_{i,t} = \frac{l^{*\theta_i}_{i,t}}{L^*_t(\gamma_1, \dots, \gamma_n, X_t)}, \ \forall i = 1, \dots, n$$

This means that different sets of weights in the regulator's objective function imply different *quotas* for the fleets. In other words, the system of *quotas* associated with the RSP can be understood as an efficient policy under a particular set of weights [29].

6.2. Calibration

The model is calibrated assuming that three fleets operate in the Northern Stock of Hake: Spain, France and the rest of the Union. We denote their variables with the subscripts *sp, fr* and *ru*, respectively. The model is calibrated to reproduce: (1) relative catches per unit of effort (c.p.u.e.) of the French and Spanish fleets in areas VII and VIII; (2) catches and biomass stock of the Northern Stock of Hake during the period 1978-2001; (3) *quotas* obtained from the average TAC's during the period 1986-2002; and (4) the target stock announced by Fischler's recovery plan.

29. See Da Rocha and Gutiérrez (2004) for an analysis of this issue in a deterministic context.

Calibration of biological resource equation parameters is based on available data for stock and total catches in the period 1978-2001 in the Northern Stock of Hake. These data were compiled by the Working Group on the Assessment of Southern Stocks of Hake, Monk and Megrim (WGHMM) from the ICES and are shown in Table A.3 in Appendix A. A stock-recruitment relation that follows a Cushing function is assuming, i.e.

$$F(X_t) = A_t X_t^{\alpha} \tag{6.1}$$

where parameter α represents the elasticity of the gross stock growth and A_t is a random variable that can be interpreted as the productivity of the resource at time t, which can change as a function of the state of nature. We assume that $A_t = e^{z_t} A$, where A is a constant and z_t is a random variable with mean zero which follows a Markov process, with a transition matrix, π.

The first step in calibration consists of estimating A and α from the biological equation expressed in logarithms,

$$\log (X_{t+1} + Y_t) = \log A + \alpha \log X_t + z_t$$

The results of estimation by OLS imply $\hat{A} = 12.8519$ and $\hat{\alpha} = 0.8095$. Both estimates are significantly different from zero (t statistics are 2.737856 and 10.683081 for A and α, respectively) and $R^2 = 0.845$ [30].

Once those parameters are estimated, the stochastic process is calibrated in such a way that the sequence of productivity shocks reproduces the stock and the total catches observed from 1978 to 2001 in the Northern Stock of Hake. In order to do this, we take five equidistant values for the state of the productivity shock, that is

$$z \in \{-0.1510, -0.0755, 0, 0.0755, 0.1510\}$$

Given the information from the estimated errors, $\hat{z}$ and the values for the states of z, we calculate the transition matrix, π, for the Markov chain that discretes a continuum process in five states (see Tauchen, 1986). The calibrated values are

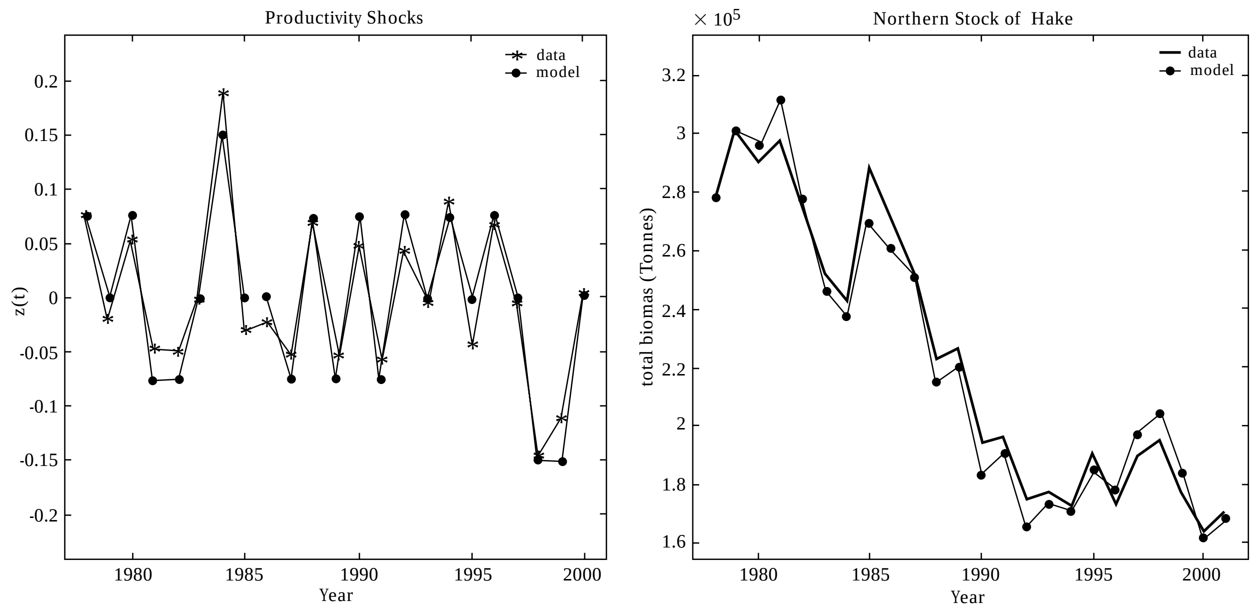
30. Other alternative functional forms for the dynamic resource equation, apart from Cushing, have been considered. The Cushing is the one that best fits the data.

$$\pi(z, z') = \begin{pmatrix} 0.0006 & 0.1991 & 0.5221 & 0.3164 & 0.0318 \\ 0.0035 & 0.1682 & 0.5428 & 0.2633 & 0.0222 \\ 0.0080 & 0.2133 & 0.5499 & 0.2133 & 0.0155 \\ 0.0146 & 0.2633 & 0.5428 & 0.1682 & 0.0111 \\ 0.0242 & 0.3164 & 0.5221 & 0.1291 & 0.0082 \end{pmatrix}$$

where $\pi_{j,i} = Pr\,[z_{t+1} = z_j \mid z_t = z_i]$.

Graphic 6.1 shows the observed and calibrated productivity shocks and stocks from 1978 on.

GRAPHIC 6.1: **Productivity Shocks and Biomass Stock in the Northern Stock of Hake**



To calibrate the capturability parameters, we assume that the total catches function is given by

$$Y_t = [1 - e^{-\lambda L_t}]\, F(X_t) \tag{6.2}$$

where λ is a capturability parameter.

In order to calibrate the productivity parameters, θ_{sp} and θ_{fr}, and the capturability parameter, λ, we use a two-step procedure. Firstly, we calibrate a parameter ϕ that reflects productivity differences between the Spanish and French trawler fleets using data from homogenous fleets. Secondly, θ_{fr} and λ are calibrated to target the French data on effort and catches. We follow this two-step procedure because we do not have effort data for the whole Spanish fleet.

To calibrate ϕ reflecting the differences in productivities when homogeneous fleets are considered we assume that effort is independent of the productivity parameters. Under this assumption we can express the relationship between effort and shares for the Spanish and French fleets as

$$\frac{s_{fr}}{s_{sp}} = \frac{l_{fr}^{\phi}}{l_{sp}} \tag{6.3}$$

In order to evaluate ϕ, we use data on c.p.u.e. by fleets provided by the WGHMM of the ICES and catches by fleets from the Instituto Oceanográfico de Vigo. In particular, the Spanish c.p.u.e. data correspond to the Coruña trawler fleet which operates in deeper waters close to the slope in division VIIb,c,j,k. The French c.p.u.e. data come from the FR-RESSGASCS survey conducted in the Bay of Biscay following French trawlers fishing in subarea VIIIa,b (see Table A.4 in Appendix A). Effort data can be calculated as catches / c.p.u.e. Shares for the trawler fleets have been calculated as the ratio of catches of each fleet in the area in which the reference trawler fleet fishes to total catches of the Northern Stock. However, since data on catches by fleets are available only for the years 1988-1990, we can only calculate effort and share data by fleets for those years. The data drawn up are summarized in Table 8 [31]. ϕ is calculated from equation (6.3) taking the average values in Table 8.

TABLE 6.1: **Effort and shares for trawl fleets [a] in the Northern Stock of Hake**

	Spain		France	
Year	**Effort [b]**	**Share**	**Effort [b]**	**Share**
1988	50.41	13.47	194.18	25.97
1989	43.75	11.40	152.12	29.79
1990	47.43	10.85	171.50	30.82
Average	47.20	11.93	172.60	28.82

[a] Drawn up from data in Table 16.
[b] Ships of 100 HP fishing 365 days.

31. We thank Javier Pereiro from the Instituto Oceanográfico de Vigo for making data available to us.

The capturability parameter, λ, and the productivity parameter for the French fleet, θ_{fr}, are jointly calibrated to reproduce the effort and catches data of the French fleet in sub-areas VII and VIII of the Northern Stock. To do this we use the capturability equation (6.2) expressing the total effort in terms of the French share and effort, that is

$$Y_t = [1 - e^{-\lambda (l_{fr}^{\theta_{fr}} / s_{fr})}] F(X_t)$$

We have data for the whole French fleet as regards effort and catches in sub-areas VII and VIII for 1988-1990 (see Table A.5 in Appendix A) [32]. Using these data, we have calculated λ and θ_{fr} so that the squared error associated with the above equation is minimized for 1988-1990. The results are $\lambda = 0.0061838352$ and $\theta_{fr} = 0.49$. We assume that Spanish productivity is proportional to the differences observed in the trawler fleet, i.e. $\theta_{sp} = \theta_{fr} / \phi$. This implies $\theta_{sp} = 0.53$. We also assume that the rest of the fleets that fish in the Northern Stock have the same productivity as the French fleet, that is $\theta_{ru} = \theta_{fr}$.

Finally, the weights in the regulator's objective function, γ_i's, and the real effort cost, ω, are calibrated jointly to reproduce the legal TACs and the target stock proposed in the Fischler recovery plan. This plan was approved in the Council Meetings held in December 2001 and June 2002 with the aim of recovering the stock of hake (see, Documents 15383/1 and 9557/02). In particular, the objective is to introduce a multiannual recovery plan for hake with a recovery period of seven to eight years and yearly increases in the biomass of 15%. Since the stock of hake in 2001 is approximately 171,000 Tn, this multiannual plan will recover the stock to around 450,000 Tn. We assume that a steady state situation will be reached when the stock has been recovered, i.e. when the stock reaches approximately 450,000 Tn.

As *quotas* for each fleet, we use the average of the legal *quotas* imposed by the CFP in areas VII and VIII during the period 1987-2002 adjusted to consider the whole Northern Stock of Hake. We know that the *quotas* imposed by the CFP in areas VII and VIII for this period are on average s_{sp} = 54.76%, s_{fr} = 30.06%, and s_{ru} = 15.18% (see Da Rocha and Gutiérrez, 2004). However areas VII and VIII only represent 93.72% of the catches in the Northern Stock of Hake. We also know that in 2000 catches outside

32. Unfortunately, we do not have these data for the whole Spanish fleet, so we cannot jointly calibrate the parameters in the biological resource equation and capturability equation.

areas VII and VIII were 9.52% for the Spanish fleet, 30.78% for the French fleet and 59.70% for the rest of the fleets (see Report ICES CM 2002, page 471). We have adjusted the data to obtain the *quotas* for the whole stock, i.e. s_{sp} = 51.92%, s_{fr} = 30.10%, and s_{ru} = 17.97%.

With these data, the calibration of the other parameters, and the assumption that β is 0.95, we use the equation system that characterize the steady state of the fishery (see equations (6.11), (6.12) and (6.13) in Appendix C) to find the values of γ_{sp}, γ_{fr}, γ_{ru} and ω that satisfy $\gamma_{sp} + \gamma_{fr} + \gamma_{ru} = 1$.

The calibration results are summarized in Table 6.2. Observe that the maximum sustainable yield (MSY) in our biological model is given by $MSY = \frac{1-\alpha}{\alpha}(\alpha A)^{1/(1-\alpha)}$, which can be sustained with a biomass of $X_{MSY} = (\alpha A)^{1/(1-\alpha)}$. Given the calibration of parameters α and A, this implies MSY = 51,444 Tn. The required biomass to maintain the MSY is X_{MSY} = 218,610 Tn.

TABLE 6.2: Calibrated Parameters in the Northern Stock of Hake

Parameter		Data
A	12.851905	Northern Stock of Hake, 1978-2001.
α	0.8095038	Northern Stock of Hake, 1978-2001.
ρ	–0.11741	Northern Stock of Hake, 1978-2001.
ϕ	0.91950	c.p.u.e. of Spanish (La Coruña) and French (RESSGASC) Trawls.
z and π	see text	Total catches in the Northern Stock of Hake, 1978-2001
θ_{fr}	0.49000	French effort in areas VII and VIII, 1988-1990.
λ	0.00618	French catches in areas VII and VIII, 1988-1990.
β	0.95000	interest rate 5%.
Parameter		**Targets**
γ_{fr}	1.2344	French TAC, s_{fr} = 0.30100.
γ_{sp}	–0.1266	Spanish TAC, s_{sp} = 0.51920.
γ_{ru}	–0.1078	Other Countries TACs, $s_{ru} = 1 - s_{fr} - s_{sp}$.
ω	439.8682	Fischler proposal criteria, X = 450,000.

6.3. Quantitative Experiments

In this section we explore how efficient the CFP was in the Northern Stock of Hake from 1986 to 2001. In particular, we ask: i) How would catches, biomass stock and profits have been if the OCFP had been implemented? ii) What would have happened if the optimal policy with side-payments had been implemented? The main findings in this section are: i) an OCFP would have generated more than 111,000 Tn of profits, which means more than 670 million euros, considering 6 euros/kilo as the price of hake and ii) a policy that allowed for side-payments (implemented by ITQ's, for example) would have increased these profits by 26%.

6.3.1. The efficiency of the CFP

In this section, we investigate whether the observed exploitation paths for 1986-2001 in the Northern Stock of Hake can be considered efficient given the *quotas* associated with the RSP, $\{\hat{s}_i\}_{i=1}^{n}$, and the initial conditions of the stock, $X_0 = X_{1986}$. To simulate the model we iterate the value function associated with the OCFP problem. Given a system of *quotas* $\hat{s}$, the dynamic program can be expressed as a function of the stock, X, and the state of nature z. Formally, the value function is given by

$$V(z, X \mid \hat{s}) = \max_{X'} \sum_{i=1}^{n} \gamma_i \Pi_i (z, X, X' \mid \hat{s}_i) + \beta E_{z'} [V(z', X' \mid \hat{s}) / z]$$

$$s.t. \begin{cases} Y = Ae^{z}X^{\alpha} - X' \geq 0 \\ z \in [z_1, z_2, z_3, z_4, z_5], \pi \end{cases}$$

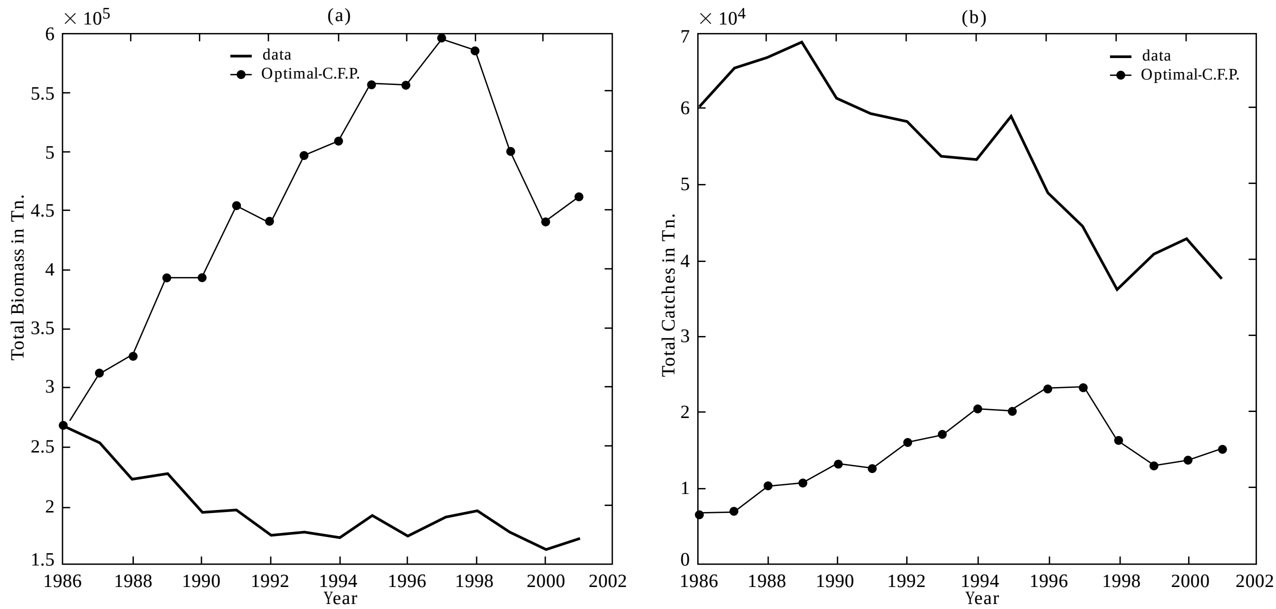
where the profits of each fleet are given by

$$\Pi_i (z, X, X' \mid \hat{s}_i) = \hat{s}_i Y - \omega \left[-\frac{\hat{s}_i}{\lambda} \ln \left(\frac{X'}{e^{z}AX^{\alpha}} \right) \right]^{1/\theta_i}$$

We calculate the OCFP using the calibrated parameters and simulate the optimal stock and catches paths associated with the stochastic shocks calibrated for the period 1986-2001. The results are illustrated in Graphics 6.2 (a) and (b), respectively.

We can see in Graphic 6.2 (a) that optimal exploitation led to a recovery of the stock until 1997, when it dropped again. Comparing this optimal path with the data we can conclude that the CFP has been a complete failure. In Graphic 6.2 (b) we can observe that until 1996, catches were greater than they should have been according to optimal exploitation. In particular, in 1986 catches were about 60,000 Tn when the optimal exploitation called for less than 10,000 Tn. The gap between the optimal and the observed catches was narrowed until 1997. However from then on this gap widened considerably. Therefore, the implementation of the CFP has been characterized by an excess of catches and effort that has depleted stocks and reduced prof-

GRAPHIC 6.2: CFP vs data in the Northern Stock of Hake: (a) Optimal Stock, (b) Catches



its. Table 6.3 shows the deviations of the observed exploitation paths from the optimal ones in aggregate terms. Catches are about 617,000 Tn more than optimal. This means that effective exploitation has deviated by more than 260% from the efficient policy. This overexploitation has depleted stocks. In 2001 biomass was about 170,000 Tn while optimal exploitation would require a resource stock of 462,000 Tn.

TABLE 6.3: Observed and Optimal C.F.P. in the Northern Stock of Hake

	Data	**Optimal C.F.P.**
$\Sigma_{t=1987}^{2001} Y_t$	854,991	237,597
X_{2001}	171,353	462,000
$\Sigma_{t=1987}^{2001} \beta^{t-16}\Pi_t$		111,698

This overexploitation of the stock has dissipated profits. If the fleets had fished efficiently the present value of the future profits would have been 111,698 Tn of resources, which means more than 670 million euros, considering 6 euros/kilo as the price of hake. Moreover, when the profits associated with the observed data for the whole period are calculated and considering the effort cost calibrated to match the target stock of the Commission, we observe that they are negative. This result is typical in open access fisheries. Therefore, we can assume that fleets are in fact operating in a situation of open access and profits are zero. This means that the inefficient exploitation of the Northern Stock of Hake has resulted in a monetary loss of more than 670 million euros.

6.3.2. Optimal Side-Payments

In this section we compare the OCFP associated with the *quotas* imposed by the Community according to the RSP with optimal exploitation in the case in which side-payments among fleets are allowed. Formally this solution is called the first optimum. It corresponds to the OCFP for cases where the regulator does not discriminate between the fleets, that is when $\gamma_i = 1/n$.

From the technical point of view, this solution could be implemented by the European Commission through a system of individual transferable *quotas* (ITQs). Observe that assigning a *quota* for catching a specified amount of fish to a fleet can lead to the first optimum provided this *quota* is transferable and divisible. In this case, each holder of the *quota* has a private property right to the fish and could sell or lease part or all of the *quota* to other fleets and receive the discounted future profit from the use of the *quota*. This may mean that over time an arbitrary distribution of *quotas*, for instance the *quotas* associated with RSP, should lead to the first optimum of effort and harvest.

TABLE 6.4: Optimal shares with side payments ($\gamma_i = 1/3$) in the Northern Stock of Hake

shares		
s^*_{fr}	0.2853	$\theta_{fr} = 0.4900$
s^*_{sp}	0.4294	$\theta_{sp} = 0.5329$
s^*_{ru}	0.2853	$\theta_{ru} = 0.4900$

Table 6.4 shows the *quotas* associated with OCFP as a result of side-payments between fleets. In other words, the Commission can share out the TAC among fleets *a priori* according to the RSP; however, if side-payments are allowed, then the TAC is shared out *a posteriori*, as Table 6.4 indicates. We can observe that the results imply a large redistribution of catches between countries. In particular there is a significant reduction of France's *quota* in favor of Spain and the rest of the Union.

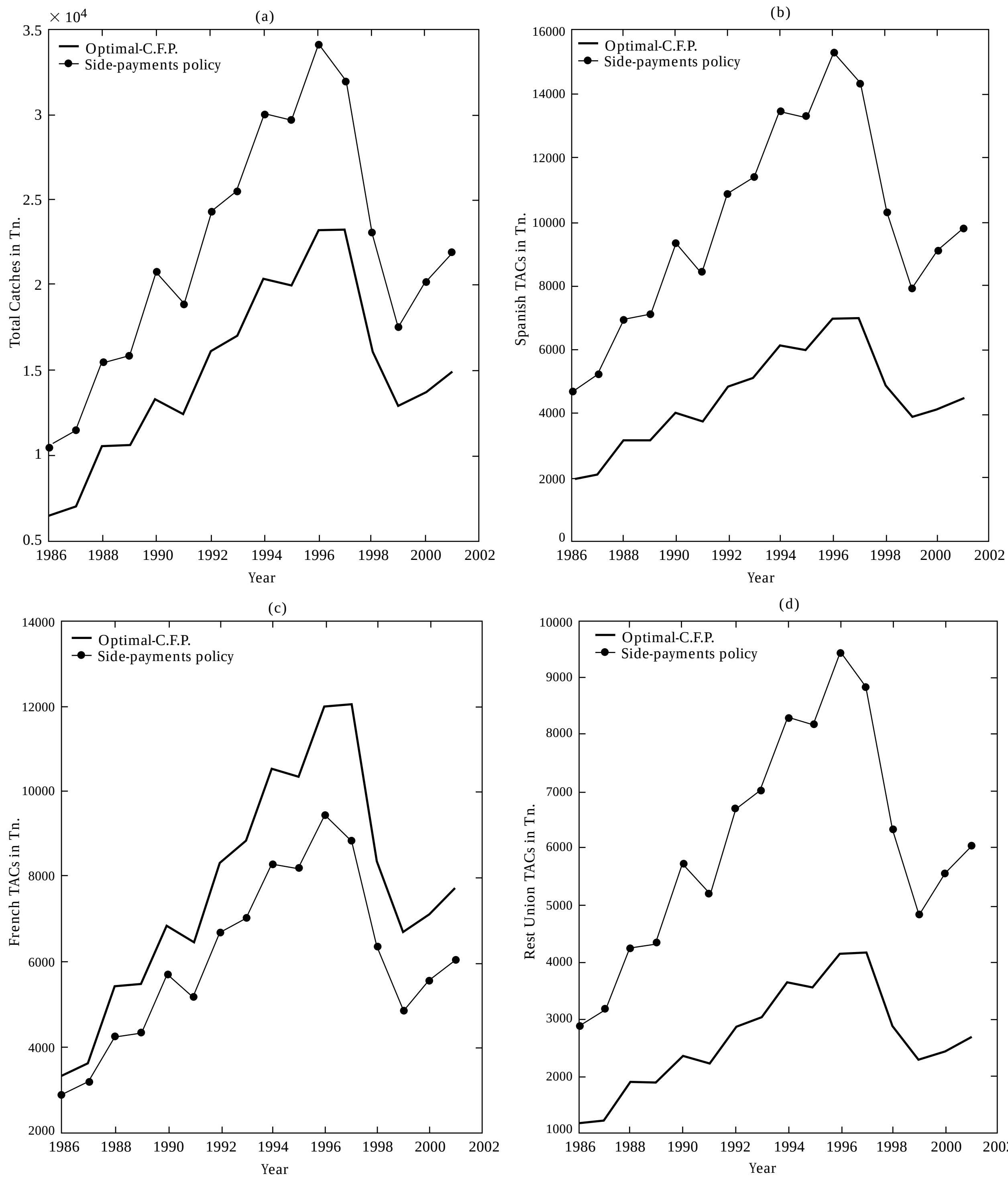
This result can also be observed in Graphic 6.3, where catch paths for each of the policies considered are illustrated. Panel (a) shows that in aggregate terms the OCFP generates lower catches than the side-payments solution for all periods. The intuition for this result is clear; the side-payment solution is the optimal solution in which aggregate profits are maximized and it therefore allows more catches. However, the redistribution of the TAC among fleets is uneven. We can observe in panels (b), (c) and (d) that the side-payments solution pushes France's catches below the OCFP policy level while those of Spain and rest of the Union are above that level.

TABLE 6.5: Side-Payments vs. Optimal C.F.P. in the Northern Stock of Hake

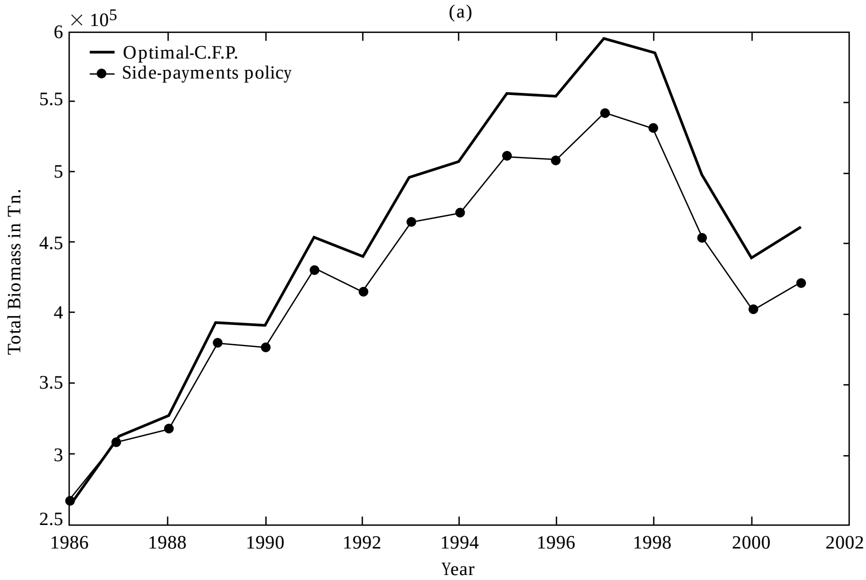
	Optimal C.F.P.	Side-payments
Catches and Stock		
$\Sigma_{t=1987}^{2001} Y_t$	237,597	351,282
X_{2001}	462,000	422,000
Profits		
$\Sigma_{t=1987}^{2001} \beta^{t-16} \pi_t^{fr}$	49,514	42,660
$\Sigma_{t=1987}^{2001} \beta^{t-16} \pi_t^{sp}$	37,534	54,956
$\Sigma_{t=1987}^{2001} \beta^{t-16} \pi_t^{ru}$	24,650	42,660
$\Sigma_{t=1987}^{2001} \beta^{t-16} \Pi_t$	111,698	140,276

Table 6.5 shows the results of the OCFP and side-payments policy in quantitative terms. Several points can be observed. Firstly, if side-payments had been allowed, the stock would not have recovered as much as with the OCFP. In particular, the stock would be about 422,000 Tn in 2001. Secondly, with side-payments the capture path would have been less severe than that implied by the OCFP. Observed catches deviate by 504,000 Tn from the side payments policy compared to 617,000 Tn from the OCFP. Thirdly, with side-payments the present value of total profits is 26% greater than under the OCFP. Moreover, this increase in total profits is shared out differently among countries: Spain and the rest of the Union increase their profits by 46% and 73%, respectively, while France's profits drop by 14%. Graphic 6.4 compares the trends in stock and annual increase in profits under the OCFP and side-payments policies. It is easy to show that the implementation of an optimal policy with side-payments generates greater profits year by year (the increase is more than 35% for some years). This rise in profits is due to a more efficient exploitation of the resource, which allows lower levels of stock to be maintained.

GRAPHIC 6.3: Optimal TAC's in the Northern Stock of Hake. (a) Total; (b) Spain; (c) France; (d) Rest of Union



GRAPHIC 6.4: Side-Payments vs CFP in the Northern Stock of Hake: Optimal Stock



7. Discussion

ANY dynamic model used to evaluate the management of a fishery must be able to reproduce a biomass path that is compatible with observed catches and stock paths. We propose an alternative stochastic approach where the stock growth path is affected by productivity shocks that follow a Markov process. The advantage of this approach is that it allows us to reproduce the stylized facts of the fishery more accurately than the traditional deterministic approach.

The existence of stochastic productivity shocks has policy recommendation implications, in both form and substance. For instance, if resource productivity depends on past productivity, both efficient TACs and sharing out depend on the size of the biomass and productivity shocks. Consequently, wide fluctuations in the biomass level do not neccesarily imply that the fishing ground is being overexploited. This is the case of the European Anchovy fishery, whose species suffers marked oscillations in productivity due to its biological cycle. Our analysis indicates that efficient management consists of allowing high TACs in years with high productivity shocks. However, since the available capacity of the fleet is restricted, the catches have an upper limit. This means keeping the TAC constant, as the ICES recommends, and letting the stock fluctuate is the efficient policy.

However, maintaining rules constant over time is not generally the right way to manage a fishery. TACs must adjust to productivity shocks. Moreover, if several fleets operate in the fishery the relative capture *(quotas)* of each fleet also has to vary over time with productivity changes. This is the case of the European Stock of Hake, where different heterogeneous fleets operate. For the Southern Stock of Hake, our results show that the larger the stock is the larger the share of the artisanal fleet must be. This is because the artisanal fleet obtains a higher quality product with a cost that drops substantially when the stock of the resource increases. Therefore, given that relative captures of each fleet change over time, implementing an ITQ system that allows captures to be shared out in a permit market each year seems a reasonable instrument for managing fisheries with heterogeneous fleets. For the Northern Stock of Hake we show that a policy that would have allowed side-payments among the fleets of different countries would have significantly increased the profitability of the fishing ground.

On the other hand, if our aim is to evaluate the benefits associated with the implementation of an ITQ system, we cannot limit the analysis to comparing steady states calculated from parameter estimations that do not adequately reproduce the resource dynamics. A correct assessment of the potential benefits from the implementation of ITQ systems must consider *quotas* as variables that depend on the size and productivity of the biomass because the participation of each fleet depends on relative productivity. In the case of the Southern Stock of Hake the artisanal fleet, whose productivity increases with the stock, would buy all the permits in the auction as long as the stock reaches the efficient value. At the same time, the participation of the trawler fleet would drop from the current level to zero. In the Northern Stock of Hake the Spanish fleet, with higher productivity, would increase its participation while the French fleet would drop from the current level.

References

AMUNDSEN, E. S., T. BJØRNDAL and J. M. CONRAD (1995): Open Access Harvesting on the Northeast Atlantic Minke Whale, *Environmental and Resource Economics*, 6, 167-185.

ANDROKOVICH, R. A. and K. R., STOLLERY (1989): Regulation of Stochastic Fisheries: A Comparison of Alternative Methods in the Pacific Halibut Fishery, *Marine Resource Economics*, 6, 109-22.

AZTI Instituto Tecnológico Pesquero y Alimentario (2004): in Season Assessment of Anchovy in the Bay of Biscay.Commission Staff Working Paper, SEC(2004) 180.

BONINO, E., (1997): *Memorandum on Questions Raised by the Preparation of the MAGP IV.*

CLARK, C. W. (1990): *Mathematical Bioeconomics. The Optimal Management of Renewable Resources*, John Wiley & Sons (2nd ed.), New York, NY.

CONRAD, J. M. (1999): *Resource Economics*, Cambridge University Press, Cambridge, MA.

COUNCIL MEETING 2435th OR(2002): of 11 June 2002 9557/02 (Presse 172).

COUNCIL MEETING 2400th OR(2001): of 17 December 2001 15383/01 (Presse 477-G).

COUNCIL REGULATION COM(2002): 773, final of 20 December 2002, *Amended Proposal for a Council Regulation on the Establishing Measures for the Recovery of Cod and Hake Stocks.*

COUNCIL REGULATION COM(2001): 326, final of 12 June 2001, *Communication from the Commission to the Council on the European Parliament on the Rebuilding Stocks of Cod and Hake in Community and Adjacent Waters.*

COUNCIL REGULATION COM(2002): 181, final of 28 May 2002, *Communication from the Commission on the Reform of the Common Fisheries Policy ("Roadmap").*

COUNCIL REGULATION (EC) No 2287/2003 of 19 December 2003 on *Fixing for 2004 the Fishing Opportunities and Associated Conditions for Certain Fish Stocks and Groups of Fish Stocks, Applicable in Community Waters and, for Community Vessels, in Waters where Catch Limitations are Required.*

COUNCIL REGULATION (EC) No 494/2002 of 19 March 2002 on the *Establishing Additional Technical Measures for the Recovery of the Stock of Hake in ICES sub-areas III, IV, V, VI and VII and ICES divisions VIIIa,b,d,e.*

COUNCIL REGULATION (EC) No 2602/2001 of 27 December 2001 on the *Establishing Additional Technical Measures for the Recovery of the Stock of Hake in ICES sub-areas III, IV, V, VI and VII and ICES divisions VIIIa,b,d,e.*

COUNCIL REGULATION (EC) No 1162/2001 of 14 June 2001 on *Establishing Measures for the Recovery of the Stock of Hake in ICES sub-areas III, IV, V, VI and VII and ICES divisions VIIIa,b,d,e and Associated Conditions for the Control of Activities of Fishing Vessels.*

Council Regulation (EC) No 2371/2002 of 20 December 2002 on *Conservation and Sustainable Exploitation of Fisheries Resources under the Common Fisheries Policy. Official Journal of the European Communities*.

Cox, D. R. and T., Hastie (1980): *Problems and Solutions in Theoretical Statistics,* Chapman and Hall, California.

Danielsson, A.(2002): Efficiency of Catch and Effort *Quotas* in the Presence of Risk, *Journal of Environmental Economics and Management,* 43, 20-33.

Da Rocha, J. M. and M. J. Gutiérrez (2004): La Reforma del Principio de Estabilidad Relativa en la Política Pesquera Comán: El Caso del Caladero Norte de Merluza, *Revista de Economía Aplicada,* vol. XII (36), 113-146.

— (2005): The Optimality of the Common Fisheries Policy: the Northern Stock of Hake, *Spanish Economic Review* (forthcoming).

Danielsson, A. (2002): Efficiency of Catch and Effort Quotas in the Presence of Risk, *Journal of Environmental Economics and Management*, 43, 20-33.

Davidson, R. and J. G. MacKinnon (1981): Several test for model specification in the presence of alternative hypothesis, *Econometrica,* 49, 781-793.

Del Valle, I., I. Astorkiza and K. Astorkiza (2001): Is the Current Regulation of the VIII Division European Anchovy Optimal?, *Environmental and Resource Economics*, 19, 53-72.

Escapa, M. and M. J. Gutiérrez (1997): Distribution of Potential Gains from International Environmental Agreements: The Case of the Greenhouse Effect, *Journal of Environmental Economics and Management,* 33, 1-16.

Flaaten, O. and K.. Stollery (1996): The Economic Costs of Biological Predation, *Environmental and Resource Economics,* 8, 75-95.

Garza-Gil, M. D. (1998): ITQ Systems in Multifleet Fisheries. An Application for Iberoatlantic Hake, *Environmental and Resource Economics,* 11, 79-92.

Garza-Gil, M. D., M. M. Varela-Lafuente and J.C. Surís-Regueiro (2003): European Hake Fishery Biobeconomic Management (Southern Stock) Applying and Effort Tax, *Fisheries Research,* 60, 199-206.

Grafton, R. Q., L. K. Sandal and S. I. Steinshamn (2000): How to Improve the Management of Renewable Resources: The Case of the Canada's Northern Cod Fishery, *American Journal of Agricultural Economics,* 82, 570-580.

Hanley, N., Shogren, J. F. and B. White (1997): *Environmental Economics: In Theory and Practice*, MacMilan Press, London, UK.

ICES (2003): Annual Report of the ICES Advisory Committee on fishery Management. Cooperative Research Report No 261.

ICES Annual Report of the ICES Advisory Committee on fishery Management. Cooperative Research Report No 255.

ICES CM 2004/ACFM:02. Report elaborated by the Working Group on the Assessment of Southern Stock of Hake, Monk and Megrim.

ICES CM 2004/ACFM:08. Report elaborated by the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy.

ICES CM 2003/ACFM:01, *Report of the Working Group on the Assessment of Southern Stocks of Hake, Monk and Megrim.*

ICES CM 2002/ACFM:05. *Report elaborated by the Working Group on the Assessment of Southern Shelf Demersal Stocks.* ICES Headquarters. 4-13 September (2001): Available in http://www.ices.dk/reports/ACFM/2001/WGSSDS/WGSSDS02.pdf.

Larrañeta, M. G. and A. Vazquez (1982): On a Possible Meaning of the Polar Motion in the Ecology of North Atlantic Cod (Gadus Morhua), ICES CM 1982/G:14.

Lucio, P., I. Martín, L. Motos, J. Santiago and A. Uriarte (1989): Informe Técnico de la Pesquería de la Anchoa en el año 1988, AZTI, Gobierno Vasco.

Meade, N. and T., Islam (1995): Forecasting with Growth Curves: An Empirical Comparison, *International Journal of Forecasting,* 11, 199-215.

Roldán, M. I., J. L. García-Martín, F. M. Utter and C. Pla (1998): Population Genetic Structure of European Hake Merluccius Merluccius, *Heredity,* 81(3), 327-334.

Sethi, G., C. Costello, A. Fisher, M. Hanemann and L. Karp (2005): Fishery Management under Multiple Uncertainty, *Journal of Environmental Economics and Management,* 50/2, 300-318.

Spence, M. (1974): Blue Whales and Applied Control Theory. In: Zadeh, C. L., *et al.* (eds.), Systems Approaches for Solving Environmental Problems, Vandenhoeck and Ruprecht, Gottingen and Zurich.

STECF (2004): Review of Scientific Advice for 2004. Commission Staff Working Paper, SEC(2004) 372.

Tauchen, G. (1986): Finite State Markov-Chain Approximations to Univariate and Vector Autoregresions, *Economic Letters,* 20, 177-181.

Weitzman, M. L. (2002): Landing Fees vs Harvest *Quotas* with Uncertain Fish Stocks, *Journal of Environmental Economics and Management,* 43, 325-338.

Appendix

A: Data

TABLE A.1: Stock and Catch Data for European Anchovy (Division VIII). 1987-2002

Year	1987	1988	1989	1990	1991	1992	1993	1994
Stock	187,108	121,612	290,148	177,922	475,187	429,583	311,139	264,576
Catches	15,308	15,581	10,614	34,272	19,634	37,885	40,293	34,631
Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Stock	259,419	305,045	427,176	333,380	420,295	437,962	222,265	173,484
Catches	30,115	34,373	22,337	31,617	27,259	36,994	40,564	17,507

Source: Report ICES CM 2004 / ACFM:08. From Table 11.7.2.2.

TABLE A.2: Stock and Catch Data for the Southern Stock of Hake. 1982-2002

Year	1982	1983	1984	1985	1986	1987	1988
Stock	83,008	78,582	67,521	55,478	50,200	48,524	45,277
Catches	17,108	22,376	21,485	18,152	16,185	15,232	15,405
Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Stock	39,569	39,549	37,832	37,065	35,622	33,1227	27,257
Catches	12,887	11,994	11,618	12,824	10,944	9,542	11,782
Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Stock	25,247	24,365	27,316	26,339	27,394	24,899	27,074
Catches	8,875	7,619	7,100	6,911	7,318	6,365	5,817

Source: Report ICES CM 2004 / ACFM:02. From Table 6.1.13.

TABLE A.3: Stock and Catches Data for the Northern Stock of Hake (Tn). 1978-2001

Year	1978	1979	1980	1981	1982	1983	1984	1985
Stock	277,849	301,131	289,775	297,869	274,870	251,573	241,759	289,182
Catches	52,908	53,799	60,459	56,264	58,057	60,128	65,149	59,939
Year	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
Stock	268,652	252,517	222,101	226,086	193,996	196,294	174,406	176,920
Catches	60,053	65,320	66,818	68,781	61,410	59,286	58,290	53,637
Year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Stock	172,519	190,523	172,909	189,652	195,118	177,133	162,990	171.353
Catches	53,140	58,862	48,759	44,357	35,877	40,648	42,624	37,192

Source: Report ICES CM 2003/ACFM:01. From Table 16, page 78.

TABLE A.4: Data from trawler fleets in the Northern Stock of Hake

	Spain		France	
Year	**c.p.u.e [a]**	**Captures [b]**	**c.p.u.e. [c]**	**Captures [d]**
1988	178.49	8998	89.35	17350
1989	179.22	7841	128.77	20490
1990	140.53	6665	110.38	18929

[a] Coruña trawler fleet. Tn/year. Data from Table 3.2a in the WGHMM ICES Report CM 2003/ACFM:01.
[b] Spanish trawler fleet fishing in area VII. Tn. Data from Instituto Oceanográfico de Vigo.
[c] FR-RESSGASC trawler fleet. Tn/year. Data from Table 3.2c in the WGHMM ICES Report CM 2003/ACFM:01.
[d] French trawler fleet fishing in area VIII. Tn Data from Instituto Oceanográfico de Vigo.

TABLE A.5: Data from all French fleets fishing in the Northern Stock of Hake

Year	Captures [a]	Share [b]	Effort [c]
1988	21895	0.327	233.45
1989	24218	0.352	257.87
1990	21472	0.349	264.84

Source: Instituto Oceanográfico de Vigo.

[a] Tn

[b] % of total stock

[c] Ships fishing 365 days.

B: Numerical Solution of Bellman's Equation

SUPPOSE we want to solve numerically the following non-stochastic Bellman equation,

$$V(X) = \max_{X'} [u(X, X') + \beta V(X')]$$

where a prime on a variable indicates its value for the next period.

We start by selecting the widest possible grid of values of variable X, i.e. $\mathbb{X} = (X^0, X^1, ..., X^m)$. Let be $\mathbb{V}_0(\mathbb{X}) = (V_0(X^0), V_0(X^1), ..., V_0(X^m))$ a vector of initial values of the function V for each of the elements in $\mathbb{X}$. Given $\mathbb{X}$ and $\mathbb{V}$, the following Bellman equation is solved for all $i = 1, ...m$

$$V_1(X) = \max_{X'} [u(X, X') + \beta V_0(X')]$$

where $X = X^i$ and $V_0(X') = V_0(X^i)$.

Once this step is solved, $\mathbb{V}_0$ and $\mathbb{V}_1$ are compared using some kind of measure. For instance, we can say that $\mathbb{V}_0$ and $\mathbb{V}_1$ are sufficiently equal whenever $|| \mathbb{V}_1 - \mathbb{V}_0 || < \varepsilon$ holds for any ε as close to zero as we want.

If $\mathbb{V}_0$ and $\mathbb{V}_1$ are not sufficiently equal, the process is repeated for any $i = 1, ...m$, taking as the initial value of $V_0(X')$ the result obtained in the first iteration, i.e. $V_1(X^i)$. Then $\mathbb{V}_2$ is calculated and so on. In general, given a $\mathbb{V}_n$, the following equation is solved

$$V_{n+1}(X) = \max_{X'} [u(X, X') + \beta V_n(X')]$$

until vectors $\mathbb{V}_n$ and $\mathbb{V}_{n+1}$ are sufficiently equal according to our measure criterion.

Suppose now that the Bellman equation we want to solve is stochastic,

$$V(X, z) = \max_{X'} \{u(X, X', z) + \beta E_{z'} [V(X', z') \mid z]\}$$

where a prime on a variable indicates its value for the next period and $E_{z'}$ means that the expectation is over the distribution of z'. The procedure for solving this stochastic Bellman equation numerically is the same as before. The stochastic variable is treated as the state variable X and the calibrated distribution of z is used in calculating $E_{z'}[V(X', z') \mid z]$.

C: Characterization of the Steady State for the Northern Stock of Hake Model

THE [OCFP] problem from section 6.1 with the functional forms proposed in section 6.2 can be expressed as:

$$[OCFP] \equiv \begin{cases} \max_{\{\{l_{i,t}\}_{i=1}^{n}\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t (\gamma_1 \Pi_{1t} + \gamma_2 \Pi_{2t} + \ldots + \gamma_n \Pi_{nt}) \\ s.t. \begin{cases} \Pi_{it} = y_{i,t}(l_{1,t}, \ldots, l_{n,t}, X_t) - \omega l_{i,t} \\ y_{i,t}(l_{1,t}, \ldots, l_{n,t}, X_t) = \frac{l_{i,t}^{\theta_i}}{\sum_{k=1}^{n} l_{k,t}^{\theta_k}} [1 - e^{-\lambda \sum_{k=1}^{n} l_{k,t}^{\theta_k}}] A_t X_t^{\alpha} \\ X_{t+1} = A_t X_t^{\alpha} - \sum_{i=1}^{n} y_{i,t}(l_{1,t}, \ldots, l_{n,t}, X_t) \end{cases} \end{cases}$$

Since we are interested in characterizing the steady state without uncertainty, we remove the conditional expectation and consider $A_t = A$. The Lagrangian associated with this problem is

$$L = \sum_{t=0}^{\infty} \beta^t \left\{ \sum_{i=1}^{n} \gamma_i [y_{i,t}(l_{1,t}, \ldots, l_{n,t}, X_t) - \omega l_{i,t}] + \mu_t [AX_t^{\alpha} - \sum_{i=1}^{n} y_{i,t}(l_{1,t}, \ldots, l_{n,t}, X_t) - X_{t+1}] \right\},$$

where μ_t is the multiplier. The f.o.c. of this problem are

$$\frac{\partial L}{\partial l_{i,t}} = 0 \Rightarrow \beta^t \left[\gamma_i \left(\frac{\partial y_{i,t}}{\partial l_{i,t}} - \omega \right) + \sum_{k \neq 1} \gamma_k \frac{\partial y_{k,t}}{\partial l_{i,t}} - \mu_t \sum_{k=1}^{n} \frac{\partial y_{k,t}}{\partial l_{i,t}} \right] = 0, \forall i = 1, \ldots, n \quad \forall t \quad (C.1)$$

$$\frac{\partial L}{\partial X_{t+1}} = 0 \Rightarrow -\beta^t \mu_t + \beta^{t+1} \left[\sum_{i=1}^{n} \gamma_i \frac{\partial y_{i,t+1}}{\partial X_{t+1}} + \mu_{t+1} \left(A\alpha X_{t+1}^{\alpha-1} - \sum_{i=1}^{n} \frac{\partial y_{i,t+1}}{\partial X_{t+1}} \right) \right] = 0, \quad \forall t \quad (C.2)$$

$$\frac{\partial L}{\partial \mu_t} = 0 \Rightarrow X_{t+1} = X_t^{\alpha} - \sum_{i=1}^{n} y_{i,t} \quad \forall t \quad (C.3)$$

First, we find expressions for $\Sigma_{k=1}^{n} (\partial y_{k,t} / \partial l_{i,t})$, $\Sigma_{k=1}^{n} \gamma_k (\partial y_{k,t} / \partial l_{i,t})$, $\Sigma_{k=1}^{n} (\partial y_{k,t} / \partial X_t)$, and $\Sigma_{k=1}^{n} \gamma_k (\partial y_{k,t} / \partial X_t)$.

Given the definition of $y_{k,t}$ (second restriction in the OCFP problem), individual catches can be expressed as

$$y_{k,t} = \frac{l_{k,t}^{\theta_k}}{\sum_{j=1}^{n} l_{j,t}^{\theta_j}} \left[1 - e^{-\lambda \Sigma_{j=1}^{n} l_{j,t}^{\theta_j}}\right] AX_t^{\alpha} = s_{k,t}\left[1 - e^{-\lambda \Sigma_{j=1}^{n} l_{j,t}^{\theta_j}}\right] AX_t^{\alpha}$$

where $s_{k,t} = l_{k,t}^{\theta_k} / \Sigma_{j=1}^{n} l_{j,t}^{\theta_j}$.

It is easy to calculate $\forall i$,

$$\frac{\partial y_{k,t}}{\partial l_{i,t}} = \left\{\left[1 - e^{-\lambda \Sigma_{j=1}^{n} l_{j,t}^{\theta_j}}\right] \frac{\partial s_{k,t}}{\partial l_{i,t}} + \lambda \theta_i l_{i,t}^{\theta_i} \; e^{-\lambda \Sigma_{j=1}^{n} l_{j,t}^{\theta_j}} s_{k,t}\right\} AX_t^{\alpha} \qquad \text{(C.4)}$$

$$\frac{\partial y_{k,t}}{\partial X_t} = \left[1 - e^{-\lambda \Sigma_{j=1}^{n} l_{j,t}^{\theta_j}}\right] \alpha A X_t^{\alpha - 1} s_{k,t} \qquad \text{(C.5)}$$

where

$$\frac{\partial s_{k,t}}{\partial l_{i,t}} = \begin{cases} -\dfrac{\theta_i}{l_{i,t}} s_{i,t} s_{k,t} & \forall i \neq k \\ \dfrac{\theta_i}{l_{i,t}} s_{i,t}(1 - s_{i,t}) & \forall i = k \end{cases}$$

Summing up (C.4) and (C.5) over $k = 1, \ldots, n$ and taking into account that restrictions in the optimization problem imply, in the steady state, that $e^{-\lambda \Sigma_{j=1}^{n} l_{j,t}^{\theta_j}} = X^{1-\alpha}/A$, we can obtain the following expressions,

$$\sum_{k=1}^{n} \frac{\partial y_k}{\partial l_i} = \lambda \frac{\theta_i}{l_i} l_i^{\theta_i} X \qquad \text{(C.6)}$$

$$\sum_{k=1}^{n} \gamma_k \frac{\partial y_k}{\partial l_i} = \left\{\left[1 - \frac{X^{1-\alpha}}{A}\right] s_i \left(\gamma_i - \sum_{k=1}^{n} \gamma_k s_k\right) + \lambda l_i^{\theta_i} \frac{X^{1-\alpha}}{A} \sum_{k=1}^{n} \gamma_k s_k\right\} \frac{\theta_i}{l_i} AX^{\alpha} \qquad \text{(C.7)}$$

$$\sum_{k=1}^{n} \frac{\partial y_k}{\partial X} = \left[1 - \frac{X^{1-\alpha}}{A}\right] \alpha A X^{\alpha - 1} \qquad \text{(C.8)}$$

$$\sum_{k=1}^{n} \gamma_k \frac{\partial y_k}{\partial X} = \left[1 - \frac{X^{1-\alpha}}{A}\right] \alpha A X^{\alpha - 1} \sum_{k=1}^{n} \gamma_k s_k \qquad \text{(C.9)}$$

Substituting expressions (C.8) and (C.9) in optimality condition (C.2), this can be expressed in the steady state as

$$\beta\alpha(AX^{\alpha-1}-1)\sum_{k=1}^{n}\gamma_k s_k-(1-\beta\alpha)\,\mu=0 \tag{C.10}$$

On the other hand, substituting expressions (C.6) and (C.7) in the optimality condition (C.1) we can express the multiplier μ_t in the steady state $\forall i = 1, \ldots n$, as

$$\mu=\frac{\sum_{k=1}^{n}\gamma_k\frac{\partial y_k}{\partial l_i}-\gamma_i w}{\sum_{k=1}^{n}\frac{\partial y_k}{\partial l_i}}$$

$$=\left\{\left[1-\frac{X^{1-\alpha}}{A}\right]s_i\left(\gamma_i-\sum_{k=1}^{n}\gamma_k s_k\right)+\lambda l_i^{\theta_i}\frac{X^{1-\alpha}}{A}\sum_{k=1}^{n}\gamma_k s_k\right\}\frac{AX^{\alpha-1}}{\lambda l_i^{\theta_i}}-\frac{\gamma_i w}{\lambda\theta_i l_i^{\theta_i-1}X}$$

Substituting this expression of μ in (C.10), and after some calculations, the following expresion is obtined

$$(\alpha\beta AX^{\alpha-1}-1)\sum_{i=1}^{n}\gamma_i s_i+\frac{(1-\alpha\beta)\omega}{\lambda XL(X)}\sum_{i=1}^{n}\gamma_i\frac{(s_i L(X))^{1/\theta_i}}{\theta_i}=0 \tag{C.11}$$

Equalizing μ for any two fleets and consider that $1-\frac{X^{1-\alpha}}{A}=\frac{Y}{AX^{\alpha}}$ and $L = l_i^{\theta_i} / s_i$, we obtain

$$\frac{[\omega L(X)^{1/\theta_i}s_i^{(1-\theta_i)/\theta_i}/\theta_i]-Y}{[\omega L(X)^{1/\theta_k}s_k^{(1-\theta_k)/\theta_k}/\theta_k]-Y}=\frac{\gamma_k}{\gamma_i},\qquad\forall k\neq i \tag{C.12}$$

Finally, equation (C.3) evaluating in the steady state establishes

$$AX^{\alpha}-X=Y \tag{C.13}$$

Equation system (C.11)-(C.13) expresses the steady state as a function of the observed data, the *quotas* s_i, the TAC, Y, and the biomass stock, X.

*ABOUT THE AUTHORS**

JOSE MARÍA DA-ROCHA ÁLVAREZ holds a PhD in Economics from the University of Vigo. He has been Visiting Professor at the Carlos III University of Madrid and the ITAM (Instituto Tecnológico Autonómico de México). He is currently Associate Professor at the University of Vigo and a member of its Research Group in Economic Analysis (RGEA). He is also a member of the Instituto Universitario de Estudios e Desenvolvemento de Galicia (University of Santiago de Compostela) and the Instituto de Estudios Económicos de Galicia Pedro Barrie de la Maza (Banco Pastor, Fundación Pedro Barrie de la Maza). His fields of specialization are regulatory economics and dynamic macroeconomics. He has authored a number of articles in scientific journals such as *International Economic Review, Review of Economic Dynamics, Journal of Economic Theory, Journal of Regulatory Economics* and *Spanish Economic Review.*

MARÍA-JOSÉ GUTIÉRREZ HUERTA holds a PhD in Economics from the State University of New York at Stony Brook. Currently Associate Professor at the University of the Basque Country, in the Department of Fundamentals of Economic Analysis II, she has been a Visiting Scholar at the University of California San Diego and the University of Warwick. Her main fields of specialization are environmental and resource economics and macroeconomics. She has published articles in the *Journal of Environmental Economics Management, Journal of Economic Dynamics and Control, Journal of Institutional and Theoretical Economics, Annales D'Economie et de Statistique* and *Spanish Economic Review.*

* The authors gratefully acknowledge the financial support of the ERDF, BBVA Foundation and the Spanish Ministry of Science and Technology.

Fundación BBVA

D O C U M E N T O S   D E   T R A B A J O

NÚMEROS PUBLICADOS

DT 01/02 *Trampa del desempleo y educación: un análisis de las relaciones entre los efectos desincentivadores de las prestaciones en el Estado del Bienestar y la educación*
Jorge Calero Martínez y Mónica Madrigal Bajo

DT 02/02 *Un instrumento de contratación externa: los vales o cheques. Análisis teórico y evidencias empíricas*
Ivan Planas Miret

DT 03/02 *Financiación capitativa, articulación entre niveles asistenciales y descentralización de las organizaciones sanitarias*
Vicente Ortún-Rubio y Guillem López-Casasnovas

DT 04/02 *La reforma del IRPF y los determinantes de la oferta laboral en la familia española*
Santiago Álvarez García y Juan Prieto Rodríguez

DT 05/02 *The Use of Correspondence Analysis in the Exploration of Health Survey Data*
Michael Greenacre

DT 01/03 *¿Quiénes se beneficieron de la reforma del IRPF de 1999?*
José Manuel González-Páramo y José Félix Sanz Sanz

DT 02/03 *La imagen ciudadana de la Justicia*
José Juan Toharia Cortés

DT 03/03 *Para medir la calidad de la Justicia (I): Abogados*
Juan José García de la Cruz Herrero

DT 04/03 *Para medir la calidad de la Justicia (II): Procuradores*
Juan José García de la Cruz Herrero

DT 05/03 *Dilación, eficiencia y costes: ¿Cómo ayudar a que la imagen de la Justicia se corresponda mejor con la realidad?*
Santos Pastor Prieto

DT 06/03 *Integración vertical y contratación externa en los servicios generales de los hospitales españoles*
Jaume Puig-Junoy y Pol Pérez Sust

DT 07/03 *Gasto sanitario y envejecimiento de la población en España*
Namkee Ahn, Javier Alonso Meseguer y José A. Herce San Miguel

DT 01/04 *Métodos de solución de problemas de asignación de recursos sanitarios*
Helena Ramalhinho Dias Lourenço y Daniel Serra de la Figuera

DT 01/05 *Licensing of University Inventions: The Role of a Technology Transfer Office*
Inés Macho-Stadler, David Pérez-Castrillo y Reinhilde Veugelers

DT 02/05 *Estimating the Intensity of Price and Non-price Competition in Banking: An Application to the Spanish Case*
Santiago Carbó Valverde, Juan Fernández de Guevara Radoselovics, David Humphrey y Joaquín Maudos Villarroya

DT 03/05 *Sistemas de pensiones y fecundidad. Un enfoque de generaciones solapadas*
Gemma Abío Roig y Concepció Patxot Cardoner

DT 04/05 *Análisis de los factores de exclusión social*
Joan Subirats i Humet (Dir.), Ricard Gomà Carmona y Joaquim Brugué Torruella (Coords.)

DT 05/05 *Riesgos de exclusión social en las Comunidades Autónomas*
Joan Subirats i Humet (Dir.), Ricard Gomà Carmona y Joaquim Brugué Torruella (Coords.)

Documentos de Trabajo

6

Fundación BBVA

Gran Vía, 12
48001 Bilbao
Tel.: 94 487 52 52
Fax: 94 424 46 21

Paseo de Recoletos, 10
28001 Madrid
Tel.: 91 374 54 00
Fax: 91 374 85 22

informacion@fbbva.es
www.fbbva.es