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A stochastic model for the Iberoatlantic sardine fishery. Global warming and economic effects

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ABSTRACT

The literature of natural resources has made wide use of deterministic dynamic models to optimally manage marine fishery resources. However, the ever-changing weather condition and, most importantly, the warming of ocean waters have a significant impact on the evolution of fishery resources. In fact, the latter of the two is a significant random component closely linked to climate change. This paper uses sea surface temperature (from here on SST) to explain the dynamics of the ecosystem biomass in stochastic growth. Observations of SST, biomass, catch and effort in the area of the Atlantic waters bathing the Iberian Peninsula are used to implement the stochastic dynamic optimization theory in a model of production to obtain optimal results for all of these variables in the short and medium term.

1. Introduction

Global warming, as an aftermath of climate change, is likely to result in local increases in the temperature of the Atlantic surface waters washing the shores of southwestern Europe. Significant changes in the physicochemical conditions of this oceanic region could produce important changes in the climatic parameters characterizing marine ecosystems at the local level and modify the extraction capabilities of fishery resources.

The natural growth rate of a stock or biomass undergoes a stochastic process in most resources and, particularly in renewable resources. This fact has been evidenced by biologists, ecologists and economists. Extensive literature focuses on the development of stochastic models of dynamic resource growth and the characterization of the distribution probability for stocks that remain unexploited beyond a pre-set rule.

Some of these models use Îto's processes, Markov processes in continuous time. These models cannot apply ordinary calculation rules because the work is not carried out with derivatives in the usual manner. They require stochastic calculations and the rule of chains known as Îto's Lemma must be made extensive to these cases as well as to the relationships between some of the expected values and differential equations.

From the 70s, stochastic models have been increasingly used in issues related to economy and ecology. Merton (1969, 1971); Goel and Richter-Dyn (1974); Tuckwell (1974); Turelli (1977); May et al. (1978); Pindyck (1984); Miranda and Fackler (2002), use an Îto's process to describe the dynamics of the labor force in a stochastic model of economic growth. Also, Merton (1969, 1971) and Black and Scholes (1973) use these models to assess options in financial markets and eliminate risk in financial contracts.

Pindyck (1984) responds to some issues about the market performance of renewable resources that arise from the presence of ecological uncertainty, e.g. how uncertainty affects the present and future value of biomass dynamics, how it affects the rate of extraction in a competitive market with property rights or what the implications are in terms of the extent to which regulation is required in cases of unassigned or even eliminated property rights.

Levhari et al. (1981) proves that markets can be analyzed within a standard framework of the capital theory, so that the dynamics of prices and the stock of resources are jointly determined by the requirement of balance. Pindyck (1984) examines and interprets this equilibrium condition within a stochastic context, i.e. when the growth of stock is unpredictable. Moreover, these authors use several examples to study how the uncertainty of biomass growth can influence the rate of extraction and profits.

Other works look at the optimal rate of extraction of biomass

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with stochastic growth. For example, Gleit (1978) uses a random continuous time path in function of the growth of the biomass to find the extraction rate that maximizes the expected value of the integer of the utility function of net income. The author proves that the optimum extraction rate grows as does the growth rate of the resource. Smith (1978) addresses the same issue, but he does so using an indirect utility function and the logistic growth function. This seems more realistic. In line with this, Ludwig (1979); Ludwig and Varah (1979) use perturbation methods to obtain numerical solutions approximate to the problem of stochastic collection in logistic growth function.

In relation to climatic environmental variations, Roe and Baker (2007); Pindyck (2007); Newbold and Daigneault (2009); Weitzman (2009a, b) study the possible consequences of the accumulation of greenhouse gases; their effect on temperature and the implications of the uncertainty of climate policy; the geometric shape of the probable distribution of temperature in the case of uncertainty; the relation between this distribution with a utility and constant relative risk aversion, etc. Pindyck (2012) studies probability distributions for changes in temperature; their economic impact on the analysis of climate change policies; and how they relate to uncertainty. The author also defines a measure of the willingness to pay as the fraction that society would be willing to sacrifice to ensure an upper bound in temperature increase.

This paper studies the influence of sea surface temperature on economic performance in a fishery. It assumes that the environmental influence variable randomly influences the biology of marine resources. Therefore, it works with a stochastic optimization model in continuous time to determine decisions concerning the quantities of biomass that can be captured so that the system is a sustainable one maximizing profits. Our analysis unfolds in an Ibero-Atlantic sardine fishery, a fishery resource shared by Spain and Portugal in the waters between the Bay of Biscay and the Gulf of Cadiz which the International Council for the Exploration of the Sea (ICES) designates as VIIIc and IXXa.

2. Sardine fishing in the Ibero-Atlantic coast

Commercially speaking, the most important sardine species in the Northeast Atlantic is the European pilchard *Sardina pilchardus* (Walbaum, 1972). This species is distributed across the areas extending from the coasts of Senegal to the North Sea as well as from the Mid-Atlantic to the interior of the Mediterranean.

The Ibero-Atlantic sardine fishery is traditionally one of the most important fisheries in the North Atlantic. Spain and Portugal share the exploitation of this fishery in the waters surrounding the Iberian Peninsula, specifically in the area ranging between the Bay of Biscay and Strait of Gibraltar. This area is bounded by what the *International Council for the Exploration of the Sea* (ICES) call the VIIIc and IXa areas. The Working Group of ICES assessing pelagic stocks is responsible for estimating the total spawning stock biomass and the annual evolution of catches for Spain and Portugal. This group is constituted by researchers from the Spanish Institute of Oceanography IEO, and the Research Institute for Ocean fishing, Portugal, IPIMAR.

Our work identifies the number of fish stock for the areas VIIIc and IXa equivalent to the fishery regions corresponding to ICES (2011a), and uses this information to carry out the empirical analysis of the relevant functions (See Table 1).

We measure the data for catches equivalent to the landings in the ports of the north and west of the Iberian Peninsula in tonnes just like marine researchers do with estimated biomass stock. The data source for captures may be seen in the documents published by ICES (2011a) about sardine landings at the ports of the Cantabrian and the Atlantic coasts of the Iberian Peninsula.

Table 1
Evolution of stock and catches of sardine.

Year	Stock	Catches	Year	Stock	Catches
1978	302,000	145,609	1995	604,000	125,280
1979	371,000	157,241	1996	409,000	116,736
1980	458,000	194,802	1997	362,000	115,814
1981	574,000	216,517	1998	313,000	108,924
1982	606,000	206,946	1999	313,000	94,091
1983	561,000	183,837	2000	250,000	85,786
1984	615,000	206,005	2001	290,000	101,957
1985	718,000	208,439	2002	422,000	99,673
1986	668,000	187,363	2003	430,000	97,831
1987	564,000	177,696	2004	427,000	98,020
1988	491,000	161,531	2005	345,000	97,345
1989	411,000	140,961	2006	544,000	87,023
1990	373,000	149,429	2007	521,000	96,469
1991	378,000	132,587	2008	379,000	101,464
1992	493,000	130,250	2009	263,000	87,740
1993	547,000	142,495	2010	172,000	89,571
1994	552,000	136,582			

Source: ICES (2011a,b).

The evolution in catches at ports in northern and western Spain and all the Portuguese ports was alike until the early sixties, when sardine landings in Portugal became significantly greater. From the sixties and until the incorporation of these two countries into the European Economic Community (EEC) in 1986, Portuguese catches dropped and have moved closer to the value of the catches unloaded at the Spanish Cantabrian and Atlantic ports. Fishery management is not a part of the Common Fishery Policy and each state carries it out independently. However, catches have fallen in both countries since 1985, with significantly greater declines in the landings at Spanish ports until the early twenty-first century. Since then, the landings in both countries have remained stable at about 65,000 t of sardines in Portugal and around 30,000 t at the Spanish ports under consideration.

The ports in the north and west of the Iberian Peninsula are the main recipients of the catches of the purse seine fleet operating in the waters of the Ibero-Atlantic sardine. The boats are active in coastal waters; so landings are made relatively close to the capture zone. In this paper, we used labor as a measure of input factor: i.e., the effort exerted on the natural resource corresponding to the days of fishing. However, this information is not public. So we have resorted to a sample of the number of tides of purse seine vessels that capture sardines based in the ports of Vigo, Ribeira, Sada and Santoña. We have done so using the data provided to us by the IEO. It is worth mentioning that ICES claims these ports represent the entire Spanish fleet operating in the fishery under analysis and incorporates this information into the factors taken into account when proposing possible fishery restrictions.

We obtained the estimate of the number of a series of efforts for Spanish ports, as a whole, by taking the data from the selected sample and transferring the ratio between effort and catches of all four ports to the total of Spain. For the Portuguese fleet we used the fishing effort data, expressed in days fished which was provided by the National Institute of Agriculture and Fishing of Portugal (IPIMAR). These values are both included in Table 2.

Some basic economic parameters are required to develop the model. So, we introduced the parameters of unit income and cost, assuming they were fixed, in real terms. In addition, we introduced the discount factor to incorporate the intertemporal preferences of the economic agent.

We used the price series provided by the Annual Fishery Statistics of the Portuguese Institute of Statistics and the first-sale prices in Galician ports provided by the government of the Autonomous Community of Galicia, as representative data for the