Chapter 17

Socio-economic research

17.1 Socio-economic research for fisheries management

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Socio-economic research applied to fisheries is a relatively recent phenomenon. The origins of bio-economy can be traced back to the pioneering work of Gordon & Schaefer (Gordon, 1953; Gordon, 1954; Schaefer, 1957) in the mid 1950s.
The importance of sustainable fisheries management and socio-economics in reaching this objective are made evident in the fundamental principles of the EU Common Fisheries Policy. Council Regulation (CE) 2371/02 defines the purpose of the Common Fisheries Policy as one of promoting "sustainable fisheries and aquaculture in a healthy marine environment capable of supporting an economically viable industry that offers employment and opportunities to coastal communities".
Within EU scientific research, projects, which also took the fisheries socio-economic and managerial aspects into consideration, began to receive Community financing as from the 1990s through the FAIR program (1994-1998). The later EU research Framework Programmes (FPs), FP5 (1998-2002), FP6 (2002-2006) and FP7 (2007-2013), increasingly tried to promote a multidisciplinary approach in scientific research applied to fisheries.
At a national level, three-year plans were published in succession from 1982 to 2006 , followed by the national three-year programme from 2007 to 2009 (then extended to 2011). These were given a legislative framework in law 41/1982, and were considered a policy instrument for fisheries, with the objective of promoting a balanced development of fisheries and aquaculture, in particular as far as research was concerned.
Initially, the first plans identified scientific and technological research as being an important tool to support the numerous functions of government, which had been expanding following the approval of law 41/82. It was then extended to managing specific topics. Next, beginning with the Three-Year Plan VII , research started to be considered necessary to carry out the very difficult task of defining the support framework to produce strategic planning and fisheries management policy for medium and long-term objectives.
Despite the variety of topics dealt with, several of the main research objectives can be summarised as follows:

- assessing the tools to be used to carry out a socio-economic evaluation of fisheries both in the short- and the long-term;
- assessing the functional relationships between the main socio-economic variables of the system, especially regarding fishermen behaviour;

- *ex ante*, intermediate and *ex post* socio-economic evaluation of possible alternative management action;
- assessing the role of incentives in managing exploitation activities;
- assessing the socio-economic importance of fisheries for coastal communities with reference not just, strictly speaking, to fisheries, but also to fisheries related sectors such as processing, marketing, construction, etc.

Socio-economic research objectives have been pursued over the last few years, and the scope of both the tools and the investigation approaches has been broadened. Amongst the main research tools used, socio-economic indicators are without any doubt the most important ones to start with when carrying out any assessment of fisheries. Comparing the indicators with suitable reference points allows sector conditions to be evaluated for a given time period. More sophisticated analysis tools were used to evaluate the technological progress of fishing fleets. As regards this topic, technology efficiency evaluation methods such as Data Envelopment Analysis (DEA) and production frontiers were used in numerous studies and in much of the research projects carried out. This is a promising research approach, dating back to 1995, which entails studying the structures and functions of fishery systems as a whole, using an approach aimed at identifying the relationships between the main sector variables and their temporal and spatial dynamics. The spread of an approach based on bio-economic models into this area was undoubtedly a turning point for research in the fields of the environment and socio-economics.

Over the last few years, indicators, bio-economic models and other analysis tools used in socio-economic research applied to fisheries, have been playing a common role in the national Management Plans envisaged in community regulations and in Impact Assessment (IA). They are used as support tools in EU decision-making activities and to guarantee that EU legislation is developed on the basis of clear, complete and balanced information.

This chapter introduces and describes the main analysis tools used in socio-economic research in fisheries. To be more specific, paragraph 17.2 is dedicated to the evolution of the bio-economic model structure, whereas paragraph 17.3 assesses the main tools for evaluating the technological efficiency of fishing fleets.

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17.2 The contribution of bio-economic modelling to fisheries management

Accadia P.

A bio-economic model can be defined as a comprehensive set of functional relationships between biological and economic variables, designed to represent a system in mathematical terms. Although they are necessarily simplified representations of reality, bio-economic models in fisheries allow the main relationships between biological processes (connected with fish population dynamics) and those of an economic nature (regarding the behaviour of fisheries operators) to be detected.

The biological and economic aspects of fishing activities are closely interconnected. The main link is undoubtedly the extraction activity carried out by the resource user. The quantities extracted, namely catches, become on the one hand fishing mortality, and on the other revenue, and therefore income. On the basis of this relationship, external factors that impact directly on the biological aspects, such as nutrients or predators, also indirectly influence the economic aspect. At the same time, external factors that directly condition the economic aspects of fishery activities, such as the management system or fuel costs, also condition the biological sphere. In this context, bio-economic models allow the complex system of interactions, dynamics, and natural and anthropogenic relationships that characterise fisheries to be quantitatively represented and measured through mathematical equations.

Despite the intrinsic limitations of a model-based approach, this tool has proved to be very useful in management. From the first studies by Gordon & Schaefer in the 1950s (Gordon, 1953; Gordon, 1954; Schaefer, 1957), over the years bio-economic models have become increasingly refined also thanks to the development of modern calculators and personal computers, so that they are now regularly used at an international level to assess the possible effects of alternative management actions.

A bio-economic model consists of a sequence of modules or components, with a component being a functional relationship or system of functional relationships between variables in which known inputs and outputs can be identified. The main components of a bio-economic model are the biological, economic and management components. These macro-components can, in turn, be reduced to simpler ones.

The biological component represents fish biomass dynamics, whereas the economic component is aimed at reproducing dynamics related to the fleet, the market and fishermen's behaviour. Finally, possible intervention approaches, criteria for selecting the various management strategies, and the management objectives themselves are considered in the management subsystem.

The basic economic components of a bio-economic model

The bio-economic models used in fisheries management have structures that can vary widely, depending on the biological and economic characteristics of the situation to which they refer. Despite the variety in the field of application, three economic components common to all models can be identified: fleet and fishing effort dynamics, price dynamics and cost dynamics. A further component can be added to these three, namely catch dynamics, which can be modelled either as part of the economic module or of the biological one.

The structure of the these economic components and the approaches used to simulate their relative temporal dynamics depend on several factors. Nevertheless, the main drivers upon which modelling processes are based include the model objectives, the quality of the available data and the characteristics of the fisheries sector being analysed.

As regards the objectives of a bio-economic model, a distinction is usually made between simulation and optimisation models. The model type determines the relevance of each economic component and the approach used for its implementation. Another important factor is the type of management action to be simulated. Input-oriented or output-oriented models can be used, depending on the current management system in the area under analysis.

The structure and availability of economic and biological data represent another very important factor in the classification of bio-economic models. These models, being generally developed to analyse a specific fisheries area or sector, have a structure that tends to be adapt to the type of data available in that area and for that type of fishery.

Finally, the structure of a bio-economic model reflects the main characteristics of the fisheries sector being assessed. Fishing activities are characterised by being strongly heterogeneous and different management procedures, as well as different modelling approaches, are adopted according to their features. For instance, fisheries can be single-species or multi-species, pelagic or demersal, can use a single fishing gear or a multitude of fishing gears.

Production functions used to simulate catch dynamics

The catch dynamic component is linked to the characteristics of the management system that has been adopted (or can be potentially adopted) for the circumstances being modelled. In systems based on output limitation, such as TAC-based management approaches, catch dynamics (equivalent to quotas) are generally obtained from the so-called Harvest Control Rules (HCRs). The TAC level, in this context, is a bio-economic model input. In Italian and Mediterranean fisheries, however, which are normally regulated using input control systems, catch dynamics are treated as an endogenous component of the model.

When incorporated into a bio-economic model, catch (or landing) dynamics can be simulated using either a biological approach or an economic one. However certain models, such as BIRDMOD (Accadia & Spagnolo, 2006), use both approaches, depending on the quality and the quantity of the data available. Indeed, compared to biological models that require large quantities of detailed information, production functions or surplus production models are a valid alternative for reproducing catch dynamics where there is no specific biological data. This circumstance is typical of multi-species contexts where biological information is generally available only for limited number of stocks.

Price dynamics

In bio-economic models, prices are generally differentiated according to species and to fleet (or fleet segment). The price of a species can be influenced by fleet nationality (the same species can be sold at different prices according to the destination country) and on the fishing gear used (which affects the catch quality and size and therefore the price). Nevertheless, when the price differences associated with the various fleets that exploit the same species are negligible, it is possible to consider a single price for total landings of that fish stock.

Prices can be considered as constant or variable. In general, optimisation models such as MOSES (Placenti *et al.*, 1992) assume constant prices. In the long term price dynamics can be influenced by a series of external factors, which can be particularly complex to predict and implement in the model. On the other hand, the forecasts provided on a yearly basis by simulation modelsgenerally allow potential price variations to be incorporated.

Fleet dynamics and fishing effort

Micro-economic theory views fishermen's behaviour as being aimed at maximising profits. Hence, fishermen's decisions can be conditioned by a series of external factors such as the adoption of new management provisions, significant variations in fuel prices or fish stock decline. The distinction between long- and short-term decisions are incorporated into almost all bio-economic models. Long-term decisions are generally simulated via investment/disinvestment functions, which can be directed towards purchasing new vessels (increasing fleet size) or improving technical efficiency (investments in technology). Short-term decisions can be considered as technical adaptations that produce variations in fishing effort. These include, for example, variations in the number of fishing days or hours, changes in the fishery areas exploited or fishing gears used (for vessels that have licenses for several fishing gears).

Cost dynamics

Costs are generally differentiated according to fleet or fleet segments in bio-economic modelling. Furthermore, cost dynamics are estimated by means of linear functions in almost all models. Differentiated approaches are adopted, however, in regard to the cost structure within the individual models. A minimum approach, used for example in MOSES (Models for Optimal Sustainable Effort in the Seas), simply distinguishes between fixed and variable costs. Fixed costs are assumed to be constant over time or a function of capacity expressed in terms of the number of vessels or gross tonnage, whereas variable costs are generally associated with variations in the fishing effort.
Some models adopt a more sophisticated approach in which specific cost items are extrapolated from fixed or variable costs and simulated using specific functions. For example, cost components that can be simulated separately include the share of added value assigned to the crew (or labour costs), fuel costs, commercial costs and capital costs.

Italian models and their main applications

Italian and Mediterranean fisheries are characterised as being multi-species and multi-gear fisheries. The distinctive features of Mediterranean fisheries, compared to Northern European one, directed management towards input control-based and technical measures. In this context, the bio-economic models developed by Italian fisheries also assumed a structure and characteristics that reflect these specific features. MOSES is the first model specifically designed for Italian fisheries. It was developed in the mid-1980s as an optimisation model that identified the optimum effort level required to maximise added value in the sector. The BIRDMOD simulation model, developed more recently, allows the effects of potential management measures to be estimated on a yearly basis. The availability of these two models has not, however, exhausted Italian research in the field of bio-economic modelling. A new class of models, known as HDA, are being developed over the last few years. These are adaptations of the BIRDMOD model which operate on the basis of simulation objectives and the data available for the area and type of fishery being investigated. A short description of the MOSES, BIRDMOD models and of the HDA class of models is provided below.

The MOSES model

MOSES is a bio-economic optimisation model for the fisheries sector developed in 1984-85 by the Institute for Economic Research for Fisheries and Aquaculture (Irepa) based on the specific features of Italian fisheries. The main objective of the model is to supply estimates of the optimum fishing effort allocation, according to area and fleet segment, on a long-term basis. The final output of the model consists of optimum fishing effort levels, the corresponding catch levels for each species and the added value for each fleet segment.

The BIRDMOD model

BIRDMOD is a bio-economic simulation model for the fisheries sector developed by Irepa and SIBM in 2006 as part of a research project funded by the MiPAAF, Directorate-General for Fisheries and Aquaculture. The model is designed to estimate the effects of a series of potential management measures, such as fishing effort limitations (for example, temporary closure of fishing or reductions in vessel numbers) or restrictions of a technical nature (for example, the use of more selective fishing gear or modifications to the minimum fishing net mesh size). The final output consists of the historical series simulated for all the variables considered in the logical and conceptual framework of the model. The output also envisages a summary assessment of simulated management measures.

HDA class of models

The HDA class of models comprises three models developed since 2007 to generate future projections based on a set of biological and socio-economic indicators for Italian fisheries. The models in this class follow a prevalently economic approach to modelling. The economic module of the BIRDMOD model provided the background to this approach. These models can be considered as variants of BIRDMOD in which the biological module is either absent or developed according to a simplified approach and generally based on logistic models. The simplification of the biological module is designed to allow the models to be also used with a shortage of biological data.

The HDA0.1 model consists only of an economic module and a management module, and can be associated with any biological model in a non-integrated approach. This approach was used as part of the Management Plans produced by the Italian Authorities to implement Article 19 of the Mediterranean Regulation (Accadia *et al.*, 2009).

Integrated approaches have been adopted, however, in the HDA1.1 and HDA1.2 models. Thus, in addition to management and economic modules, these two models also include biological and state variation modules. Both these models were used as part of a study to evaluate a series of alternative management scenarios suggested by the European Commission to reform the Common Fisheries Policy in 2012. The output from the HDA class models consists of simulated historical datasets for the biological and socio-economic variables included in the logical and conceptual framework of the model.

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17.3 The impact of technological progress on the Italian fleet overcapacity level

Gambino M.

Fishing fleet overcapacity, one of the main causes of the decline in fisheries resources, is partly due to the lack of attention given by scientific research and management activity to carefully defining and quantifying capacity and fishing effort. In particular, the rapid technological growth which has led over the years to a considerable increase in the productivity of several fleets, and therefore in fishing intensity, was undervalued factor for a long time. Studies carried out in Italy on the effects of generalised fishing capacity reduction programmes (Sabatella & Spagnolo, 2004) demonstrated how between 1997 and 2002 the nominal reduction in capacity of the Italian fleet was a mere 2% per annum, both in terms of tonnage and engine power. This was well below the technological efficiency growth rate estimated to be around 4% per annum at an EU level (Villasante & Sumaila, 2010). Nevertheless, the same data indicates that between 1997 and 2002, the numerical objectives of the Multi-Annual Guidance Programme (MAGP) were fully achieved in terms of tonnage and engine power.
Fishing capacity is commonly defined as the capacity of a vessel or group of vessels to catch fish. It is traditionally quantified on vessel characteristics, such as tonnage and engine propulsion power. This does not really reflect the amount of effective capacity, which according to the type of fishing activity, should also include other physical variables such as volume of fish holds, freezing capacity and bollard pull. Capacity is one of the fundamental components of the fishing effort, and its amount depends on a set of production factors applied to the production process. The concept of capacity utilisation is closely connected to the ones of fishing capacity and fishing effort, and is defined as the capacity level or, alternatively, as the rate of current or potential catches that can be achieved for a vessel at its maximum capacity. Whenever the current capacity level is below the one that can be potentially reached, a fishing fleet is in an excess capacity or overcapacity situation. Excess capacity is essentially a short term phenomenon, relating to underuse of a vessel and can be attributed to utilization causes, such as lower market prices, rising costs and management measures like an imposed fishing moratorium.
Eliminating overcapacity is one of the main objectives of current fisheries management. Related to this are most of the problems currently affecting the sector, such as over-capitalisation, excess employment, over-exploitation of stocks and decrease in revenues. However, the current estimation procedures seldom take into consideration the variation in capacity arising from the introduction of innovations in the production process. This implies that capacity estimates should take on a “dynamic” perspective so that a capacity estimate also includes the effects of

technological progress which can be measured in terms of greater fishing vessel efficiency. It was estimated, for example, that between 1965 and 1995, the technological coefficient of thirteen fisheries grew by more than 270%, moving from 0.53 in 1965 to 1.98 in 1995 with an annual growth rate of almost 9% (Fitzpatrick, 1997). Analogous surveys carried out in more recent years at an international level estimated that at an EU level there was an annual technological efficiency growth rate of around 4% (Villasante & Sumaila, 2010).

Technological progress can be estimated essentially on the basis of two distinct methodologies:

- statistical calculation of indicators relating to catches per unit effort (CPUE)
- econometric analysis to estimate technical efficiency.

Regarding the first type of indicator, catches per unit effort (CPUE) are productivity indices which can be used both for temporal analysis and for horizontal comparisons between fishery firms. The catches per effort unit ratio compares the variation in production with the effort unit variations, and is based on the assumption that an increase in technological progress should give rise to an increase in fishing mortality and, hence, in catches. Thus, as effort increases, the catches to effort unit ratio should show a tendency to increase. Nevertheless, the catches per unit effort (CPUE) trend requires correct and careful interpretation and should be analysed as part of a long and homogeneous historical dataset. A more correct and exact estimate of technological progress is supplied by an econometric analysis of the production frontiers, whose shifts over time imply that there is technical progress. Production frontier estimates are based on a classical definition of the technical efficiency of a firm, which consists in the ability of each decision making unit to reach the maximum production level for a given input set (Farrell, 1957). Once the production frontier of the most efficient fisheries company has been defined, technical efficiency (TE) is defined as the ratio of the current production of a vessel to its potential production, as represented by the frontier itself. Hence, a TE ratio equal to one identifies a technically-efficient business. A TE ratio of less than one implies that the business is below the frontier and is, therefore, technically inefficient.

The production frontier is commonly estimated using two alternative econometric approaches:

- Stochastic Production Frontier (SPF) estimates
- Data Envelopment Analysis (DEA).

SPF estimates hypothesise that there is a functional relationship between production and the fishing effort components:

$$Y_{it} = f(x_{it}, \beta)\ \xi_{it} \quad \text{(eq. 1)}$$

where Y_{it} is the output, x_{it} is the input vector, β represents the parameters to be estimated and ξ_{it} is the efficiency level for the individual fishing business i at the time t. ξ_{it} varies over an interval from 0 to1. A level of 1 implies the maximum level of efficiency.

The non-parametric DEA approach is a linear programming technique which, unlike stochastic estimates of the production frontier, does not require a production function to be specified and estimated. DEA estimates the reference frontier on the basis of the production units that really exist, which allows a very flexible estimate of the production frontier to be made. It is nevertheless a deterministic approach, which does not take the presence of the stochastic component of the data into account, so that an output data variation due to external shocks, or to measurement errors, is always attributed to technical inefficiency. DEA is output oriented if it measures how much the production level can be proportionally increased without modifying the quantity of the production factors used. Alternatively, it is input oriented if it measures the extent to which the inputs used can be reduced, leaving the output unchanged.

The DEA output-oriented mathematical formula, given the current use of the available inputs and the variable returns to scale, is Max θ (eq. 2)
with:

$$\theta \ u_{0,m} \le \sum_j z_j u_{j,m} \ \forall m \qquad \sum_j z_j u_{j,n} \le x_{0,n} \ \forall n$$

$$\sum_j z_j = 1 \qquad z_j \ge 0$$

where θ is a scalar one, which indicates how much the production of each firm can increase, using the inputs (variable and fixed) in an efficient way. $u_{j,m}$ is the output produced by the firm j, $x_{j,n}$ is the input quantity used by company j, z_j are the weighting factors that measure the distance of firm j from the production frontier.

The value θ is estimated for each vessel separately, with $u_{0,m}$ and $x_{0,n}$ which indicate, respectively, the target output and input levels. The input factors include both the fixed and variable production factors which are tied to their current levels. The restriction $\sum z_j = 1$ considers variable returns to scale.
Technical efficiency (TE) is thus estimated by $TE = 1/\theta\theta$ (eq. 3)
This indicates the maximum output expansion level through efficient input use.

An empirical analysis applied to the bottom trawling fleet and mid-water trawling vessels of the Northern and Central Adriatic on the basis of DEA methodology (Gambino, 2004) showed that in all the fleets considered, more than 80% of the vessels operate at the limit of their capacity, and therefore, almost all of them were efficient. A limit to the application of this methodology to Italian fisheries can be found in the fact that in analysing the capacity components, factors such as the fishermen's skills or the use of on-board technology were neglected. These factors can be a discriminating factor as regards the efficiency of different vessels, and, therefore, the relative fishing capacity estimates. Furthermore, the essentially random nature of Mediterranean fishery makes a stochastic parametric estimate of production functions preferable to DEA. Comparative research applied to the Italian fisheries context (Coppola *et al.*, 2004) has shown that DEA is less reliable than stochastic estimates in homogeneous fishing areas, where it is possible to estimate a single production function to a certain degree of accuracy. Hence, the technical efficiency analysis applied to the Italian fleet, from the 1990s onwards, concentrated more on applying production frontiers (Coppola, 1998). A further advantage of an SPF approach consists in the fact that technological progress can be easily estimated, even through estimating returns to scale. Rising returns to scale are a measure of technological progress, assuming constant fish stocks. For example, applying a Cobb-Douglas function to the historical 1972-2000 dataset of the Northern and Central Adriatic bottom trawling fleet gave rising returns to scale of nearly 2% per annum. In particular, the Cobb-Douglas equation estimated a long-term (or equilibrium) elasticity of 0.59 per aggregate effort (KW*fishing days) and 2.70 per Gross Tonnage (GT). These estimates are consistent with economic theory. The greater marginal productivity of tonnage compared to aggregate effort confirms the long term tendency to prefer a greater use of the capital factor compared to effort.

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