A note on progress in the bioeconomic modelling of fishing activity in the North Sea

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(This note has been prepared using the results of the research team which undertook EC contract FAR MA 1-234. This note should, therefore, be read in conjunction with the reports presented by that team[1].)

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1. Introduction

Over the relatively recent past, bioeconomic modelling has advanced by integrating major theoretical and analytical progress made in both economic and biological modelling. The movements from static towards dynamic models and from global towards analytical models were the first steps in this advance.

More recently, research has turned towards veritable optimisation models incorporating risk, asymmetrical information, and chaotic and multiple equilibria. Attempts to validate such models have been based on case studies of more and more homogenous fisheries (ie small numbers of stocks and exploitation systems) so that the objective function is quite explicit and limited. This change of emphasis has occurred however without a re-consideration of the aim of the models nor of their underlying assumptions (cf bibliography).

Faced with increasingly sophisticated mathematical developments, it is worth noting that "the gap which exists between technical advances in modelling and the utilisation of the results, especially in the formulation of management policy, remains mortifying" (Gates, 1989). The broad questions studied remain within the tradition of bioeconomic modelling, notably: measuring and explaining situations where biological and economic equilibria are exceeded, evaluating the impact of technical regulatory measures and more generally simulating the dynamics of the systems of exploitation and the levels of wealth that they create (rent, producer surplus, distribution of wealth ...).

Within the framework provided by these questions, recent work (cf bibliography) has considered areas such as:

- the spatial management of effort
- the management of national fleets exploiting stocks with very variable abundance in areas open to international competition
- risk management in open access fisheries

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[1] The full reference is: EC project MA.1.234: A bioeconomic model of the North Sea multispecies multiple gears fishery. Contractors: DIFER, IFREMER, SFIA, DIFMAR. Project leader: Hans Frost.

- the management of investment when effort is directly regulated
- the measurement of the efficiency of fisheries policies
- measuring the advantages of compliance with regulations
- the spatial optimisation of control systems in applying regulations.

Generally the aim of such modelling is to explain and predict the impact of management systems on exploitation systems and vice versa. Work to improve understanding of fisherman behaviour has concentrated on knowledge and characterisation of exploitation systems including value-added by the onshore sector (fleet typologies, production systems, firms' strategies ...). The neo-classical economic basis of such modelling has so far limited the use of alternative approaches, such as those of institutional economics.

The result has been an increasingly complex description of the behaviour of firms exploiting open-access resources, but within a decision and management framework which is assumed to be static and non-adaptive. The nature of the administrative process is assumed to be given and unable to cause substantial changes in individual or collective choices.

Over and above the purely technical limits to modelling (some of which are discussed below in the context of the North Sea), it is this static framework that limits the usefulness of modelling especially when dealing with complex management situations (the case of European resources for example). Modelling cannot be considered as the unique method of assessing public policy towards resource management. The assessment of policy cannot be limited to measuring the impact of certain technical measures aimed at reducing effort (mesh size, horse power, fishing time ...) or allowable catches (quotas in their various forms). It is often the precise nature of its application (an adaptive, participative approach based on an ability to simulate and predict) together with effective control measures that determines the effectiveness of a chosen policy.

2. General considerations

Before moving on to discuss an application undertaken in the case of the North Sea fisheries, this section considers some general problems with the economic aspects of bio-economic modelling, especially where a simulation/forecasting approach is required.

2.1 Price formation

One feature of simulation models is that they often take prices as exogenous. The usual justification for this is that the fishery under consideration is part of a world market for the target species and that catches from that particular fishery will not influence the world price. Another reason is that in most cases the shape of the revenue curve is such that even if price is variable the **optimal level of exploitation** is not very sensitive to price changes.

In practice however the price situation tends to be complicated in various ways. First, landed prices received by fishermen may vary according to the quantity landed, first because of the quantity itself and second because the quality of fish may be inversely related to quantity. Second, in many cases a price structure may exist for the species such that larger individuals command higher prices than smaller ones. In some cases, eg Octopus, the number of price categories may be substantial.

An improvement in the level of catches and/or in their structure may be negated at the economic level by price changes. The fishermen could even find themselves worse off if price is sufficiently sensitive to landings.

Economists have tried to model demand in fisheries in various ways. One area that seems deserving of future research would be to try to integrate a demand model into a general simulation framework for a fishery (such as BEAM IV). Otherwise arrays of prices need to be output from economic models and input into simulation models (depending on the purpose of the model).

Prices are important for another reason: they partially determine the level of resource rents available from the fishery. Resource rents are important for two major reasons: they are the reason that there is a fishery problem at all, and they are the major benefit that will flow from fishery management. An estimate of resource rents is needed, therefore, if predictions are required concerning the likely levels of fishing effort and the costs of a failure to manage fisheries effectively. The fact that prices do not affect the optimal level of exploitation is fine if all that is required is some estimate of this level; but is irrelevant if what is required is an estimate of how far away from it the fishery will be.

Demand must therefore be taken into consideration, ideally prices should be endogenous. However the difficulty of achieving such a result should not be underestimated. Demand is a multi-variate function. The price of the species is important, but so are other factors. Economic theory suggests that, in general, the most important of these will be the prices of other species, the prices of competitive foodstuffs (eg chicken), and real consumer incomes. However, in any particular case, a whole range of factors may be important ranging from the Pope to the weather. A demand study is an iterative process whereby likely variables are identified on the basis of theory and knowledge of the particular circumstances. Data is collated on relevant variables (or proxies (instruments) if the original variable is unobservable or data is unavailable). Empirical estimation is undertaken. The relevant variables list may then be modified. The model is then maintained by the regular collection of data and re-estimation. Generally regression techniques are used as the basis for demand estimation.

2.2 Fishermen's behaviour

Probably the most difficult aspect of forecasting and simulation concerns predicting the behaviour of fishermen in response to economic (and other) stimuli and hence in response to management measures.

One approach is to argue that fishermen are fishing for profit and that this is the key variable. In simulation models the usual approach is to argue that if profits are positive then entry to the fishery will occur and if they are negative exit will occur. However this approach suffers the drawback that bang-bang solutions generally emerge and so constraints are usually imposed on the fishery to prevent this happening. For instance, it might be argued that it takes two years to commission a new fishing vessel so that profits now will lead to an influx of vessels in two years time. On the exit side, it might be argued that entry and exit conditions are asymmetrical so that if losses occur fishermen will nonetheless carry on fishing providing they cover their variable costs since their assets are fixed in the fishing industry.

In the case of a particular fishery however numerous complications have to be considered. First, a bang-bang solution may be the most accurate if vessels can switch their effort from fishery to fishery in response to profits. Second, clearly the profits available from alternative fisheries and even alternative occupations are important, so that even with accurate predictions of profits for a particular fishery it may be difficult to predict the behaviour of fishermen.

There is also a need to consider different time periods since the reaction of fishermen may be very different in the short run, when they simply inherit the consequences of yesterday's investment decisions, and in the long run, when they decide the level of investment in various economic activities of which fishing may be only one. The importance of an understanding of behaviour cannot be overemphasized in the context of designing management measures. Some anecdotal evidence may help to give a flavour of the kind of problem being faced.

If fishermen are aiming to maximise profits and a tax is imposed on landings then their desired level of effort will remain unchanged. They will make less profit because of the tax but this will be true of all levels of effort so that the point at which they maximise their profits will not alter. The only exception to this would be if the tax was so high as to drive them out of business. If however their target is to achieve only a satisfactory level of profits then imposing a tax will encourage them to increase their effort in an attempt to re-establish their previous profit level. In this case a tax would have the unintended side effect of increasing fishing effort simply because fishermen's objectives are misunderstood.

In the Moroccan pelagic fishery, installation of power blocks had no noticeable effect on employment. Although difficult to understand to begin with, this result is easily explained once it is realised that many vessels are (effectively) owned by the crew, whose major concern is employment. Unless features such as this are understood, it will be impossible to predict the impact of management measures.

The problem in this area is not simply one of data collection but of investigations to determine the factors underlying fishermen's tactics and behaviour.

2.3 Exploitation level versus regulatory framework

Much of what has gone before stresses the difficulty of arriving at an optimal exploitation level and predicting responses to it. It is for this reason that much of fisheries economics has been concerned with finding an optimal regulatory framework - the opinion being that it matters less what the target level of exploitation is than how it is achieved.

Fisheries economics currently lays great stress on the issue of ownership of resources. The reason is simple. The problem of fisheries management arises because a valuable resource (the fishery) belongs to no one. The fishermen confuse therefore returns which should accrue to the resource owner with those that should accrue to the resource exploiter. If the fishermen both owns and exploits the resource then his reaction is different (the problem is not of overexploitation of Scottish salmon farms - although even in aquaculture some element of overexploitation may occur due to lack of ownership of the marine/brackish environment). Once ownership of the resource is allocated to a person/company/body then that entity should extract the returns due to the owner (resource rents) and the attraction of exploiting the resource will be correspondingly diminished. As a result many of the fisheries problems which are common at present will be resolved (most notably the issue of overexploitation) although other problems may appear (eg Australia - need for stock assessments, paid for by industry; New Zealand - disputes over ownership).

3. Bio-economic models for the North Sea

This section considers the way that some of the problems discussed above were dealt with in bioeconomic modelling of the North Sea. In order to draw as many lessons as possible from the work undertaken over a three year period in developing bio-economic models for the North Sea fisheries, the following points are discussed:

1. The objectives of the North Sea programme
2. The basic model framework
3. Results
4. Concluding remarks

The aim is to extract the most significant developments.

3.1 The objectives of the North Sea programme

As noted above, bio-economic modelling is generally applied to well-defined fisheries using a clear objective function. However in the case of the North Sea programme, the geographical, biological and economic entities taken into consideration were widespread and diversified, and the research objectives were ambitious. The attempt to model North Sea fisheries pre-supposed the following questions:

- i the variability and biological interaction of the resources

- ii the social, administrative and economic differences arising from the different national contexts (even when they are organised within a common European zone)

- iii the differences in objectives leading to different assessments of the efficacy and efficiency of management

- iv the identification of the real goals of the CFP underlying the measures undertaken towards the resource, the markets and production structure.

- v the problem of heterogeneous national databases.

In summary it can be said that the North Sea context did not particularly facilitate the bio-economic modelling exercise. The interest for the group of economists concerned was the attempt to study a complex EC fishery by expressing mathematically different modules of a relatively classic model (see below 3.2). It was expected that progress would be made on the costs and earnings module by one country, on price formation and investment functions by another ... The research strategy aimed to integrate, using the modular structure, the various theoretical advances made. The stages laid down for this exercise were:

1. description and analysis of interactions
2. formation of landed price, analysis of supply and demand
3. cost and investment functions
4. development of a bio-economic model
5. analysis of the impact of CFP

The results obtained so far concern the first three elements.

3.2 The STCF model framework

An STCF sub-group meeting held at Nantes, France in September 1989 established the basic model framework used in the North Sea study. The first part of model calculates a do-nothing baseline simulation and then compares the impact of proposed management measures to this. The comparison is done using the relationship between catches, prices and costs of fishing. This relationship enables one to calculate total revenues and profits. The model then considers the way that fishing effort might be expected to develop in response to such profits.

The structure of the model is quite simple. The difficulty is the inter-relationship between variables making it difficult to know where to break in to the cycle.

Essentially:

[1] $\pi = TR - TC$

[2] $VA = \pi + w$

[3] $w = \alpha.TR$

[4] $TR = p.q$

[5] $p = p(q,n)$

[6] $q = q(f \ldots)$ (ICES multi-species model)

[7] $TC = c(f,s,q)$

where π = profits, TR = total revenue, TC = total costs, VA = value added, w = wages, α = share rate, p = price, q = quantity landed, n = a set of other variables influencing demand, f = effort, s = stock size.

Some simplification of equation [7] is possible since both s and q depend on f, so that ultimately TC depends solely on f, for a given level of technology, this being a standard assumption of fisheries economics.

Equations 1-4 are definitional. The important part of the model is the correct specification and estimation of equations 5-7. Equation 6 should flow from the biological side of the model, although if the biological model is specified in terms of mortality (or multipliers of effort) some way has to be found to translate the results into nominal fishing effort so that equation 7 becomes meaningful. Equation 5 is the demand relationship and this will flow from the economic side of the model. The precise specification of the equation will depend on the fishery or fisheries being studied.

The link with fisherman behaviour (and the element of circularity) is introduced by equation 8 which attempts to specify how fishing effort is determined. Such an equation is clearly required. Models where the impact of management measures is investigated by simulating the operation of the fishery over a large number of periods on the assumption that effort is exogenous are likely to give very misleading results. Generally, in such models, measures such as mesh size increases and seasonal closures look very attractive because only the impact of these measures on profitability is considered. However, changes in profitability will affect behaviour which will affect the long-run profitability of such management measures. The result is that a fishery can easily be driven into a situation similar to that of the US part of the Pacific Halibut fishery where the fish stock itself is in fine shape but the fishery operates two days per annum with vastly excessive levels of fishing effort. At each stage a reduction in open season length looks attractive but the impact is to encourage yet more effort into the fishery requiring yet another reduction in season length and so on, apparently until the season length tends to zero.

[8] $f = f(\pi^*, o, w)$

where f = effort, π^* = target profit level, o = other objectives, w = weather.

Fisheries economics expects that due to the very competitive nature of fishing, those enterprises that fail to maximise their profits will be driven out of business in the long run. Fisheries economic models frequently assume therefore that the goal of enterprises will be profit maximisation and that π^* will be the principal determinant of fishing effort. However, it is very important to verify this hypothesis since if fishermen are following different goals predicting their response to management measures will be impossible.

Some modifications were later made to the model. In particular the effort function was broken into an effort allocation function (equation [9]) representing short-run effort decisions and an investment function (equation [10]) representing the long run.

[9] $f = f(\pi_{t-1}, I_{t-1}, O, Q)$

[10] $I = I(\pi, r, T)$

where r = real interest rates and T = technology.

3.3 Results

The first task was to structure an economic database with series relating to prices, production costs, landings, revenues, wages and effort. These data (constituted on a national basis - UK, Denmark, France) led to the selection of fishing fleets and the identification of the major species (in revenue terms). Results obtained include landings (by weight and value) by biological category (demersal, pelagic) by species and often by landing place and by fleet (in terms of "métier"). The species considered are generally: plaice, herring, cod, mackerel, sole, haddock, whiting and saithe. The price series are over 10 years in most cases. Results have also been obtained relating to the identification and verification of the seasonality of the price series. Data relating to the fleets' composition and dynamics (by length class, HP, port, métier) are relatively homogenous over a 10-year time period. Investment data remain general in terms of numbers of new vessels, capital invested (insurance values in Denmark's case), second-hand values, engine replacement costs ... These series are usually available for 5 to 10 years. The data set was obtained from fisheries ministries or official agencies, and from the specialised financial sector. Another data set, with a homogenous structure, relates to international trade. This contains imports and exports by species, product groups, exporting and importing country. Again 10 years data are available.

The complete data set was the basis for the general description of the fisheries undertaken in the first part of the project.

The data requirements and their availability will now be considered using the examples of particular modules. Although concerned with a wide range of issues, research concentrated on two questions which are at the heart of an understanding of the dynamics and results of exploitation and of regulation:

- i fishing strategies (choice of inputs, gears, zones, target species ...)
- ii the mechanism of price formation underlying revenue determination.

3.3a Fishing strategies

The model developed allows the behaviour of the North Sea fisheries to be simulated in terms of métiers, species and country. At this stage, disaggregations in terms of size and age are not considered (data availability and size of database are two problems encountered in this area). This phase of the simulation can only be used to test the gaps between the actual and predicted situations. Once tested the system of equations could be used for optimisation purposes. More immediately the model might be used to evaluate the impact of sectoral regulatory measures (measuring the gains and losses associated with different technical measures).

Along with some estimations (cf para 2.2 below) it was felt necessary to test using interview methods the adequacy of certain hypotheses concerning fishermen's behaviour taking into consideration non-economic or combined variables (ie combinations of economic variables) that may influence strategic behaviour. In an attempt to understand the motivations underlying fishermen's choices, a set of parameters was considered directly by interview. The traditional postulate of neo-classical models, profit maximisation, is not always necessary to understand fishing behaviour. The factors that affect the daily decisions of fishermen may be combinations of short and long term objectives. A good understanding of objectives is essential if models are to have a solid foundation[2]. The interview results tend to demonstrate that because of the combination of economic and non-economic factors it is inappropriate to model simply in terms of relative revenue or profit.

Whilst not wishing to go into a description of the different technical measures used in the CFP, it is important to note the impact that modifications of biological, technical or economic parameters may have on short and long-run fishing strategies. In the short run it is usually the parameters determining the composition and distribution of effort that are changed (fishing time, target species, fishing gear). Structural changes in the level of capital and labour employed tend to occur in the longer run.

3.3b Some estimations

Costs and earnings functions were estimated at the métier level using standard econometric techniques. The verification of the economic data was done by comparison of various sources (Ministries and other management agencies, fishermen, banks).

The structure of costs is strictly related to the time scale being considered. This is the case for instance with fixed and variable costs. The latter depend on fishing time or on landings while the former are independent of the level of activity. In this case the time period is the "short run" (ie from one trip to one year of activity). Only vessels in operation over the period are taken into account. The number of fishing days is also used but the problem of steaming and searching time has not been resolved which biases the number of days absent as an indicator of activity. The equation used is:

$$TC = TVC(Q,v,L) + TFC$$

TC = total cost, TVC = total variable cost, TFC = total fixed cost, Q = landed weight, v = landed value, L = length of trip.

For a given vessel, these costs are broken down for each of its activities (different fisheries with different target species at different times).

The estimation of capital depreciation requires some knowledge of opportunity costs. In most cases cost data are available but in terms of average values for groups of vessels. Eventually

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[2] In the case of the North Sea study, interviews were undertaken with skippers from a sample drawn so as to ensure that it was representative of the units being regulated by the policy being evaluated. As a result the sample is not representative of the North Sea fisheries sector (small vessels are under-represented or absent). The sample was stratified by size and métier. 227 people were interviewed in GB from which data were derived concerning various aspects of their activity and especially concerning their reasons for practising different métiers, either in terms of maximising (profits, turnover, labour and vessel rewards, quota, a combination of revenue and quality of life, landings ...) or in terms of satisficing (profits, revenues ...). Other motivational factors were included - eg decision to purchase a vessel, decision to undertake a fishing trip, decision to return to port, choice of fishing zone.

costs per vessel may be required. The list of costs taken into account includes: diesel fuel, landing taxes, auction hall costs, wages, gear, maintenance, insurance, interest, depreciation. Work on cost data often involves breaking down global figures for given vessels or working from averages. No exhaustive and detailed fishing cost database exists. Typically some values are estimated and others obtained by interview. In the case of the Scottish fleet for example the estimated function was:

$$\log TVC = a \log N + b \log V$$

and for the English fleet:

$$\log TVC = a \log N$$

where N is days absent and V is value landed.

Wages (W) for both fleets were estimated as:

$$W = a + bV$$

The set of equations is estimated by vessel group in terms of métier or a homogenous group in terms of activity over some given time period (the métier being the utilisation of one gear to target a particular species in a particular place).

In the case of the Danish fleet linear programming was used to simulate the choice between different combinations of target variables. These trials confirm the importance of the time period being considered.

In addition to the estimations concerning the possible choice of activity, the research team attempted to assess separately the validity of the various relationships that might later be used in an optimisation model. In addition therefore to simulations relating to fleets and species, a simulation was undertaken with the general goal of maximising the value-added by the fishing sector. The latter may seem premature at this stage of the research given the difficulties, not yet dealt with, involved in modelling biological and economic interactions between modules which have been investigated separately at different stages of the project. This aspect of the work must be considered exploratory aimed mainly at the connection between individual strategies and the global economic goals. Annual data were used for this phase with the result that the time scale has been aggregated beyond that necessary for an understanding of the behaviour of the fishermen.

3.3c Price and markets module

The study of price formation and market interrelationships (type of marketing, international trade, landing places, nature of supply and demand ...) was the second module of the North Sea programme. The theme of this aspect of the research was to investigate the need for separate and simultaneous estimation of price formation equations for major species and within each species for product classes (size, refrigerated, frozen ...). The hypothesis of exhaustivity implied a considerable increase in the number of equations. The second hypothesis to be considered was linked to an understanding of market hierarchies (place of sale, port, country ...) which might explain the role of price leader played by one place on one species or product. Identification of causal links from a dominant species should improve the definition of management units rather than relying simply on geographical, biological or political entities. In a case study of sole in France, the market leader (spot price) was identified as were measures of dependence for related markets.

Within the context of bio-economic modelling, this finding led to an attempt to refine the understanding of factors explaining the variability or stability of revenues, of profits and of fishing strategies[3].

The research undertaken in the module concerning price formation is typical of the methods used throughout the study. It demonstrates well the idea of integrating within the model new information whilst meeting the objectives of:

- reducing the number of variables explaining fishermen's behaviour by identifying and specifying the relationship between similar variables (prices, revenues, profits)

- and limiting the number of independent variables (spot price in this case) so as to limit data requirements.

Starting from a position where price is often exogenous and constant, the research attempted to include a price function while limiting the negative aspects (data needs and increased number of equations).

3.4 Concluding remarks

First of all, the limited scope of this paper must be noted. It certainly does not aim to present all of the important work undertaken within the framework of the STCF North Sea group nor within project FAR MA.1.234. The aim rather was to expose the basic philosophy and to use the results obtained to make a contribution to the so-far incomplete modelling exercise.

Major theoretical questions remain which have not been considered here relating to stock-recruitment relationships, nominal and effective effort, natural mortality, predator-prey relationships, and the need to define precise objective functions that can be evaluated as the CFP.

The work discussed has set out the data problems: constitution of the database, validation, relationship between the biological and economic datasets. The most important aspect of the

[3] Sole was chosen partly because of its importance in French fisheries and partly because of the complexity of intra and international trade in it. This species also has the advantage of a relatively detailed statistical coverage from landings by size to different levels of prices (portside, wholesale, retail). It is also a species caught in various zones by various fleets and is subject to EC quota and marketing regulations. International competition plays an important role in price determination. Finally, sole is sold in various ways (fresh, refrigerated, fillet, frozen ...).

study is the demonstration that before attempting to model a system as complex as "North Sea fisheries" it is essential to define the entity to be modelled. This definition might begin by considering the timescale over which data is to be collected concerning different variables and over which different relationships are to be estimated.

A balance needs to be found between the theoretical applications concerning fleet behaviour presented in the economics literature and the desire to assess the impact of the CFP on complex North Sea fisheries. Such a balance might begin by on the one hand, a clear identification of the important variables, actors, and functions in the North Sea case and on the other by a review of the international literature in this area so as to identify the advantages, limits and disadvantages of different approaches to these questions.

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