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Market-Based Fisheries Management:

A Selected Overview

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INTRODUCTION

Market-based management is a relatively new term that has been used by various authors in different connections and with different meanings. The aim of this review article is to give an overview over some publications where this concept has been used (or could have been used). I will start by giving a discussion of the objectives of and approaches to fisheries management. Based on this discussion the review of the literature is divided in two categories, namely incentive-based management and traditional command-and control management. At the end a summary and some conclusions are presented. The list of papers that is being reviewed here is by no means exhaustive but rather focusing on some of the aspects of market-based management.

Objectives of fisheries management

Fisheries management is supposed to fulfil objectives of economic, biological, social and political character. In the following I will in particular focus upon the economic and biological objectives of management. The main economic objective is to achieve efficiency subject to the biological constraint, which is to maintain long-term sustainability.

Economic efficiency and biological sustainability can in principle be regarded as separate issues. Sustainable harvest can be achieved at different suboptimal levels from an economic point of view. Vice versa, a given harvest can be taken efficiently even though it does not represent a sustainable harvest. It is therefore a successful combination of these two issues that characterizes good fisheries management.

Alternatively one can say that the overall objective of fisheries management is to avoid economic and biological overfishing. Economic overfishing is defined as fishing a given catch using excessive costs and resources. Such excessive costs are usually due to overcapacity, and the long-term goal is therefore to reduce this overcapacity caused by externalities inherent in exploitation of common pool resources.

Biological overfishing can be divided in two categories. Strong biological overfishing is defined here as harvesting at a non-sustainable level such that the stock continually declines.

Unless this is part of a deliberate interim policy to reduce the stock from a too high level[1], this will eventually lead to extinction. Weak biological overfishing is defined as harvesting at a sustainable (steady state) level, but such that the same catch also could have been harvested sustainably at a higher stock level.

As economic efficiency and biological sustainability are separate objectives, they call for separate tools for management. Sustainability can be achieved through catch quotas (total allowable catches = TAC), limited entry, effort restrictions, time restrictions, taxes, etc. Catch quotas is probably the one that is most frequently used of these means, but it is often combined with other restrictions.

Economic efficiency, on the other hand, has to do with how this catch is taken no matter what size it has. This is primarily a question about how the catch is harvested in time and space and, not least, how it is allocated between fishermen. Allocation between vessel and gear types, geographical distribution and distribution in time over the season are all included here. The overruling objective is to achieve cost efficiency and avoid wasteful use of the fishing effort and thereby avoid unnecessary costs. This includes all kinds of costs, even the costs of management itself. The overall aim, however, is to find the optimal size and structure of the fishing fleet.

The two main objectives of fisheries management are economic efficiency and biological sustainability. In the following, it will be shown that market-based management tools can deal with both these objectives. When there is more than one objective, however, we also need more than one tool. In general, we need as many management tools as we have objectives. It is therefore often useful to combine market-based management tools, the definition of which I will come back to later, with other management tools.

Approaches to management

Fisheries management can be defined in two broad categories, one is the command-and-control approach to management and the other is the incentive-based approach (Grafton et al. 2006). The command-and-control approach is basically what the name says, a managing authority who tries to the best of its ability to calculate optimal targets or reference points for

[1] Fish stocks can sometimes be too large with respect to biological surplus production.

some key variables, and then do their best to control that the agents behave according to the rules and live up to the targets and the limits they have been given. The tools may be total catch quotas, individual non-transferable catch quotas, effort restrictions, time restrictions, etc. This is a top-down kind of management. It may under favourable conditions be very efficient because it is a direct form for management. It requires, however, that the authority has sufficient knowledge and information to set the correct targets and limits. It requires also that the agents find these targets and limits reasonable, otherwise history has shown that fishermen try to avoid rules they find unjust or unreasonable.

Incentive-based management, on the other hand, is the opposite of top-down management. The idea is that by giving the agents correct motivation, they will have incentives to avoid biological overfishing and economic inefficiency themselves. Such motivation is usually associated with some sort of rights-based fishing. This can be individual property rights to harvest shares, community rights or territorial rights. Other mechanisms to enhance motivation are, for instance, taxes or fees, pricing of ecosystem services, etc.

In many ways, the failure of the command-and-control approach has motivated the introduction of incentive-based management. The term market-based management has very often been associated with the latter approach. The reason for this is that as soon as property rights exist, markets for these property rights will form in some way whether they are institutionalized or not. On the other hand, managing authorities can also take market considerations into account when they calculate their optimal policies. In fact, it is my claim that lack of such market consideration is one of the main reasons for the failure of the command-and-control approach. It is a matter of fact that market-considerations usually imply more restrictive and conservative exploitation of the resources. The reason for this is that both lower harvest and higher stock levels improve the economic efficiency when market considerations are taken into account. Lower harvest implies higher prices for the product whereas a higher stock will improve the availability of fish and therefore reduce operating costs. Both these aspects contribute to better economic performance and, at the same time, to preserve the stock.

There are several reasons why market considerations usually have not been taken into account. One reason is general scepticism to this line of thinking as many believe that market considerations only imply reaping short-term benefits without thinking about the future.

Another reason is that, with the traditional approaches, market considerations require huge amounts of data and information that are typically not available and may be very costly to provide and include in management. Therefore biological reference points such as target fishing mortality, target escapement levels, minimum threshold levels for the spawning stock, etc., have been dominating in most countries' fisheries policy.

Fortunately, methods exist to evade the information problem. In the following it will be shown that there are several advantages to be gained by collecting information about the state of the fishery through the market for property rights. The need for large amounts of detailed information can also be evaded by applying simplified approaches and including market considerations within the framework of command-and-control management.

Market-based management tools.

The two most common market-based management tools are taxes and rights-based management. In addition market considerations can also be included by the authorities in traditional command-and-control management. How this can be done will be reviewed later in this article.

Taxes reduce both short- and long-term effort because it makes harvesting more costly. In the long run it will also affect the optimal equilibrium and reduce overcapacity. In principle an optimal tax should reflect the external costs each fisherman imposes upon others by reducing the fish stock. In practice it is an immense task to gather all the information necessary to achieve this. Rights-based management is associated with property rights one way or another. In principle, at least, the need for information here is less as decisions are left more to the individual agents in the fishery. In particular, the need for information is evaded through so-called minimum information management schemes that will be reviewed in a later section.

INCENTIVE-BASED MANAGEMENT

Incentive-based management is about giving correct incentives and motivation to achieve the objectives of management. In order to do this, fishermen must have an interest in the overall performance and development of the fishery and not only in their own activities. This way it will be possible to internalize some of the inherent externalities in the fisheries sector. These externalities (effects that fishermen have on each other) tend to cause overcapacity and reduce economic efficiency. One obvious way to give fishermen a stake in the overall performance of the fishery is by issuing property rights. This is called rights-based management.

Rights-based management includes individual quotas (IQs), individual transferable quotas (ITQs), community quotas (CQs), etc. It works through the idea that allocating exclusive right to harvest, for example a certain fraction of the TAC, will provide incentives to preserve the resources and harvest efficiently. Rights-based management is, in other words, one kind of incentive based management. In the following, I will particularly focus upon ITQs.

Individual Transferable Quotas (ITQs)

Although property rights can be in many forms, ITQs are by far the most common. The main purpose of ITQs is to increase efficiency by reducing overcapacity. It is, in other words, primarily a tool for economic efficiency and not for stock conservation as some people seem to believe, although this may be an indirect effect through the incentive mechanism.

The literature contains many examples of the success of ITQ systems with respect to increasing economic efficiency. Clark et al. (1988) and Geen and Nayar (1988) were among the first to develop models to describe and analyse ITQ-fisheries, namely the ITQ-system implemented in New Zealand.

Arnason (1993) describes the evolution and structure of the Icelandic ITQ system and discusses the social and economic impetus of the system in the various fisheries. He finds clear indications of general improvement, sometimes substantial, of the fisheries in question. Adelaja et al. (1998a) find that the same applies to the Mid-Atlantic Surf Clam and Ocean Quahog fisheries after introduction of ITQs, namely enhanced value of individual vessels, reduced excess capacity, better economic performance and even an overall resource conservation effect. These results are supported by Weninger (1998). Adelaja et al. (1998b) find no evidence of monopoly power in these fisheries although the number of operators has declined drastically.

Dupont and Grafton (2000) study the economic effects of ITQs in a Nova Scotia multi-species fishery, in particular effects on inputs, outputs, prices and vessel exit. They find that the introduction of ITQs has led to increased quality and price of the products and assisted fishers to voluntarily exit from the fishery. Further, Dupont et al. (2002) perform an empirical study of capacity and capacity utilization in the same fishery and compare the fishery before and after introduction of ITQs. Their main conclusion is that there is little evidence of significant change in individual capacity utilization but the aggregate excess capacity in the fishery has been reduced. Finally, Dupont et al. (2005) study individual vessel performance over time and across vessels in this fishery. The short-term results suggest that larger vessels have benefited most from ITQs but all vessels have enjoyed higher prices for the output. The long-term results indicate that the ITQ program has encouraged exit from the fishery and thereby more efficient operations to prevail.

Anderson (2000) investigates intertemporal effects of introducing ITQs and finds that these depend upon a large variety of factors such as the prevailing regulation program, current stock size, existing fleet size, composition and mobility and upon the dynamics of the stock and fleet.

Eero, Vetemaa and Hannesson (2005) examine the ITQ system used in the Estonian trawl fishery, which combines this with auctioning part of the quota. They find that an auction system in parallel with ITQs can be considered and effective way to increase the share of property rights to the most efficient enterprises and hence speeding the process of reducing excess capacity.

Newell et al. (2005) examine the development in New Zealand’s ITQ system, which is the world’s largest, over a period of 15 years. The study covers 33 species and more than 150 markets for fishing quotas. They find evidence of economic rational behaviour and increasing prices over time indicating increased profitability due to rationalization.

In his book “The privatization of the oceans” Hannesson (2004) gives a thorough review of the development of property rights in fisheries with an historic overview dating back to the sixteenth century. In particular Hannesson reviews the development of ITQs, and examine both cases where it has been successful and cases where it has been less successful.

Minimum Information Management Schemes (MIMS)

In this section so-called minimum information management systems will be reviewed in a bit more detail. Arnason (1990) was among the first to use the term market-based management in connection with fisheries. The background is the well-known fact that there exist externalities in commercial fisheries that lead to inefficient harvesting, overexploitation and excess capacity. It is also well-known that these problems in theory can be solved through various means such as taxes, quotas, limited entry, effort control etc. A drawback with most of these means is that they are costly to implement correctly and require a huge amount of data and information. It is argued that in most fisheries the data requirements for calculating optimal taxes, quotas, etc. greatly exceed the capacity of the managing authorities and these means are therefore of little practical use.

Instead a system is suggested that use the market mechanism in order to allocate quotas optimally and reduce effort with a minimum of information about the fishery at hand. This is called Minimum Information Management Schemes (MIMS). This is a system where the managing authority takes advantage of the market mechanism in order to solve the inefficiency problem inherent in fisheries. It is demonstrated that both catch quotas and taxes can be used to manage a fishery optimally, but in order to calculate the optimal time path of quotas the manager needs at his hand an immense amount of data and information about the economics of the fishery. The authorities actually need to know all the economic details of all the fishing firms in order to allocate the harvest shares optimally.

The idea with MIMS is that no one knows better the economic details about each firm than the firms themselves. As the biological state of the fish stock is also an important determinant of each firm’s profits, it is reasonable to believe that the firms make efficient use of their information in a competitive environment. The result of this is that only those firms who make efficient use of their information will survive in the long run.

The next question is whether there exists a way for the authorities to use the market information in order to determine an optimal quota allocation. The answer is a system of individual transferable share quotas (itsq). The main difference between share quotas and quantity quotas is that variations in the total allowable catch will be directly inflicted upon the firms without compensation whereas with a quantity quota system variations in total allowable catch will be compensated by the authority through active participation in the market.

The properties of the share quota system are that these share quotas are permanent shares in the total allowable catch rate and serve as an upper limit on the individual catch rate. Further there exists a market where these share quotas are perfectly divisible and transferable and the traders are price takers. The total allowable catch rate and the initial shares are determined by the quota authorities. Under this system, and given a time path of total catches, the social optimum and the individual optimum will be the same. However, the authority still needs a huge amount of information about the economic conditions in order to determine the optimal total catches. The idea behind the minimum information management scheme is that all this information can be gathered by the authority by monitoring the market for share quotas instead of having to gather information about each individual firm. The reason for this is that the market price for quotas equals the present value of the expected future resource rent in the fishery. All the authority then needs to do is to adjust total quotas such that the value of outstanding quotas is maximized. It is, however, important to keep in mind that the assumption about permanent share quotas is crucial for this scheme to work.

The theoretical framework for the minimum information management scheme was developed by Arnason (1990). Batstone and Sharp (2003) used data from one of New Zealand's snapper fisheries to test this theory empirically. Econometric analysis confirms the proposition that quota prices can be used by the managers to improve the decision process for total allowable catches. The rent maximizing catch in 1996 using the empirical model was estimated to 3982 tonnes which was remarkably close to the industry's proposal of 4000 tonnes and at the lower end of the range recommended by the biologists, which was 4150 – 7350 tonnes. The biologists' aim, by the way, was to find quotas that resulted in maximum sustainable yield (msy).

The MIMS appears to be sound both from a theoretical and an empirical viewpoint. It is, however, important to keep in mind the underlying assumptions, and in particular the assumptions about perpetual share quotas.

Asche (2001) show another type of information that can be extracted from available data on the quota market, namely the fishermen's implicit discount rate. This again gives information about how well the system is working. Asche finds that typically discount rates are very high shortly after introduction of ITQ systems, and then they start falling. This indicates that it takes time before the full benefit of ITQ systems can be reaped, and it also gives an argument for not letting the property rights be perpetual as this hinders flexibility.

Problems with ITQs

However, as many authors point out, there may also be problems associated with ITQ systems. Anderson point out that ITQ-systems may give some adverse incentives such as inefficient processing at sea if quotas are stated in unprocessed terms (Anderson, 1991) and high-grading at sea (Anderson, 1994). Turner (1996), however, finds that the problem of high-grading can be overcome by replacing weight-based ITQ-programs with value-based ITQ-programs.

Lindner et al. (1992) examine the generation of resource rent during a transition to an efficient quota management system and find that industry returns may be low or even negative during the adjustment phase. Again the case is New Zealand.

Boyce (1992) demonstrate that even though an ITQ-system is efficient with respect to internalizing the inherent common property externality it may still be subject to other externalities that are not reflected in the quota prices, for example production externalities like congestion. Danielsson (2000), however, disputes Boyce’s result that ITQs are inefficient in the presence of congestion externalities. Other inefficiencies that may prevent ITQ-systems from working properly may be rent-seeking and the principal-agent problem as pointed out by Edwards (1994).

Squires et al. (1994) use a model with pseudo-data to study incentives for disinvestment and industry exit after quota exchange has taken place. They find that the expected capacity reduction may not always occur except over a protracted period even if sufficient quota change take place due to imperfections in the market. If opportunities outside fishing are perceived to be small, the sufficient quota exchange may not even take place. They suggest that attention should not only be given to the market for fishing rights but also to the market for inputs such as capital and labour.

Matulich et al. (1996) include both processors and harvesters in an analysis of ITQs, and find that under harvester-only allocation of fishing rights, processor quasi-rents will be redistributed to harvesters and may jeopardize adoption of ITQ-schemes unless the processors are compensated or unless initial allocation is given both to harvesters and processors.

Matulich and Sever (1999) elaborate further on this question and develop two alternative Pareto-safe initial allocations between the harvesting and processing sectors. Market structure is shown to be crucial both to achieve efficiency and to avoid unintended wealth redistribution.

Mathiasson (1997) points to the problems that arise if local authorities have different objectives than central authorities. Local authorities may, for example be more concerned with keeping quotas within their municipality in order to avoid unemployment than with overall economic efficiency. Hannesson (2000) points out that if labour is rewarded by a share-system, ITQs may lead to overinvestment. Market power in the labour market on the side of the crew may, however, correct for this to some extent.

Armstrong and Sumaila (2001) use a model to analyze the effects of a hypothetical ITQ system in the North-East Arctic cod fishery. They find that the existing allocation of the Norwegian TAC between trawlers and coastal vessels leads to economic losses. Further the model shows that if the two vessel groups harvest upon separate substocks that interact cannibalistically, then introduction of an ITQ system may not be bioeconomically optimal. The reason for this is that the biological advantage of harvesting with two different groups may be lost if the ITQ regime leads to too much concentration of quotas within one group. This is a likely development as concentration of quotas within the trawl group will give the best economic outcome.

Many authors emphasize that the transition to a more efficient fishery with optimal fleet structure may take a long time. Vestergaard et al. (2005) point out that one explanation for this may be sunk costs. Their analysis shows that the annual lease price of quotas for a long period will be in a range where the long-run optimal fleet structure is not attainable.

Alternatives to ITQs

Community rights, territorial rights, etc., all represent incentive-based management mechanisms in addition to ITQs. Young (1999) describes the fishing-right system in the Australian state New South Wales. This is in many ways similar to ITQs, but focus is on fisheries rather than species. Instead of quotas of each species they use allotment of shares in the fishery. The purpose is to give fishermen a direct financial interest in the future of the fishery and thereby increase the probability that fishery use will remain both sustainable and consistent with social objectives through time. Holland (2000) argues that group rights can achieve the same benefits as individual rights with an example from Alaskan groundfish fisheries.

Holland 2004 review a number of cases where inefficiencies continue to exist under systems with rights-based management; both ITQ systems and territorial user rights. He suggests better spatial refinement of the quotas, that is specified rights to undertake different activities in different areas as one remedy for these shortcomings. Holland, however, acknowledges that this may turn out to a quite costly enterprise.

Landing Fees vs. Quotas

In this section I review some papers on fees and taxes, and in particular how taxes compare to quotas.

Weitzman's pioneering work (1974) within the pollution control literature shows that if the marginal benefit function is relatively flat compared to the marginal cost function, tax regulation is preferred to quantity regulation and vice versa. Jensen and Vestergaard (2003) discuss the conditions for generalizing the analysis in Weitzman (1974) to fisheries, and find that the results hold for schooling fisheries with and without search costs but they may not hold for a search fishery.

Weitzman (2002) compare two market-based fisheries management instruments, namely landing fees and harvest quotas in the presence of stochastic stock-recruitment. The model used is the one developed by Reed (1979). Reed shows that when the harvest is chosen after the uncertainty has been resolved, the optimal policy is a bang-bang constant escapement policy. Clark and Kirkwood (1986) use the same model to show that when managers are forced to make decisions before uncertainty has been revealed, the optimal solution is a fairly complicated non-constant feedback solution that must be solved numerically. Weitzman uses the same framework as Clark and Kirkwood for his comparison. Harvest quotas have the advantage of directly controlling the quantity caught but are unable to prevent the use of excess effort and thereby secure economic efficiency. Landing fees, on the other hand, will reduce the excess effort to some extent but can not prevent overexploitation of the stock in years with low recruitment. Weitzman only considers a proportional (linear) landing fee. As a reference solution he uses the hypothetical perfect-information first-best solution of the stochastic problem; that is when the uncertainty is revealed one period ahead. The somewhat surprising result then is that a landing fee is able to attain this first-best solution, and is therefore always superior to the harvest quota.

The logic behind this is that the first-best policy is the most rapid approach to a constant escapement, and such a constant escapement can not be achieved by setting a harvest quota before the uncertainty is revealed. A correctly chosen landing fee, on the other hand, can achieve the most rapid approach to any escapement level from any recruitment level. Therefore an optimal landing fee is always superior to a harvest quota policy. The bottom line is that by using a landing fee the manager can set aside the need to know the actual recruitment and concentrate only on escapement. The landing fee achieves this because it is a control of effort rather than harvest. By controlling harvest there is no way to avoid the need to know the recruitment. As usual, the result depends on the assumptions in the model. If the uncertainty is of economic instead of biological character, or if marginal profits are fairly independent of the stock, harvest quotas may be preferable to a tax.

The use of taxes as an incentive-based instrument is also advocated by Sanchiro (2003). Androkovich and Stollery (1991), however, point out that the difference between quotas and taxes may be small, and for practical reasons quotas may be preferred.

Murillas Maza (2004) points to the fact that ITQ systems are only efficient if quota prices equal the social shadow price of the resource. If this is not the case, he suggests combining the ITQ-system with a property tax rate under management flexibility in order to restore efficiency.

MARKET CONSIDERATIONS IN COMMAND-AND-CONTROL FISHERIES

Feedback rules for quota management

Another type of market-based management that allows improvement in TAC decisions by using information about the market without immense amounts of data, is the so-called feedback approach. Feedback rules for management where proposed already by Clark and Munro (1975). In this case market considerations are directly incorporated in the process of determining optimal TAC-levels.

Feedback rules, or feedback control laws, are defined in dynamic optimization as a rule for determining the control (e.g. harvest) at any time as a function of the state (e.g. the fish stock). In multidimensional models the control vector will be a mapping of the state vector, but I will concentrate on the one-dimensional case here.[2] In principle any rule giving the control variable as a function of the state variable is a feedback rule or feedback control law, even if it is taken out of thin air, but that will of course not be an optimal feedback rule. In order to be an optimal feedback rule it must be based on dynamic optimization.

What are the advantages of feedback rules compared to traditional solutions? To answer this we must know what the traditional solutions are. The problem is to determine an optimal total allowable catch rate given a dynamic constraint in the form of a biological growth function for the stock and some objective function. The objective is usually to maximize either the private net revenue or social welfare.

Traditionally much of the focus has been put on linear models. A linear model is a model where all functions are linear in the control variable, and this is typically a model with constant prices and costs. That is, prices and costs can not depend on the level of harvest or fishing effort. In the case of a linear objective function the optimal solution is a so-called bang-bang solution. A bang-bang solution is a variant of the most rapid approach path (mrap) solution which is equivalent to corner solutions in static models. It tells us that the best thing to do is to move to the optimal steady state as soon as possible. The optimal steady state is found by setting the differential equations in the solutions equal to zero and solve, which gives the long-term optimal combination of stock and harvest. The bang-bang approach says that if the initial stock is below the optimal stock, harvest should be set to zero to make the stock grow at maximum speed. If the initial stock is higher than the optimal one, harvest should be set as high as possible to make the stock decrease at maximum speed. It is, in other words, a very simple rule but nevertheless a feedback rule as it defines the optimal harvest (control) as a function of the stock (state). At the optimal stock level the harvest should be the corresponding surplus growth at that stock level. At all other stock levels harvest should be either zero or as high as possible.

[2] In non-autonomous models the control variable given as a feedback law is a function of time as well as the state variable.

The simplicity of the bang-bang rule makes it of very little practical use. Hardly any managing authority would impose a harvest moratorium, for example if the stock is close to, but not quite at, the long-run optimal stock level. However, when the model is too simple to be of practical value, it ought to be sophisticated. Typically linear models lack information about market relationships. They also lack fixed costs associated with idle capital and transition costs associated with the transition from idle capital to full use of the fishing effort. These are fairly significant details that can partly explain why the results from linear models usually are useless. The only useful result from linear models then is the steady state itself. This calls for more realistic non-linear models.

Non-linear objective functions, on the other hand, yield optimal feedback solutions that are not of the bang-bang type. Clark and Munro (1975), Conrad and Clark (1987) and Clark (1990) all suggest non-linear models, and they point out that feedback solutions would be particularly useful in this case; see also Walters (1986). They also point out that using the traditional approach it is very difficult to find the feedback solutions because the differential equations for the costate variable and the control variable become highly non-linear and almost impossible to solve.

Sandal and Steinshamn (2001) have overcome this problem by using an alternative approach. Instead of focusing on the costate variable, as is common in the traditional approach (Clark, 1990), they use the criterion for interior optimum to eliminate the costate variable. Doing this results in one differential equation less to solve no matter what dimensionality the problem has. For example, with one fish stock and without discounting, there is only one equation left to solve and, furthermore, this is an ordinary equation, not a differential equation. This means that the optimal harvest is given implicitly as a function in one variable, namely the state, that is as a feedback control law. What is more, depending on the complexity of the problem the feedback rule can many times be found as an explicit function, For example, if the objective function is quadratic in the control variable, the feedback rule can always be found as an explicit equation, the so-called square-root formula for renewable resources (Sandal and Steinshamn, 1997).

The most obvious way to make a model non-linear is to use information about the market. As stated earlier, linear models use constant prices and constant costs. If the constant price of fish products is replaced by the demand function for fish, the model becomes non-linear and will yield useful feedback rules for management. If the demand function is linear, the objective function will be quadratic, and we will get an explicit solution for the feedback rule. If the demand function is a more complicated, non-linear function, we will still get an implicit expression for the feedback rule as an ordinary equation, which can easily be solved numerically.

The above is all in the case with zero discounting. In the case with positive discounting, there will be only one differential equation to solve instead of two as in the traditional approach. This makes the solution much easier to find.

The solution is particularly simple in the case of zero discounting. One problem, however, immediately comes to mind, namely that the integral to be maximized is infinite? This would be a problem using the conventional definition of maximum, but there is an alternative, namely Mangasarin's sufficiency theorem for catching-up optimality (CU-optimality).[3] Intuitively speaking, this can be explained by the fact that two dollars a day in infinite time is better than one dollar a day in infinite time although both alternatives sum to infinity.

What about the alternatives to feedback solutions? One alternative is just to find the steady state by setting all time derivatives equal to zero. This is obviously inferior as it only gives us one point and not the entire path. Nevertheless, it is a common and necessary procedure when the differential equations are impossible to solve.

The next alternative is to solve the differential equations the traditional way, namely as a function of time. This means that the manager has to know everything in advance and then, by solving the problem, he gets a plan for the future including a forecast of the stock development. If the stock, for some reason, does not develop according to scheme, the whole dynamic problem has to be solved again, and the previous solution is useless. Any small deviation in the stock development from the model means that the whole problem has to be solved all over again. In other words, if the actual development is not following the model, then the recommended policy will only be correct at time zero.

[3] Another alternative is to use Arrow's sufficiency theorem for over-taking optimality (OT-optimality).

The feedback rule, on the other hand, does not find the solution as a function of time but rather as a function of the current stock. This means that it treats all points in time as zero because it includes the actual stock and not some forecasted stock. It does not matter whether the stock development behaves according to the model or not. The feedback rule only looks at the observed stock and does not care about why the stock is at whatever level it may be at any time. This means that sporadic disturbances to the stock development immediately are taken care when calculating the optimal catch.

What information is needed to specify the feedback rule? All that is needed to calculate the optimal catch for the entire fleet is aggregated information on biological and economic aspects of the stock in question. This will be used for statistical and econometric analysis in order to estimate the parameters in the biological and economic submodels. The biological model requires a growth function for the stock, and the economic model requires a demand and a cost function. In principle, therefore, three aggregated functions are sufficient.

The reason why feedback rules of this kind come in the category market-based management is that they are based on systematic information about the market. Feedback rules based on linear models are rather trivial and of little practical use as they are of the bang-bang kind. Linear models contain hardly any information about the market. In order to get interesting and useful output the model must be non-linear, and the main sources of non-linearities come from the market. The most obvious one is to replace the constant price by a more sophisticated demand function. Another alternative is to replace the constant cost parameters by more sophisticated increasing marginal costs, which is equivalent to sophisticating the supply function.

Another interesting aspect of this procedure is that there is no restriction on how complex and sophisticated the stock-dependence may be in any of these functions. This means that any biological growth function with all kinds of non-linearities (depensation, critical depensation, etc; see Clark, 1990) can be used. Most of the literature is based on simple symmetric, logistic growth functions. Also the stock dependence in the cost function may be of arbitrary complexity. Even the demand function may have non-linear dependence on the fish stock if that is considered relevant. The only limitation on the complexity of the stock dependence is that the functions must be economically meaningful in order to provide meaningful results.

The main idea behind the feedback procedure is that sophisticating the input models moderately in all parts yields much more useful results than by sophisticating one part of the model very much, for example the biological submodel, and leaving other parts very simple. An example of this could be a highly sophisticated year-class model on the biological side but with very simple economics (constant price and cost parameters, etc.). Such a model, although good as a biological model, would be of little use for economic purposes. The bottom line is that no chain is stronger than its weakest link. Therefore sophisticating all links of the model somewhat is better than sophisticating one link very much.

Application of feedback models on actual fish stocks has been performed, among others, by Grafton et al. (2000) and Arnason et al. (2004). Grafton et al. (2000) find that if a moratorium on Canada’s Northern cod fishery had been implemented a couple of years earlier, the stock would probably have recovered much sooner implying both economic, social and biological gains compared to the actual development of this fishery. Arnason et al. (2004) find that the cod fisheries in Denmark, Iceland and Norway have been overexploited both economically and biologically. This has been the case both before and after TAC regulation and extended economic zones were introduced in the late seventies. Great economic savings could have been achieved by a more conservative harvesting policy.

SUMMARY AND CONCLUSIONS

In this review article I have looked at various tools for market-based management. Market-based management can be found both in the framework of incentive-based management and more traditional command-and-control management. Within incentive-based management emphasis has been put on rights-based fishing, in particular the market for ITQs, and on taxes. Special emphasis was put on the minimum information management aspect of ITQs. Various problems with ITQ systems have also been reviewed. Other alternatives, such as group quotas and territorial rights, have been briefly mentioned.

Command-and-control fisheries are still by far the most common kind of management and can therefore not be neglected. This kind of management has often been criticized for its failures and mismanagement. In this article I claim that one of the reasons for this mismanagement is lack of market considerations on the part of the managing authorities. Feedback rules based on general knowledge about market relationships have been suggested as an alternative to traditional management, which very often is focusing solely upon biological reference points.

The overall conclusion is that market considerations are necessary in order to improve fisheries management and avoid economic and biological overfishing. Incentive-based management is, almost by definition, market-based, and especially so-called rights-based management like ITQ systems. But market considerations can also be included in traditional command-and-control fisheries, for example through the feedback model. Taxes and fees are also market-based management tools, and have been proved to be superior to quotas under certain conditions.

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