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Bioeconomic Models and the Formative Evaluation of Fisheries-related Programs: Potential Synergy

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Background: Bioeconomics combines methods from the biological study of living resources, particularly population dynamics, with methods of economic analysis. Most applications have been in program design for resource management. Although formative evaluations often deal with potential improvements to design based on examination of the program at some point in the early or middle period of its life, there has been little interplay between bioeconomic modelling and evaluation of programs in the context of fisheries management programs.

Purpose: This paper describes the potential synergy between the analytic modelling techniques from bioeconomics and the formative evaluation of programs that support sustainable fisheries.

Setting: NA

Intervention: We focus on how feedback from qualitative formative evaluation methods could be used to improve the development and use of realistic bioeconomic models to inform program design, which would in turn improve formative evaluation.

Research Design: NA

Data Collection and Analysis: NA

Findings: NA

Keywords: *bioeconomic models; formative evaluation; fisheries-related programs*

Introduction

Although the field of bioeconomics now encompasses many areas where the disciplines of biology and economics converge (e.g., Journal of Bioeconomics), we focus on the management of renewable resources, particularly fisheries. Study of the growth of fish stocks and the interplay between fish behavior and the methods used to catch them is key to developing a production function. Analyzing the role of government in management and the design of programs requires the economic modelling of all participants in the fishery. Scott Gordon developed a theory of the open-access or common-property fishery that is often used as a starting point for analysis (Gordon, 1954). As the field developed, books by applied mathematician Colin Clark have been very influential, and Mathematical Bioeconomics has become a standard text (Clark, 1976, 2006, 2010).

In this paper, we will argue that new realistic bioeconomic models related to fisheries management could be developed in formative evaluations of programs, or that existing models could be elaborated and revised to better conform with observation.

The qualitative methods often used in formative evaluation could be applied to provide a detailed description of the constraints and incentives facing fishermen, and the important biological and ecological issues. Many bioeconomic models in the literature are not intended for application to specific situations, but serve the purpose of illustrating general principles of fisheries management. Nevertheless, we contend that the realism of models may be limited by the simplicity of the underlying assumptions, and opportunities for the improvement of existing models, or the development of new ones, may arise during the conduct of formative evaluations. Conversely, models that are more realistic would be useful in improving the design of programs at the formative evaluation stage.

Key components of our thesis—qualitative methods, the methodology of economic modelling, and the role and methods of formative evaluation—are reviewed in turn. We first examine qualitative methods with particular attention to how they can be used in developing economic theory. Some key literature on the methodology of economics is then presented. Finally, the section on formative evaluation provides a context for our thesis on the application of bioeconomic models.

The paper next turns to examples of how qualitative methods may be useful in developing and refining bioeconomic models. After introducing a classic bioeconomic model of Common Property Resources (CPR), specific applications of qualitative methods to the analyses of fisheries by the 2009 Nobel laureate in Economics, Elinor Ostrom, are given as examples, highlighting the added realism and practicality her analysis brings to CPR theory, in some cases changing the conclusions.

We then focus on the synergy between methodologies, with bioeconomic models, refined using qualitative methods, potentially applied to formative evaluations. After a brief general discussion of the role of bioeconomic models, we examine Ostrom's work and how her methods might be applied in evaluation. Next, we illustrate how qualitative methods could be used to improve bioeconomic models describing the potential for extinction of fish species. Since the risk of overfishing leading to extinction is a critical issue for fisheries management, we argue that more realistic bioeconomic models in this area would be a useful tool in formative evaluation. We conclude with a section presenting an example of a study where qualitative methods are used in the specification of bioeconomic models of fisheries in Yucatan, Mexico and point out how these models would be useful in formative evaluation.

Qualitative Methods and Model Development: Grounded Theory

An overview of Qualitative Methods

Qualitative researchers in the social sciences attempt to gain a very in-depth understanding of social phenomena and processes through a variety of methods such as interviews, focus groups, field observations, site visits, collection of documents, and case studies. Interviews may be structured using specific questions from an interview guide, much like a survey (Patton, 2002), or they may be unstructured, with very general questions designed to elicit responses that would be difficult to anticipate (Patton, 2002). According to Fontana and Frey (2000, p. 653), "The former [structured] aims at capturing precise data of a codable nature in order to explain behavior within pre-established categories, whereas the latter [unstructured] attempts to understand the complex behavior of members of society without imposing any a priori categorization that may limit the field of inquiry." Focus groups, although often carefully planned, may go even further than unstructured interviews in permitting new and unanticipated themes to emerge. An interactive group setting, with participants hearing each other's responses, may stimulate new ideas and evoke memories (Patton, 2002). When studying a particular human activity, observing both program participants and non-participants in a field setting, including visits to sites where the activity takes place, is a standard qualitative method, and the resulting field notes are considered qualitative data (Patton, 2002, Chapter 6). Often such activities are accompanied by extensive administrative documentation that may be gathered by researchers and considered as qualitative data (Patton, 2002, pp. 293-294). All of these methods may be applied in case studies that examine particular human constructs or events in detail.

A very important notion in the analysis of qualitative data is that of "coding." Strauss and Corbin (1998, p. 3) define coding as, "The analytic processes through which data are fractured, conceptualized, and integrated to form Theory." By labelling segments of the data with short phrases that connote themes important to the research, structure is added that permits further analysis. The context of various codes and relationships between them can then be analyzed. The frequency of codes may be reported, and, in some cases, researchers may even apply statistical analysis techniques that permit the analysis of discrete variables. Computer software may aid in the implementation and organization of the coding, and in analysis of the codes.

A prominent theory of how knowledge is gained from such methods has been termed "grounded theory," (Glaser and Strauss, 1967). This approach uses the qualitative data collected to develop new theories or elaborations of theories, rather than testing established theories. The new theories so developed can therefore be viewed as empirically "grounded." While the primary field of application has been sociology, the procedures have been used in some economic research dealing with complex institutional arrangements, such as in industry studies, analyses of the behavior of firms, and the analysis of market structures (Finch, 2002).

Role of Qualitative Data in Developing Economic Theory

Finch (2002) uses examples from industrial organization research to illustrate the role of grounded theory in developing economic theory. The procedures he reviews include coding of three types: open, axial, and selective. Open coding, intended for description, is undertaken to simply categorize the phenomena being researched. Axial coding emphasizes circumstances that may be perceived as opportunities by agents, and so could form the basis for explanations of their actions. Selective coding takes the final step, and codes the patterns and connections that may form causal explanations. Finch summarizes coding as, "The means of comparison through which explanations may be formulated at a level beyond each individual instance, and involves related activities of description (open coding), analysis (axial coding) and explanation (selective coding)" (Finch, 2002, p. 220).

Because grounded theory procedures are not well known among economists, Finch relies on examining the methodology of economists who have used qualitative methods, particularly fieldwork and case study techniques. He reviews three major contributions to industrial organization research. A study on research and development, market structure and concentration uses primarily detailed cases studies (Sutton, 1998). Finch contrasts the approach used in this study, which uses specified models as a point of departure and is primarily top-down and deductive in approach, with the grounded theory method, which is bottom-up, letting the qualitative data suggest models. Sutton's case studies are used to choose between competing game-theory models. Studies of the pricing decisions in competitive oligopoly (Andrews, 1949 and 1964), and of price and output decisions in large business organizations (Cyert and March, 1992) use interviews with business managers as a technique for developing theory, very much in the spirit of grounded theory.

We will advocate a mixed approach, using established bioeconomic models as a point of departure when they are available, using qualitative and quantitative data to test the model predictions, but also using qualitative data to detect new issues and processes that might fruitfully elaborate the model, or even lead to new models. The complementarity of quantitative and qualitative methods is the theme of recent work by Rao and Woolcock (2003, 2005). They stress the complementarities of measuring and understanding outcomes through econometric methods and qualitative methods respectively. We place more emphasis on the role of qualitative data in the interplay between the deductive process in the specification of models and the testing that leads to elaboration of models. Quantitative data is often essential for testing models, and potentially refuting them. Qualitative data may cast doubt on model specification, although rarely as convincingly as quantitative data, but it has the advantage of improving the understanding of the process being modelled, so that necessary refinement or alteration of the model may become evident. We summarize our view of complementary methods in Figure 1.

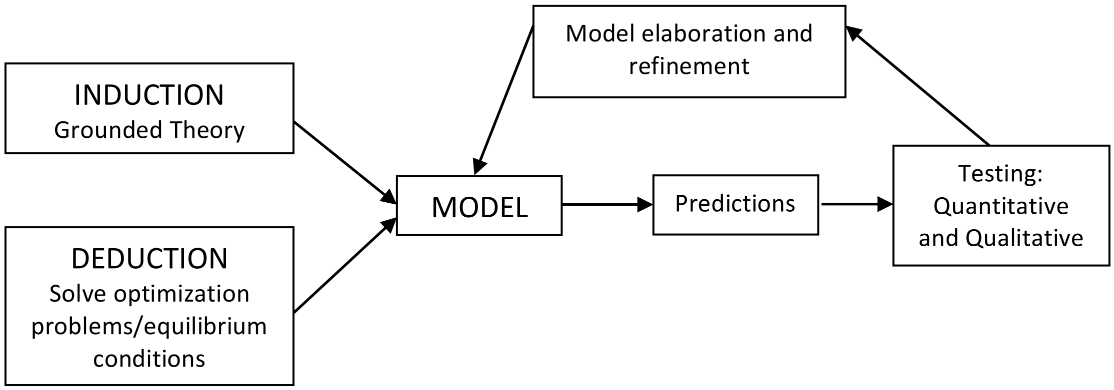

Figure 1. Complementary Methods

The Constructs of Economic Modelling

In this section, we step back and review economic modelling itself from a methodological point of view. We position our arguments within the context of competing theories of the purpose of modelling before returning to our main thesis on the value of using the qualitative methods of evaluation in the development of models.

Economic modelling is in essence a positivist approach to economics where an economic model tries to explain the "what is" as opposed to the "what should be" of normative economics. According to Hands (2001, p. 48), three approaches constitute the body of knowledge of positive economics: that of Terence Hutchinson, that of Milton Friedman and that of Paul Samuelson.

Hutchinson can be credited for transforming economics from a field where praxeology dominated, to a field where the logical positivism of Karl Popper was applied. Indeed, Hutchinson's approach to positive economics rested on three criteria; the logical positivist criterion of cognitive meaningfulness, the logical empiricist criterion of empirical testability and the falsificationist demarcation (Hands, 2001).

Friedman's contribution to positive economics is largely due to his 1953 seminal essay "The Methodology of Positive Economics." In this essay, Friedman advances that the truth of the assumptions that make up an economic theory do not matter as long as it is successful in making empirical predictions (Friedman, 1953). This approach, as we shall see below, has been criticized by some economists, particularly Alan Musgrave and Daniel Hausman (Hands, 2001, p. 53).

Samuelson's operationalist approach to positive economics was key to shaping modern economic modelling. Samuelson considered a theory to have meaning in the operational sense if it implies some restrictions upon empirically observable quantities by which it could conceivably be refuted. An example is the predicted reduction of output by a firm subject to a per-unit tax, a result derived from a simple theory of the firm by the method of comparative statistics (Samuelson, 1947).

Therefore, the subject of this paper is more a continuation of Samuelson's approach to positivist economics than Friedman's. The paper posits that qualitative data is used to improve science behind economic modelling rather than using an approach to economic modelling where the truth of assumptions in models is inconsequential.

Indeed, there have been criticisms of Friedman's approach from two angles. First, Musgrave has argued that there are different kinds of assumptions in positive economics but only negligibility assumptions can be ignored (Musgrave, 1981). According to Musgrave both domain (an assumption that specifies that a theory works in some particular domain) and heuristic assumptions (assumptions that are initially assumed to be negligible, but eventually, at a later stage, will be weakened to see if they have any impact) have an impact on the validity of the results of an economic model (Hand, 2001). The approach proposed in this paper for the use of qualitative data could help ensure that domain and heuristic assumptions are true. A second criticism of Friedman's approach has been formulated by Hausman who uses the metaphor of buying a used car to demonstrate the logical fault in Friedman's approach. In this demonstration, Hausman uses three arguments (Hausman, 1992):

1. A good used car drives reliably (over-simplified premise).
2. The only test of whether a used car is a good used car is whether it drives reliability (invalidity from 1).
3. Anything one discovers by opening the hood and checking the separate components of a used car is irrelevant to its assessment (trivially from 2).

As shown by Hausman, a weakness of Friedman's approach is that it does not allow adaptation of an economic model to forward-looking applications. Again, this paper proposes the use of qualitative data to ensure that underlying assumptions will allow a model to make accurate predictions. We will argue later that this is a critical requirement in application to formative evaluation.

Furthermore, the interplay between deduction (in this case economic modelling) and induction (in this case based on quantitative data) has already been used in economics. An approach known as the hypothetico-deductive method proposes that a hypothesis leads to deduction, which formulates a proposition, which is then empirically tested. Induction can then be used with the results of the empirical test to revise the hypothesis (Dow, 2002). In fact, a well-known economic theory, the Philips curve, was developed using the hypothetico-deductive method (Dow, 2002).

Formative Evaluation: A Means for Improving Programs

According to program evaluation theory, there are two major types of evaluation, which serve different goals (Scriven, 1967). The first is formative evaluation, which is designed to provide feedback and advice for improving a program (McDavid et al., 2006). In other words this type of evaluation is forward looking, as its overall goal is to help with the development of programs by improving performance and governance (McDavid et al, 2006). The second type is summative evaluation, which is designed to provide feedback and advice about whether or not a program should be continued, expanded or contracted (McDavid et al., 2006). In this case, the goal of this evaluation is to provide accountability to program stakeholders (McDavid et al., 2006).

There is a wide range of formative evaluations that can be undertaken. An intrinsic or theory based formative evaluation is a normative approach where abstractly formulated intermediate outcomes for programs are assessed against a body of knowledge to test their feasibility (Scriven, 1967). Alternatively, a pay-off or empirical approach uses program data to compare whether it is on due course to reach its stated objective (Scriven, 1967). However, in practice, formative evaluations often use a hybrid approach where both elements of program theory and tangible realization of programs are assessed together in order to determine the viability of the program design.

Formative evaluation can be undertaken at various stages of program implementation. It can be undertaken while the program is still in the conceptualization phase. It can also be used during the actual rollout of the program to inform implementation improvements as well to report on progress. Finally, it can also be used at the end of the rollout of a program to help interpret the implementation strategy's impact (Stetler et al., 2006).

Qualitative methods are particularly suited to formative evaluation, where there is a need for depth in understanding how a program functions in order to recommend improvements. This has been noted by Patton (2002) as one of the contrasts with summative evaluation.

> Summative evaluations seldom rely entirely, or even primarily, on qualitative data and naturalistic enquiry because of decision makers' interest in measuring standardized outcomes, having controlled comparisons, and making judgments about effectiveness from relatively larger samples with statistical pre-post and follow-up results. ...Formative evaluations, in contrast to summative ones, serve the purpose of improving a specific program, policy, group of staff (in a personnel evaluation), or product. ...Formative evaluations often rely heavily, even primarily, on qualitative methods. Findings are context specific. (Patton, 2002, p. 219-220)

Because the goals of formative evaluation include improving the design and implementation of programs, we argue that bioeconomic models, while often developed to inform the original design of programs, could, particularly if their realism is improved through the use of qualitative methods, also be used in formative evaluation as a tool for revealing and addressing faulty design issues. We will develop this thesis further in the section entitled "Potential Synergy between Bioeconomic Modelling and Formative Evaluation of Fisheries-Related Programs."

Application of Qualitative Methods to Bioeconomic Modelling: The Work of Elinor Ostrom

A Standard Model of a Common Property Fishery

We begin by providing a sketch of a standard model in this section so that, in the following sections, we can better illustrate how Elinor Ostrom applies qualitative methods leading to modifications of the model and potentially different conclusions. We use Ostrom's work as an example because it has been recognized as a profound critique of the existing literature on bioeconomic models of Common Property Resources (CPR). Colin Clark (1976) provides a simple statement of a CPR model of a fishery inspired by that of H. R. Gordon (1954). The model is based on the Schaefer fisheries model that combines a logistic growth model with proportional effort-harvest relationship (Schaefer, 1957).

The logistic growth model (Verhulst, 1838) is given by

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right) = F(x) \qquad (1)$$

where x is the size of the fish population, and K is the environmental carrying capacity or saturation level, and r is the intrinsic growth rate.

To make this an economic model, consider a price p for a unit of fish and a cost c for a unit of effort E, so that total revenue $TR = pY(E)$ and total cost $TC = cE$. The key economic assumption for the CPR fishery is that:

$$\text{sustainable rent} = TR - TC = pY(E) - cE = pEx - cE = 0 \qquad (2)$$

By setting equation (1) equal to zero and solving simultaneously with equation (2), we get an equilibrium zero-rent effort given by:

$$E_\infty = r\left(1 - \frac{c}{pK}\right) \qquad (3)$$

and an equilibrium zero-rent stock level given by:

$$x_\infty = \frac{c}{p} \qquad 4)$$

In this model, costs are considered what economists call opportunity costs: the cost of not undertaking the best alternative. Gordon referred to equations (3) and (4) as the *bionomic equilibrium*. If $E > E_\infty$, then total costs would exceed total revenues, so that some fishermen would leave the fishery, thus decreasing effort. If $E < E_\infty$ then the reverse would hold, and, *because of the open access condition*, additional fishermen would be attracted and effort would increase. Bionomic equilibrium, as predicted by the Gordon model, is a gloomy situation, where all of the economic rent that could have accrued to society, if effort could be constrained, is dissipated.

The approach to model development here appears to make considerable use of deductive methods. What economists sometimes call "stylized facts" are noted—in this case the existence of fisheries that appear to yield only meagre income to fishermen. A model is constructed that is consistent with these facts by hypothesizing constraints and objectives for the fishermen, and deducing the outcome.

In an influential article, Hardin popularized the phrase, "Tragedy of the commons," to describe the CPR situation, as well as related situations such as pollution of commonly held environments and population increase (Hardin, 1968).

Elinor Ostrom's Approach: Governing the Commons

Overview of her objectives and methods. Elenor Ostrom has analyzed qualitative data from case studies related to a number of CPR situations, including several fisheries (Ostrom, 1990). Often she reports a much different situation than the bionomic equilibrium predicted by the Gordon model.

Ostrom is particularly concerned with proposed solutions to the CPR situation. She presents evidence from the literature that these proposals typically take one of two forms: introducing property rights (Privatization) or centralized coercive action by government (Leviathan). She then argues that, in practice, a third way characterized by self-organization has often been found.

> Instead of presuming that the individuals sharing a commons are inevitably caught in a trap from which they cannot escape, I argue that the capacity of individuals to extricate themselves from various types of dilemma situation varies from situation to situation. The cases to be discussed in this book illustrate both successful and unsuccessful efforts to escape tragic outcomes. Instead of basing policy on the presumption that the individuals involved are helpless, I wish to learn more from the experience of individuals in field settings. Why have some efforts to solve CPR problems failed, while some have succeeded? What can we learn from experience that will help stimulate the development and use of a better theory of collective action—one that will identify the key variables that can enhance or detract from the capabilities of individuals to solve problems? (Ostrom, 1990, p. 14)

This statement of her objectives resonates with the objective of qualitative methods in program evaluation given by Rao and Woolcock in their argument for mixed methods.

> … in conducting evaluations, quantitative methods are best suited to measuring levels and changes in impacts and to drawing inferences from observed statistical relations between those impacts and other covariates. They are less effective, however, in understanding process—that is, the mechanisms by which a particular intervention instigates a series of events that ultimately result in the observed impact. … Qualitative methods are particularly effective in delving deep into issues of process; a judicious mix of qualitative and quantitative methods can therefore help provide a more comprehensive evaluation of an intervention. (Rao and Woolcock, 2005, p. 286)

Qualitative methods help to answer the questions, "Why?" and "How?" In so doing, they may be considered to develop new models. In the next sections, we present two of the cases studied by Ostrom. In one case, the fishermen have found a "solution" to the CPR problem. In the other, circumstances prevented such a solution, and the Gordon model CPR equilibrium prevailed.

Success of the self-organization model: the case of Alanya Turkey. Ostrom (1990) presents a case study of the Alanya inshore fishery, as described by Berkes (1986), where the following rules allotting fishing sites among about 100 fishers had evolved over more than a decade:

- Each September, a list of the licensed fishers is prepared.
- Locations are named and listed so that each is suitable for one fisher without congestion.
- Locations are assigned to fishers for the period September-May by lottery to fish using traditional nets.
- From September to January, fishers rotate locations eastward, and after January, they rotate westward. This gives all fishers equal opportunities.

The agreement to a lottery limits fishing effort, and the rules on locations and the gear and location restrictions prevent dissipation of rent through overcapitalization. Cheating will be observed by the fishers in the best spots, and the few infractions are handled by fishers at the local coffeehouse.

Ostrom views this model as a middle ground between privatization and centralization.

> Although this is not a private-property system, rights to use fishing sites and duties to respect these rights are well defined. And though it is not a centralized system, national legislation that has given such cooperatives jurisdiction of "local arrangements" has been used by cooperative officials to legitimize their role in helping to devise a workable set of rules. That local officials accept the signed agreement each year also enhances legitimacy. The actual monitoring and enforcing of the rules, however, are left to the fishers. (Ostrom, 1990, p. 20)

Ostrom's analysis of this case study, which consists of presenting the key features that solve the CPR problem, in fact constitutes a new bioeconomic model of a CPR fishery. The rules and methods of enforcement are the new constraints, and the fishermen then proceed to maximize their income. However, rent is not dissipated, and a profitable fishery is possible. Ostrom provides a summary of the key reasons for this success.

> The system has the effect of spacing the fishermen far enough apart on the fishing grounds that the production capabilities of each site are optimized. All fishing boats have equal chances to fish at the best spots. Resources are not wasted searching for or fighting over a site. No signs of overcapitalization are apparent. (Ostrom, 1990, p. 19)

The simple Clark model described at the beginning of this section has been altered. By a combination of a limited number of licenses and allocation of fishing sites the total fishing effort has been reduced below the rent-dissipating level E_∞ of equation 3. Even in the case of a fishery where total catch has been restricted to an optimal level, Clark has shown through simple bioeconomic models that suboptimal outcomes may still arise if fishermen have an incentive to overinvest to compete for a greater share of the fish (Clark, 2006). The allocation and rotation of sites have prevented this outcome in the Alanya fishery.

If a formative evaluation of the management regime that included this fishery were conducted, we would argue for use of a bioeconomic model including the features that Ostrom has outlined in order to explain the success of the fishery and to ensure that the situation is maintained.

Failure of the self-organization model: the cases of Bodrum and the Bay of Izmir Turkey. Ostrom (1990) presents case studies where institutional failure and fragility appear to have prevented a solution to CPR problems, and rent dissipation occurs as predicted by the Gordon model.

Bodrum is about 400 kilometers west of Alanya, and in 1983 had a larger inshore fishery (about 400 fishers). According to Berkes (1986, p. 76) it was a "textbook example of rent dissipation in a fishery." Ostrom points out some key features absent in the Alanya case. Large trawlers, some built by Borum fishers with Turkish government encouragement, participated in the inshore fishery due to lack of enforcement of a 3-mile limit for such vessels. Their early success stimulated entry to the fishery. A boom in the tourist trade lured part-time fishers and charter boats into the fishery.

The Bay of Izmir fishery, further north on the Aegean coast, has an even larger inshore fishery, with about 1800 fishers in 1983. Although in this case trawlers were excluded by the Turkish Coast Guard, internal division of the fishers into subgroups with conflicting interests prevented the emergence of effective self-regulation, resulting in a Gordon model CPR situation.

While Ostrom does not develop formal mathematical bioeconomic models of these particular failures, she shows in her analysis of the CPR situation (Ostrom, 1990, pp. 14-18) how game theory models may be useful in understanding the potential for self-organization. She suggests that the failure of the Bodrum and Bay of Izmir fisheries was due to "large groups that were characterized by severe heterogeneity of interest and of relevant time horizons." (Ostrom, 1990, p. 146). Apparently, the costs of overcoming these were too great to permit self-organization. A political regime permitting low-cost enforceable agreements would be required.

Potential Synergy between Bioeconomic Modelling and Formative Evaluation of Fisheries-Related Programs

The Role of a Bioeconomic Model

A bioeconomic model summarizes how a regulatory system (or lack of one) operates. In a normative setting, the model typically poses an optimization problem with constraints and demonstrates the solution of the problem. In a positive setting, the model may include multiple optimization problems for agents and their solution, as well as equilibrium conditions that are expected to be established in the fishery.

Formative evaluations of a fisheries program could benefit from a bioeconomic model when an explicit and succinct description of the program's function and how it accomplishes its goals is provided by the model. Such models could also be used to make predictions that would then be confronted with quantitative data. All of this would contribute to the evaluator's understanding of the program and the extent to which it has been successful. To fulfill these expectations, the models must be realistic. We argue that qualitative methods used in the development of the models have the potential to provide local and institutional details that are vital to ensure realism. To support this argument, we provide examples from the theoretical literature followed by practical examples of our proposed modelling approach.

Examples

Elinor Ostrom's work. In the previous section, we presented examples of how Ostrom used qualitative methods that are often part of formative evaluation methodology to develop better bioeconomic models. This type of work, with models enriched in a local context, could be useful in the formative evaluation of fisheries programs. Especially if the models were made more formal and explicit than in Ostrom's illustrative examples, potential improvements in fisheries management might be based on their predictions.

For example, in the cases of Bodrum and the Bay of Izmir discussed in the previous section, a management regime might facilitate the enforcement of agreements between the diverse groups in the area. In the Bodrum area, it appears that enforcement of a 3-mile limit to exclude large trawlers from the inshore fishery would be critical. Some form of licensing of those catering to the tourist industry might also be helpful.

Extinction and property rights. Recently some controversy has arisen among leading academic fisheries economists and biologists about the incentives for private owners of a fisheries resource to deliberately "cash in" the resource by exploiting it to biological extinction. Articles appearing in the journal Science have questioned the realism of earlier bioeconomic models that demonstrate conditions under which exploiting a resource to extinction would be optimal for a private owner (Grafton, Kompass and Hilborn, 2007; and Costello, Gaines and Lynham, 2008). A defense was then provided by the originators of the earlier results (Clark, Munro, and Sumaila, 2008).

Applied mathematician Colin Clark presented a bioeconomic model illustrating the potential for deliberate fishing to extinction (Clark, 1973 and 1976). The model is based on what has become a classic formulation of dynamic renewable resource harvesting (Bjørndal and Munro, 2003).

The problem is expressed as maximization of the present value:

$$PV = \int_0^{\infty} e^{-\delta t}\{p - c[x(t)]\}h(t)dt \tag{5}$$

where p is the price of the harvested recourse, $c(x)$ is the unit harvesting cost when the population level is x, assumed to be a non-increasing function of x, δ is the discount rate being used by the resource manager, and h is the harvest rate. A growth model $\frac{dx}{dt} = F(x)$ is assumed, such as that given by the logistic model in equation (1).

Analyzing this model further, Clark (1973) showed that, assuming $F''(x) < 0$ (a condition referred to as purely compensatory growth) and a decreasing cost function with $c''(x) > 0$, necessary conditions for extinction as an optimal policy (for a private resource owner) are that:

$$p - c(0) > 0 \text{ and } \delta > F'(0) \tag{6}$$

while the slightly stronger conditions:

$$p - c(0) > 0 \text{ and } \delta > 2F'(0) \tag{7}$$

are sufficient.

These conditions represent a profitable fishery when the stock is near depletion with a high discount rate relative to the intrinsic growth rate of the fish stock.

The condition on the profitability of fishing at low stock levels depends on the relationship between the harvest rate, fishing effort, and the stock of fish.

A very commonly used model (Bjørndal and Munro, 2003, pp. 157-158) is:

$$h = qEx \tag{8}$$

where h is the harvest rate, E is effort, and q is a constant termed the catchability coefficient. This means that there is a linear relationship between h/E, or Catch per Unit of Effort (CPUE) as it is termed by biologists, and the stock level x.

Consequently, the effort per unit of harvest is given by $E/h = 1/qx$, so that if the cost per unit of effort is b, then the cost per unit harvest at stock level x would be given by:

$$c(x) = \frac{b}{qx} \tag{9}$$

Clearly, equation (9) leads to costs of harvest that approach infinity as the stock gets small, ruling out the extinction conditions given by Clark.

But, is this always a realistic model? Clark and Monroe claim that it may not be, citing quantitative empirical evidence against the linear relationship between CPUE provided by Cooke and Beddington (1984) and Mackinson, Sumaila, and Pitcher (1997). Clark (2006) describes three cases where the model would not be realistic:

1. Mobile pelagic species that school, maintaining local density.
2. Immobile demersal species, evenly dispersed, and harvested progressively by draggers (much like loggers harvesting old-growth forest).
3. Migratory species that concentrate at certain stages in the migration.

A specific example of how the catch per unit effort actually increased with a decline in stock is provided by Stevenson, Tissot and Dierking (2011). In their analysis of West Hawaii's aquarium fishery, they reveal that, "Catch per unit effort and total catch of the most commonly targeted fish, yellow tang (Zebrasoma flavescens), have increased since the implementation of the MPAs [Marine Protected Area], yet its abundance has declined by 45% in areas open to aquarium fishing between 1999 and 2007." (Stevenson et al., 2011, p. 813). Their analysis of fleet dynamics constitutes a bioeconomic model. When juvenile fish recruitment was perceived as weak, fishers would dive deeper and collect larger, older fish as a response. Generally the most efficient and experienced fishermen, highly motivated by job satisfaction derived from the aquarium fisher lifestyle, remained in the fishery, often adopting new technology such as GPS location. These factors combined to increase catch per unit effort in the face of declining stocks. The authors suggest that economic arguments showing barriers to biological extinction might not apply when fisher job satisfaction is strong in fisheries with declining stocks.

Clark et. al. (2008) argue that the policy question relating to private ownership is closely related to the analysis discussed above, because optimal policy from the point of view of a social manager may be quite different from that of a private owner. They point out that "existence value" is a quintessential public good. They go on to suggest that "contingent valuation," a survey-based economic technique for the valuation of non-market resources, be used to measure existence value, which they then incorporate into the bioeconomic model explicitly. They demonstrate how this can lead to a situation where the social manager would conserve the resource while a private owner would not. They also point out that another well-known difference between the social manager and a private owner concerns the appropriate discount rate, which may be much lower for the social manager.

Suppose that data relating harvest rate, effort, and stock levels were scarce. In this case, it might still be possible to interview fishers to get an understanding of the relationship between the cost of harvest and the stock. The empirical evidence, based on harvest rates, indicates that this may not increase steeply at low stock levels. Bjørndal and Munro (2003) suggest that, with schooling fish and modern fish-finding equipment, fishing can remain profitable even at declining stock levels. This appears to be a situation where qualitative data, consisting of key-informant interviews with fishermen, might reveal whether or not the cost of harvest would escalate with low stock levels. This would depend on the behavior of fish, the capture technology, and the degree of cooperation and information sharing between fishermen. Interviews with biologists might shed light on the realism of equation (8). This approach to developing the underlying bionomic model might form part of a formative evaluation of a program that involved property rights.

Another very important issue is the assumption that $F''(x) < 0$. If this does not hold, then the growth curve may include a region where $F(x) < 0$ for values of x near to $x = 0$. This implies a minimum viable population, a situation that would greatly increase the fragility of the population and the chance that it would be fished to extinction. Again, if quantitative data were not available for a particular fishery, qualitative data in the form of expert opinions from biologists in key-informant interviews might be used to determine how likely this would be.

Stevenson et al. (2011) used interviews with fishermen to develop a model of fleet dynamics. For example, semi-structured in-person interviews were used to determine fisher age and fishing effort, pre-survey interviews obtained information about the social environment and perceptions surrounding the aquarium fishery, and in situ observations were used to document fishing methods.

The issue of existence value under public ownership might also be explored using formative evaluation methods. Actual measurement of the of the existence value using contingent valuation would require survey methods, but key-informant interviews with fisheries managers might reveal evidence for such valuation, perhaps based on feed-back from public workshops and information-sharing activities.

In cases where the bioeconomic model indicates that private sector control could lead to extinction, it appears that a program design feature ensuring sufficient public sector control to protect the species would be vital. Clark et al. (2008) finish their paper with an argument that private sector influence over fisheries management through schemes such as Individual Transferable Quotas (ITQ) can be beneficial, but should be implemented in a way that ensures ultimate management control rests with the public sector. Stevenson et al. (2011) suggest that their fleet dynamics model could be used to improve a fisheries management program, saying that, "In particular, in addition to developing management plans based on reef-fish abundance or fish import/export data for the aquarium trade, our results show that it will be essential to understand how and where fishers operate." (2011, p. 820). There appears to be potential here for a bioeconomic model to add value to formative evaluation of a management program.

Modelling fisher behavior with logistic regression. In developing a model of three fishing communities in Yucatan, Mexico, Salas et al. (2004) have used qualitative data in specifying models. The choice of explanatory variables was based on initial interviews with selected fishers from the communities. The initial selection was a random 30% sample, although nonparticipation reduced this to 10% in two of the three communities studied. Fishers were asked about the main factors taken into consideration when choosing a target species.

The models took the form

$$P_{S_i} = \frac{\exp(T_i)}{1+\exp(T_i)} \qquad (10)$$

where P_{S_i} is the probability that a fisher chooses S_i and T_i is a linear combination of variables involved in the choice. The coefficients in T_i are parameters that were estimated from data provided by fishers' logbooks and economic data from the fisheries cooperatives.

Two models of the form given by equation (10) were specified: an "economic model" based partly on literature indicating the importance of economic variables, and a "resource availability model" based on the key variables determined from the interviews. The explanatory variables for the economic model were previous revenues for each species, weather, travel costs, opportunity costs, and an indicator for the fisher's community. The resource availability model substituted catch per unit effort for revenue.

The model is potentially bioeconomic, since fishers reported on interspecies predation that affected the abundance of the prey species (lobster) when the predator (octopus) was underfished.

Unfortunately, the authors do not provide details of the qualitative analysis that led to the selection of these variables, although they indicate that the set of numerical and categorical variables was based on a subset of commonly occurring reasons given in the interviews. As shown in Figure 1, the aforementioned study shows that qualitative data in this case could have also proved to be useful for further refinements of the model. For example, qualitative data could be used to ensure that the most accurate opportunity cost is used in the model. In the Salas et al. study, opportunity cost of labor was considered as the minimum wage per day in the region. However, using qualitative data, an analyst might be able to detect if wage per day assumptions have varied since previous trials or if new factors are intervening in the calculation of opportunity costs such as opportunities in the informal economy or the value of leisure time.

The article concludes that successful fisheries management plans should be local in nature. As such, the collection of qualitative data to properly develop and calibrate fisheries management models will most likely become more prevalent. The prediction of fishing effort allocation through these types of models might be useful in the formative evaluation of fisheries management programs. The authors also suggest that their analysis could be extended to examine spatial and temporal variation of the explanatory variables and suggest that further work could evaluate elements that contribute to rent dissipation in these types of fisheries.

Conclusion

In this paper, we have presented evidence for a dual thesis: that the realism of bioeconomic models could be improved through the use of qualitative methods commonly used in formative evaluation, and also that such models, especially if realistic and specific to a situation, have the potential to improve formative evaluation. Based on evidence that verifying and testing underlying assumptions are necessary requirements to obtain accurate and realistic bioeconomic models, we explored the benefits of using the synergies between bioeconomic modelling and formative evaluations. The inductive approach, which often characterizes formative evaluations due to the use of qualitative information, can assist in defining the appropriate parameters of bioeconomic models. Inductive methodologies used in formative evaluations can, through a feedback loop, also help ensure that assumptions and parameters of an existing bioeconomic model are relevant (see Figure 1). For example, the paper provides evidence that bioeconomic models without the potential for species extinction under management regimes involving private resource ownership could prove to be incorrect. We have argued that if an inductive method, based on qualitative data, were used to revisit the model specification, the model deficiencies, which hinge on the assumption of a linear relationship between Catch Per Unit Effort (CPUE) and the stock level, might be revealed. Similarly, formative evaluations, whose objective is usually to assess if the implementation of a program is successful and to suggest potential improvements, can be bolstered by the deductive methods of bioeconomic models. We have argued that the development and refinement of a bioeconomic model in this way would provide a useful tool in making recommendations for improvement of fisheries management programs in particular. Examples were provided as evidence that bioeconomics models tailored to assess a local fisheries program could provide a robust line of evidence in formative evaluation. In this way, formative evaluations could be improved through the application of bioeconomic models.

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