The Way Forward: Getting the Economic Theory Right - The First Steps

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ABSTRACT

The University of British Columbia based Global Ocean Economics Project will, in its second phase, be addressing the issue of the rebuilding of hitherto overexploited capture fisheries. In so doing, it looks forward to working closely with the OECD. The paper argues that the first step in this second phase is to ensure that the underlying theoretical foundation is sound. Restoring overexploited capture fisheries, to a marked degree, involves the rebuilding of fish stocks. If fish stocks constitute "natural" capital, then a program of rebuilding the fish stocks is, by definition, an investment program. The paper argues that, while the theory of capital, as it pertains to fisheries is reasonably well in hand, the theory of investment pertaining to fisheries is not. This paper is designed to get the discussion of the theory of investment in fish resources underway. It does so by focussing on the highly sensitive policy question of the optimal rate of investment in such resources. The maximum rate of resource investment is achieved, of course, by declaring an outright harvest moratorium.

Keywords: Natural capital, Theory of investment, Non-malleable capital

Introduction

The Global Ocean Economics Project (GOEP), in the work that it has done to date, is in agreement with the World Bank/FAO report, *The Sunken Billions* (World Bank and FAO, 2009) that the world capture fishery resources are far from realizing their economic potential[1], with a key reason being that they have been subject to extensive overexploitation. Both the GOEP and the *The Sunken Billions* report estimate that, on average, these resource assets are, at best, offering rates of return not exceeding zero. In banking parlance, they are non-performing assets[2] (World Bank and FAO, i*bid*.; Munro, 2010a).

    The Sunken Billions report estimates that, in order for world capture fishery resources to realize their full economic potential, the world capture fishery biomass would have to be increased by 100-200 per cent (World Bank and FAO i*bid*.). The obvious question is how do we achieve the realization of this full economic potential goal? It is this question to which the GOEP will be directing its attention in its second phase, and, in so doing, will hope to complement the work being done by the OECD through its project: The Economics of Rebuilding Fisheries. It should be noted, in passing, that this author had the privilege of participating in the OECD Workshop on The Economics of Rebuilding Fisheries, in May 2009 (OECD, 2010; Munro, 2010a).

    One area in which academics, this author included, should be able to make a contribution lies in helping to ensure that the underlying economic theory is sound. Without sound economic theory, we cannot make much progress in terms of empirical work, let alone in terms of offering useful policy advice

    The objective of this paper is a modest one. What I hope to do is no more than to start the discussion on the underlying economic theory, by sketching out one or two key issues that we need to

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[1] Although, at this stage, the estimates of the GOEP and *The Sunken Billions* report differ.
[2] The marine equivalent of subprime mortgages, if you will.

examine. Much of what is to follow arises out of thinking that I had done on the question, when preparing a survey paper for the OECD 2009 workshop, referred to above, and in doing work for the FAO on a synthesis study, in the form of a Fisheries and Aquaculture Technical Paper, based upon the *The Sunken Billions* report, and the many case studies that were commissioned by the World Bank and FAO to complement the *The Sunken Billions* report (Munro, 2010a; 2010b). Having said this, in these two papers I touch upon the economic theory but lightly.

Some Basic Concepts and Issues

In both the papers that I prepared for the OECD and the FAO, I start off with the fundamental proposition, now accepted all but universally, that all natural resources, certainly including capture fishery resources, constitute "natural" capital[3]. From this it follows that, when we talk about a fish stock rebuilding program, what we are really talking about is a resource investment program. In the OECD paper, I state that we have to look at the issue from both an intra-EEZ perspective, and from the international perspective. We must then go further and examine the interaction between intra-EEZ management of the fishery resources and international management of these resources (Munro, 2010; forthcoming). My comments to follow are sufficiently broad that they apply to both the intra-EEZ and international cases.

With regards to the theory of investment, I like to go back to Gardner Ackley, former Chairman of the US Council of Economic Advisors, whose graduate textbook in macroeconomics was among the most widely used, from the early 1960s until the 1980s (Ackley,1961;1978). Ackley is insistent that a distinction be made between the theory of capital and the theory of investment, and criticizes many of his fellow macroeconomists for confusing the two.

The distinction between the two theories lies, in turn, in the economist's favourite distinction between stocks and flows. The theory of capital is designed to answer the question about the optimal stock of capital at any one time. Investment involves flows. Investment theory deals with the question of the optimal rate at which the stock of capital is to be built up, or run down, given that the existing stock of capital is either below or above the optimal stock level (Ackley, *ibid.*)

As economists, I would suggest that we have the theory of capital, as it pertains to capture fishery resources, reasonably well in hand. The theory of investment, pertaining to capture fishery resources, is another matter. I will point to what I think is a widespread misperception, which has important policy implications. To deal with what I think is a misperception, I will not be developing anything new, but rather will be going back to the decades old *Econometrica* article that I co-authored with Colin Clark and Francis Clarke (1979), an article, which I claim, has gained the status of a "classic", in that it is often cited, but seldom read, with many of its key points being forgotten or ignored.

In reviewing this "classic" article, I conclude that the article is finally coming into its own. Indeed, I was reminded that the article abstract states the following: "---- the results may have profound implications for problems of rehabilitation of overexploited fisheries-----"(Clark, Clarke and Munro, 1979, p.25).

That being said, I have to confess that the economic intuition, underlying the implied optimal resource rebuilding program in the article, is less than transparent. Let us see, if we can gain a better understanding of the underlying economic intuition.

It should also be added that all of the discussion will be in terms deterministic models. Of course, at some point we have to deal with uncertainty, but first things first.

The Basic Bioeconomic Model of the Fishery

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[3] e.g. see: World Bank, 2005.

Let me start off with a quote from the Introduction to the OECD volume, *The Economics of Rebuilding Fisheries: Workshop Proceedings*, prepared by the Chair of the Workshop, Rebecca Lent. She states:

-----a basic bioeconomic model would generally indicate that the shortest timeframe to rebuild a stock is ideal through cessation of fishing until the objective is reached (Lent, 2010 , p.20).

She then goes on to suggest that there may be reasons why we might in fact want to take a slower approach. It is here, I would argue, that the difficulty lies.

The basic bioeconomic model, which is normally cited, is the one appearing in Colin Clark's, *Mathematical Bioeconomics* , first edition, 1976, which in turn owes its origin to the article that Colin and I published a year earlier (Clark, 1976; Clark and Munro, 1975). To be more specific, the "basic" bioeconomic model is the linear, autonomous version of our 1975 model.

I find that, in terms of making the economics transparent, the best approach to take in developing this the basic bioeconomic model is the one that Colin and I use in our 1975 article. That approach is to treat the problem as a linear optimal control problem, which is solved via the famous L.S. Pontryagin maximum principle (Clark and Munro, 1975)[4].

The social manager's objective is that of maximizing the present value of the resource rent from t = 0 to t = ∞. The biomass, x(t), is the state variable, and the rate of harvest, h(t), is the control variable[5]. Without going through the whole model, we come up with the following well known equation for the optimal biomass, x*:

$$F'(x^*) - \frac{c'(x^*)F(x^*)}{p - c(x^*)} = \delta \qquad (1)$$

where $F(x)$ denotes the net natural rate of growth of the fishery resource, $c(x)$ denotes unit harvesting costs, and δ denotes the social rate of discount.

The optimal approach path, from x(0) to x*, is given by:

$$h^*(t) = \begin{cases} h_{max} & \text{if } x(t) > x^* \\ F(x^*) & \text{if } x(t) = x^* \\ 0 & \text{if } x(t) < x^* \end{cases} \qquad (2)$$

(Clark, 1976; Clark and Munro, 1975).

Let us look at Eq.(1) and Eq.(2). Eq. (1) is our capital theory equation, in that it determines for us the optimal stock of "natural" capital, in the form of fish biomass. Eq. (2) is our investment theory equation telling us, by implication, what the optimal rate of investment in the "natural" capital is. Sure enough, it tells that, if x(t) < x* , the situation that we are now facing, the optimal rate of positive investment in the "natural" capital is in fact the maximum, which is achieved by setting h(t) = 0. Declare an outright harvest moratorium, and maintain the harvest moratorium until x(t) = x*. Turn a deaf ear to the howls of the fishing industry, and to those of the communities dependent upon the industry.

This is what I believe I am seeing over and over again in papers discussing fishery resource recovery programs[6]. Let it be acknowledged that the Most Rapid Approach Path (MRAP) does come up

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[4] In *Mathematical Bioeconomics,* Colin applies a simpler mathematical technique in developing the strictly linear dynamic model (he has to bring the maximum principle to bear for the non-linear version). While the mathematics is simpler, the economics lacks the desired transparency (Clark, 1976).

[5] It is always pointed out that one could just as easily let the rate of fishing effort, E(t), serve as the control variable, with the choice being a matter of taste and convenience.

[6] See , for example, Moma (2007); Bjørndal and Bezabih (2008);Warui (2008); and Gates (2009). The paper by Bjørndal and Bezabih on the Western Channel sole fishery does, when discussing the rebuilding of the stock, makes it explicit that the authors' analysis of the resource investment program, which will

again and again in *Mathematical Bioeconomics* . Furthermore, we should note, in passing, that some authors do listen to the howls of the fishing industry, and concede that a "reasonable" resource recovery program might have to be implemented, in which there is not an outright harvest moratorium, suboptimal though this "reasonable" program may be.

The word now appears to be out that, if the appropriate model is a non-linear one, say, for example, because the demand for harvested fish exhibits finite price elasticity, the most rapid rate of investment/disinvestment in the stock, when $x(t) \neq x^*$, is not optimal. A slower rate of investment is in order (e.g. Lent, 2010). This is, in fact, very old news, and was discussed in detail by Clark and Munro in 1975 (Clark and Munro, 1975, Part 4).

Be that as it may, a rule of thumb, which I learned in my graduate student days, is that, when the stock of capital is below or above the optimum, one should invest/disinvest at the most rapid rate, unless there are penalties associated with rapid investment/disinvestment. Obviously, if, for example, the social manager is faced with a demand for harvested fish exhibiting finite price elasticity, there will penalties associated with rapid investment/disinvestment in the "natural" capital.

The real issue, I would contend, the one that is most likely to elicit howls from the fishing industry, and the dependent communities, is the ease with which the vessel, processing and human capital can be shifted in and out of the fishery – the problem of so called malleability of produced and human capital relevant to the fishery. This leads us to the "classic" article – often cited, but seldom read. We shall review this article, within the framework of the theories of capital and investment.

Non-malleability of Produced and Human Capital and the "Classic" Article

Some background is in order. After Colin and I had written our 1975 article, and when *Mathematical Bioeconomics* was on its way to publication, Colin received a letter from the American economist, Herbert S. Mohring, who had recently done research on the Pacific halibut fishery in Alaska (Mohring, 1973). Mohring asked, if we really believed the apparent optimal resource investment program arising out of our linear, autonomous model (Eq. (2)). From his experience with Alaskan fisheries, it seemed obvious that this policy could easily wreak havoc. If the fishery resource was being rebuilt, and an outright harvest moratorium was declared, where would the displaced vessels, fishers, processing workers go? We had no justification, he continued, for assuming that the vessels, fishers and processing workers could quickly and easily find alternative employment. We agreed that he had a point.

In retrospect, Mohring had a very good point indeed. The point is well taken for many developed fishing state fisheries, and, if anything, has even greater relevance for a large number of developing fishing state fisheries, particularly those with artisanal fisheries.

We addressed the Mohring question by focussing on vessel capital alone and asked, what would happen if the relevant vessels had no, or very limited, alternative uses outside of the fishery under consideration. The mathematics proved so daunting that Colin had to turn for advice to his colleague, and specialist in optimal control theory, Francis Clarke. Francis' role quickly evolved from that of advisor to that of a key member of the Mohring inspired team. The ultimate result of the team's work was the "classic" article: "The Optimal Exploitation of Renewable Resource Stocks: Problems of Irreversible Investment" (Clark, Clarke and Munro, 1979).

In the article, we adopt the concept of "malleability" of capital from Kenneth Arrow (Arrow, 1968), with reference to constraints, or lack thereof, on the disinvestment of vessel capital used in the fishery. Other than allowing for such constraints, we adopt all of the assumptions of the basic bioeconomic

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maximize the present value of resource rents through time, is based upon the linear autonomous model that we have just discussed.

model[7]. Here, in quick review, are the basic elements of the Clark, Clarke and Munro model (Clark, Clarke and Munro, *ibid*.)

$$\frac{dx}{dt} = F(x) - h(t), x(0) = x_0 \tag{3}$$

$$h(t) = qE^\alpha(t)x^\beta(t) \tag{4}$$

where $E(t)$ is the rate of fishing effort, and where, by assumption, $\alpha = \beta = 1$
Equations (3) and (4) relate directly to the Schaefer biological model.

$$0 \le E(t) \le E_{max} = K(t) \tag{5}$$

where $K(t)$ denotes the stock of vessel capital at time t. Eq. (5) states that the maximum rate of fishing effort, at time t, is determined by $K(t)$, which implies that the rate of fishing effort may be below the maximum.

$$\frac{dK}{dt} = I(t) - \lambda K, \quad K(0) = K^0 \tag{6}$$

where $I(t)$ denotes the rate of gross investment in K, and where λ, a constant, denotes the rate of depreciation.

The resource manager's objective functional is given by:

$$\max PV = \int_0^\infty e^{-\delta t}(ph(t) - b_{oper}E(t) - \phi(I(t)))dt \tag{7}$$

where p, a constant, denotes the price of harvested fish, b_{oper}, a constant, denotes unit fishing effort operating costs, and where:

$$\phi(I) = \begin{cases} \pi I & \text{if } I > 0 \\ \pi_R I & \text{if } I < 0 \end{cases} \tag{8}$$

where π denotes the purchase price of K, and where π_R denotes the unit resale value of K, after purchase.

We set out various degrees of "malleability" of vessel capital, which can be shown as follows:
i. $\pi = \pi_R$
ii $\pi_R = \lambda = 0$
iii $\pi_R = 0; \lambda > 0$
iv $\pi_R < \pi; \lambda \ge 0$

Case i denotes perfect malleability of vessel capital, in which all undepreciated vessel capital can be sold off at its purchase price – directly analogous to the concept of highly liquid financial capital. Case ii is the polar opposite, prefect non-malleability of vessel capital. Investment in such capital is quite literally an irreversible decision. The capital has no resale value and never wears out. Cases iii and iv are intermediate cases, which we refer to as quasi-malleable capital. In Case iii, for example, while the resale value of the vessel capital is zero, the rate of deprecation of vessel capital is positive, with the consequence that the capital can be disposed of gradually through time (Clark ,Clarke and Munro, *ibid.*).

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[7] Processing capital in the article is ignored, as if all the harvested fish is being sold in the fresh fish market. It is implicitly assumed that all relevant human capital is perfectly malleable.

Look at Case i. If vessel capital is perfectly malleable, then we will always have $E(t) = K(t)$, since any unwanted vessel capital can be sold off at its purchase price π. It can then be shown that the stock variable, K(t) drops out, and we are left with a one state variable x(t), one control variable E(t)[8], optimal control problem (Clark ,Clarke and Munro, *ibid.*)[9]. In other words, we have the basic bioeconomic model. From this we conclude that the basic bioeconomic model of Clark and Munro, 1975, and Clark, 1976, assumes *implicitly* that vessel (along with processing and human)[10] capital is **perfectly malleable** (Clark, Clarke and Munro,1979, Part 3), which, of course, Colin and I had not realized in 1975-76.

If the vessel capital is other than perfectly malleable, Cases ii-iv, then we do indeed have a control- theoretic problem, but one with two state variables, the resource biomass, x(t), as before, and the stock of vessel capital, K(t), along with two control variables, the rate of fishing effort, E(t), as before, and the rate of (gross) investment in vessel capital, I(t). While we have a control- theoretic problem, we find the following, if we turn to Part 7 of the article, the Proof of Optimality, which is almost entirely the work of optimal control theory expert, Francis Clarke. Francis states explicitly that, if the vessel capital is other than perfectly malleable, the Pontryagin maximum principle does not go through (Clark, Clarke and Munro, 1979, p.37)[11]. Another, much more complex, approach has to be applied.

From this 30 year old article, we can thus conclude that the application of the basic bioeconomic model to problem fish stock and fishery rebuilding, given that the linearity conditions are met, is just fine, so long as one can safely assume that the relevant produced and human capital is perfectly malleable. If this assumption is not valid, then basic bioeconomic model is quite simply inappropriate to the problem at hand.

Quasi-malleable Vessel Capital - The Standard Case

Let us now focus on the case quasi-malleable vessel capital, which I would contend is the standard case. Instances of vessel capital that are virtually perfectly malleable, with respect to a specific fishery, are not unknown, but they are hardly commonplace. The case of perfectly non-malleable vessel capital, while useful for expository purposes, is essentially a theoretical extreme.

We shall restrict ourselves to Case iii ($\pi_R = 0; \lambda > 0$) in the discussion to follow. This is the simpler of the two quasi-malleable vessel capital sub- cases.

In any event, in order to deal with other than perfectly malleable vessel capital, Clark, Clarke and Munro have to make a clear distinction between fishing effort operating costs and total fishing effort costs, where total fishing effort costs are equal to fishing effort operating costs plus the "rental" cost of vessel capital[12]. This leads to a distinction between operating harvest costs and total harvesting costs (Clark, Clarke and Munro, 1979, pp.28-30).

We now have two stocks of capital - x(t), K(t) – and two investment programs to deal with. To make life more complicated there is an interaction between the two capital theoretic problems.

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[8] Recall that it is a matter of taste and convenience whether we use h(t) or E(t) as the control variable ,with respect to x(t). See: n.5.

[9] The services of vessel capital can be viewed strictly as a flow variable. The cost of vessel capital can be seen as a "rental" cost, with the unit "rental" cost of vessel capital being expressed as: $(\delta + \lambda)\pi$ (Clark, Clarke and Munro, *ibid*.).

[10] See: n.7. In the article, the focus is wholly on the malleability of vessel capital .In the concluding part of the article, the authors state that the non-malleability of human capital should lead to similar results to those arising from non-malleable vessel capital. One can add that the same should be true for non-malleable processing capital (Clark, Clarke and Munro, 1979, p. 47).

[11] See, as well: Clarke (1983).

[12] See n.9.

Consider now the following state – space (x(t), K(t)) – feedback control figure, based upon Clark, Clarke and Munro.[13] Focus first on x^*, $\tilde{x}$, K^* and $\tilde{K}$. The biomass level x^* represents what the optimal biomass would be, if total fishing effort costs were always relevant, and is what the optimal biomass would be, if vessel capital was perfectly malleable. This is, of course, and can be seen as the optimal biomass level forthcoming from the basic bioeconomic model.

Figure 1 here

The biomass level, $\tilde{x}$, is what the optimal biomass would be, if the only relevant costs were operating fishing effort costs, and is what Clark, Clarke and Munro refer to as the "free" vessel capital optimal biomass level. It is given by the following equation:

$$F'(\tilde{x}) - \frac{c_{oper}'(\tilde{x})F(\tilde{x})}{p - c_{oper}(\tilde{x})} = \delta \qquad (9)$$

where $c_{oper}(\tilde{x})$ denotes unit operating harvest costs.

The fleet levels, K^* and $\tilde{K}$, are the minimum fleets sizes required to harvest x^* and $\tilde{x}$ respectively on a sustained yield basis.

Next observe (or let us be reminded) that the figure is divided into three regions, R_1, R_2 and R_3, in which the optimal controls are specified. R_3, which does not interest us particularly in the context of the problem at hand, applies to the case when the initial biomass exceeds x^*. Investment in fleet capacity will, by assumption, take place on a "pulse" basis.[14] It is proven that it will never pay to invest in K, at any biomass level below x^* (Clark, Clarke and Munro, 1979, *ibid.*).

In R_1, the optimal strategy is to shut the fishery down, I(t) = E(t) = 0. In R_2, gross investment in K is to be set equal to zero, but the optimal strategy calls for fishing flat out with the existing, but declining, fleet,i.e.E(t) = K(t). The curve σ_1, is a so called switching curve, marking the switch from E(t) = 0 to E(t) = K(t), or the reverse[15].

Now let us suppose that the fishery had operated under conditions of Pure Open Access, and that the fishery has stabilized at Bioeonomic Equilbrium, at the biomass level x_{BE} and fleet level K_{BE}. Robert McKelvey demonstrates that in a fishery with quasi-malleable vessel, such as we have in our example, there are Pure Open Access analogues to $\tilde{x}$ and x^*, with x_{BE} being the analogue to x^*, i.e. reflecting total harvesting costs (McKelvey, 1985).

Next, we suppose that the fishery comes under the control of a social manager, whose control is of iron like quality. The social manager is unhappy with the current state of affairs, and hence wishes to undertake a fish stock/ fishery rebuilding program, or to state it differently, wishes to engage in a resource investment program. What is the optimal policy? The social manager has no choice but to engage in a fleet investment program simultaneously. The optimal fleet investment policy is straightforward. We have to infer the optimal "natural" capital investment policy.

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[13] See: Clark, Clarke and Munro, 1979, Figure 2.
[14] i.e. in R_3, we have I(t) = + ∞
[15] We shall have more to say about σ_1.There is a second switching curve, σ_2, which marks the switch from I(t) = ∞, to I(t) = 0, or the reverse.

In the figure, we have $x_{BE} << \tilde{x}$. There is no necessary reason why this should be so. It would be possible to have: $x_{BE} \geq \tilde{x}$ [16]. In any event, in our example, we have the case of what Clark, Clarke and Munro (1979) refer to as drastic resource overexploitation.

In spite of what we have said about the unrealistic nature of Case ii, perfectly non-malleable vessel capital, let us assume, just for the moment, that Case ii applies [17]. This will help set the stage for the complications that arise, when the vessel capital is quasi-malleable.

Be that as it may, if the vessel capital is perfectly non-malleable, then to the resource manager, the vessel capital is to be seen as "free" capital. The acquisition cost of the capital is a bygone, only vessel operating costs are relevant. The nature of the vessel capital will affect the answer to the capital theory question pertaining to the fish stock. The biomass level, $\tilde{x}$, will be the optimal ,or target, biomass level. The biomass level, x^*, would simply be irrelevant.

The "free" capital is abundant, $K_{BE} > \tilde{K}$. The optimal resource investment program is straightforward, identical in form to the one that we would have with perfectly malleable vessel capital, other than the fact that the biomass target is different. There are no penalties to rapid investment in the fish stock, so that the optimal resource investment policy would be to invest at the maximum rate, declare a harvest moratorium, and maintain the moratorium, until $x(t) = \tilde{x}$. From that point on, one should harvest $\tilde{x}$ on a sustained yield basis indefinitely.

Now let us revert back to the assumption that the vessel capital is quasi-malleable – Case iii: $\pi_R = 0; \lambda > 0$. Life is about to become much, much more complicated.

As before, at the beginning of the resource management program, the vessel capital is, to the resource manager, a "free" asset. It is now, however, also a decaying asset, since $\lambda > 0$. Recall, as well, that it never pays to invest in K at any biomass level below x^*.

While the resource manager's focus is initially on $\tilde{x}$, this has to be seen as no more than a short run optimal biomass level. The day will inevitably come when $K(t) < \tilde{K}$. Given the constraints on investment in K, it will become impossible to harvest $\tilde{x}$ on a sustained yield basis. The resource will in time increase above $\tilde{x}$, like it or not. The resource level x^*, is now very relevant, and is to be seen as the long run optimal biomass, the target biomass that really counts.

The optimal long run policy is to allow the resource to grow to x^*, but to set I(t) = 0, until $x(t) = x^*$. At that point, investment in K is to take place to increase it to the point that $K(t) = K^*$. From thereon in, it will be optimal to harvest x^* on a sustained yield basis [18].

So what specifically is to be done, commencing the resource management program at $x(t) = x_{BE}$ and $K(t) = K_{BE}$, now that we are faced with quasi-malleable vessel capital? The resource manager,

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[16] Recall that x_{BE} is based upon total harvesting costs, while $\tilde{x}$ is based upon operating harvesting costs.

[17] If the vessel capital was perfectly non-malleable, the fishery, under Pure Open Access ,would in fact stabilize at the Pure Open Access equivalent of $\tilde{x}$ (McKelvey ,1985).

[18] By implication , once we are at the point that: $K(t) = K^*$, we will have $I(t) = \lambda K^*$, from thereon in.

recognizing that the "free" vessel capital is decaying asset, is fully aware that the state of affairs, in which only operating costs are relevant, is a temporary one.

The economic benefits arising from the fact that only fleet operating costs are relevant can be seen as a Marshallian quasi-rent[19]. Thus, quasi-malleable vessel capital gives rise to quasi-rent.

The resource manager is reluctant to see this quasi-rent being lost. On the other hand, realizing the quasi-rent, will reduce that rate of investment in the hitherto heavily overexploited fish stock. Thus, the resource manager faces a tradeoff . The resolution of the tradeoff is to be found by turning to the switching curve σ_1, which leads us to the question: where does this switching curve in fact come from? The Clark, Clarke and Munro answer is as follows.

Consider the following return function $S(x, K)$. The return function is determined in the following manner. Take an initial position (x, K) at $\tilde{x}$ or to the left of $\tilde{x}$. The return function corresponds to the policy of I(t) = 0; E(t) = K(t) until $x(t) = x^*$, together with an increase of K(t) to K*, when $x(t) = x^*$ (Clark, Clarke and Munro, 1979, p.33). The switching curve σ_1 is then given by the solution to the following equation:

$$\frac{\partial S(x, K)}{\partial x} = p - c_{oper}(x) \qquad (5)$$

(Clark, Clarke and Munro, *ibid.*).

The L.H.S of Eq.(5) can be interpreted as the PV marginal resource rent gained from a marginal investment in x. The R.H.S. of Eq.(5) can, in turn, be interpreted as the cost of the marginal investment in x, in terms of forgone current quasi- rent. Thus, the switching curve σ_1 can be seen as the locus of all combinations of x and K at which Eq. (5) holds.

If we are at a point that: $\frac{\partial S(x, K)}{\partial x} > p - c_{oper}(x)$, then implement a harvest moratorium and invest in x at the maximum rate, forgoing the current quasi-rent. Once we are at a point that Eq.(5) holds, then a switch occurs. It now becomes optimal to realize fully the existing quasi-rent, and to accept a rate of investment in the resource stock that is below the maximum. The policy then becomes one of activating the entire existing fleet[20].

In the example shown in Figure 1, it pays to activate the entire existing fleet, *before* we reach the point that $x(t) = \tilde{x}$.[21] How is this possible? It is possible, because of the recognition of the inevitable day when $K(t) < \tilde{K}$.

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[19] All that is required to have the fleet carry out its harvesting activities is that the fleet revenues be sufficient to cover fleet operating costs. Thus revenue in excess of the operating costs can be seen as a form of rent, but a rent, however, which is strictly temporary. Alfred Marshall characterizes such rent as quasi-rent. See: Marshall, 1927. See, in particular, Marshall, 1927, p. 424n.

[20] We have assumed that $x_{BE} \ll \tilde{x}$. As we noted, there is no necessary reason why this should be so.

Suppose, for the sake of argument, that we had: $x_{BE} = \tilde{x}$. In that case, the resource manager's   trade off problem would vanish. The optimal policy would be to allow the existing, but decaying , fleet asset to be fully activated from the beginning. The resource manager would, of course, be faced with the problem of ensuring that fleet capacity did, in fact steadily diminish as x^* was approached.

[21] The example that we show in Figure 1 is just one of several outcomes. The trajectory, commencing at $x(t) = x_{BE}$, $K(t) = K_{BE}$, will obviously be influenced by both the rate of growth of the resource and the rate of depreciation of vessel capital. It is conceivable that we would have an outcome in which, when $x(t) = \tilde{x}$, we find that $K(t) > \tilde{K}$. We could then have a very complex optimal policy calling for

In any event, once we have activated the entire fleet, optimal policy calls keeping the entire fleet activated as we approach x^*. Given that the existing fleet is a decaying asset, let there be no doubt that investment in the resource, $x(t)$, is taking place. We are assured that, until x^* is achieved, we will have $h(t) < F(x)$ [22]

Thus, upon reaching the switching curve, σ_1, we find that, while positive investment in the fish stock is taking place, the rate of investment in the fish stock is below, perhaps well below, the maximum. What is the economic rationale? The rationale lies simply in the fact that investing in x at the maximum rate, until $x(t) = x^*$, comes with an economic penalty. The aforementioned quasi-rent will be entirely lost.

To summarize, if we are faced with an overexploited fish stock, and thus there is a call for a fish stock investment program, then it is appropriate to invest in the resource at the maximum rate (i.e. declare and maintain a harvest moratorium), if the vessel capital is perfectly malleable, or if it is perfectly non-malleable. If the vessel capital is quasi malleable, investing in the resource at the maximum rate is sub-optimal, unless the overexploitation is severe, and then only during the first stage of the resource investment program.

Some Conclusions

There is now widespread agreement that world capture fishery resources have been seriously overexploited and that a major fishery rebuilding program is in order. One of the first contributions that academics can make, in this regard, is to ensure that the required underlying economic theory is sound.

If capture fishery resources constitute "natural" capital, then, by definition, a program of rebuilding capture fish stocks/fisheries is inherently an investment program. Hence, in terms of the theory, what is required is a well thought out theory of investment in fishery resources. We argue that the theory is less than fully developed. This paper is designed, not to present a fully developed theory, but is rather designed to do no more than get the discussion under way.

The theory of investment, we recall, addresses the question of the optimal rate of investment/disinvestment in a stock of capital that is below/above its optimal level. Thus, with regards to hitherto overexploited fish stocks, it should be expected to address the question of how rapidly the rebuilding of the fish stock/fishery should occur. The basic rule of thumb that we put forward is that the optimal rate of investment (positive or negative) is the maximum, *unless* there are penalties associated with rapid rates of investment.

What has been referred to as the basic bioeconomic model, which has been very widely used, prescribes a rate of investment in hitherto overexploited fish stocks equal to the maximum. This, in turn, implies a program consisting of an outright harvest moratorium that is to be maintained, until the fish stock has achieved its optimal level.

In the paper, we focus on a common, and particularly contentious, question, pertaining to the rebuilding of fish stocks/fisheries. The question is what is to be done, what resource investment program should be implemented, if the relevant produced capital and human capital cannot be easily and costlessly be shifted out of a fishery that is to be rebuilt? Technically, we would say that the produced and human capital is non-malleable.

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harvesting at $x(t) = \tilde{x}$ on a sustained yield basis temporarily, and then, before we have $K(t) = \tilde{K}$, unleashing the entire fleet, even though this would temporarily cause $x(t)$ to fall below $\tilde{x}$! See Clark, Clarke and Munro, 1979 for further details.

[22] See Eq.(3) .Note, as well, that, as we approach x^*, E(t) will be steadily declining.

To see what, if anything, the theory tells us, I turn back to a decades old article, which I claim now has the status of "classic", in that, while often being cited, it is seldom read. I argue that the article is now coming into its own, but also willingly concede that the economic intuition underlying the article's technical results often borders on the opaque. We have some digging to do.

The "classic" article restricts itself to the case of non-malleable vessel capital, but it is of value, nonetheless. The article, to begin with, points out that the basic bioeconomic model, so widely used, assumes implicitly that the relevant produced capital and human capital are perfectly malleable. If this assumption is valid (and given that certain linearity conditions are satisfied), then it is indeed true that there are no penalties associated with rapid investment in the resource. In the many, many real world cases, in which such capital is less than perfectly malleable, the basic bioeconomic model is inapplicable. This model deals with the problem of non-malleable human and produced capital in the economist's time honoured fashion of assuming the problem away.

We then specifically focus on what we believe to be the most common case of what the article refers to as quasi-malleable vessel capital – the case in which the capital can be shifted out of the fishery, but only slowly, e.g. through attrition. In this case, we find, rapid investment in the fishery resource, as the long term optimal stock level is approached, come with a significant economic penalty. Consequently, on strict economic grounds, program of gradual investment in the resource is called for. The optimal rate of resource investment, from an economic perspective, is below, perhaps well below, the maximum.

The truly contentious question, of course, is what to do, if the relevant **human** capital is non-malleable. Think of developing fishing state artisanal fisheries. The authors of "classic" article assert that their analysis should prove to be applicable, *mutatis mutandis*, to the case of non-malleable human capital (Clark, Clarke and Munro, 1979, p.47).In broad, general terms, the assertion is almost certainly correct. There are virtually certain to be economic penalties associated with rapid investment in the fish stock, when the relevant human capital is non-malleable.

That being said, human capital is not vessel capital. Thus, for example, in our discussion of the consequences of the presence of non-malleable vessel capital in the fishery, we examine the costs and benefits of rapid investment in the resource stock strictly in terms of the commercial net economic returns from the fishery. With the presence of non-malleable human capital in the fishery, many of the relevant costs and benefits are virtually certain to be non-market in form. We can, at this point, say nothing further, other than to state the obvious, namely that substantial additional research is required.

The issue of non-malleable produced and human capital is but one of many questions pertaining to the theory of investment in capture fishery resources that require extensive research. To repeat this paper is designed to do no more than open up the discussion. An entire program of research lies before us.

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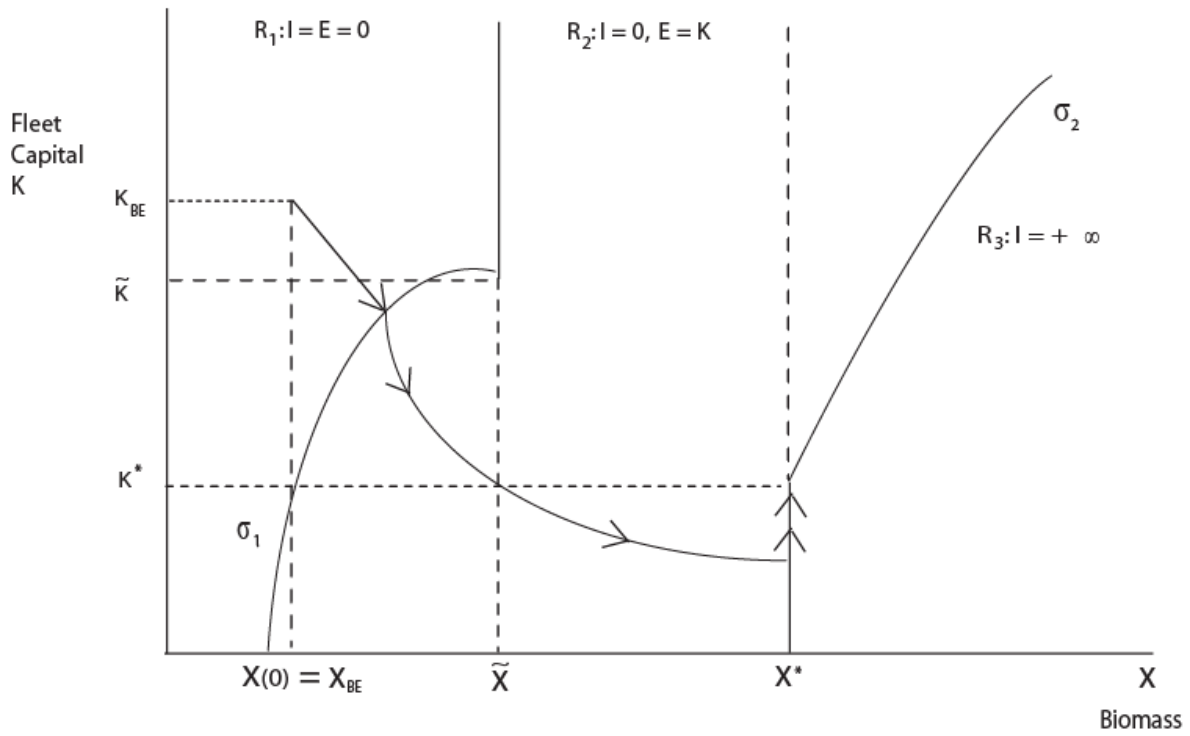
Figure 1. Optimal Fishery Resource Management with Quasi-malleable Vessel Capital.
Source: Clark, Clarke and Munro, 1979.

By assumption: $\pi_R = 0$; $\lambda > 0$

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