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MODERN FISHING TECHNOLOGY AND PROFITABILITY IN A SECOND BEST SITUATION

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Abstract
This paper formulates a simple biomass growth model of a fishery. In this model, fish are exploited in a restricted open-access regime where a fixed number of harvesters exploit the fish stock in a myopic profit-maximizing manner. It is demonstrated that more modern fishing technology has a two-sided profitability effect, where the direct, short-run, positive effect is counterbalanced by a negative, long-run, indirect effect that slows population growth. In the steady state, it is shown that more modern technology dissipates the rent under already high exploitation pressure, while the opposite occurs if the fish stock is initially little, or moderately, exploited.

1. Introduction

Statistics from the United Nation's Food and Agricultural Organization (FAO) demonstrate that many of the world's fish stocks are depleted, many are overexploited, and only a minor part of all wild fishery resources can be said to be in a healthy state (FAO 2005). The reasons for this bleak picture include the unregulated nature of many fisheries combined with valuable fish stocks. In addition, new and modern fishing technology plays a role (see, e.g., FAO 2003). The goal of this paper is to take a closer look at the technology side of the debate and, from a theoretical point of view, demonstrate how and to what extent modern and more efficient harvesting technology may be a disaster for not only the 'sustainability' but also the profitability of a fishery. Modern fishing technology includes larger and better-equipped boats, use of new synthetic materials, new fish-finding equipment and techniques and so forth, with calculations indicating that productivity growth over the last few decades has been very significant (see, e.g., Eggert and Tveteraas 2007 and the references therein).

The suggestion that new and modern technology can be a 'bad' may come as a surprise as more efficient technology, at least among economists, has always been seen as a welfare-improving device (e.g., the pioneering growth-accounting work in Abramovitz 1956). In a fishery, however, the blessings of more modern technology depend crucially on the institutional structure, and in a *regulated* fishery with well-defined property rights, new and more efficient technology is likely to be beneficial. For example, predictions from the standard sole-owner model (or the social planner model, see, e.g., Clark 1990) are that improved harvesting technology, *ceteris paribus*, will increase rents but will reduce fish abundance in the long run (the steady state). However, and also following this model, ever-increasing fishing efficiency will normally never constitute an overexploitation threat[1].

In an *unregulated* fishery, however, where the fishermen do not price the fish stock (a zero shadow price) the picture may be quite different. The so-called open-access fishery has for many years served as the benchmark of this exploitation scheme (e.g., Gordon 1954, Homans and Wilen 1997). In this paper, we follow this tradition. Our approach is, however, somewhat more general as we study the situation where the harvesters exploit the fish stock in a *myopic* profit-maximizing manner: that is, the fishermen maximize short-term profit while taking resource abundance as given. Therefore, just as in the standard open-access solution, the

[1] It can be easily demonstrated that the utilization approaches the costless harvesting case when efficiency approaches infinite.

exploiters impose no shadow price on the natural resource stock. However, in contrast to standard open-access, the number of harvesters is assumed to be fixed. The exploitation takes hence place within a regime what Skonhoft and Solstad (2001), among others, refer to as *restricted open-access* where, contrary to a common property regime, no forms of group cohesion and identity –like social norms- are assumed to influence individual behavior[2]. Contextually, the sort of resource management setting we have in mind may fall within Ostom's (1990) notion of small-scale common-pool resources as for instance inshore fisheries, but where economic, cultural and economic changes, in short 'modernization', have changed the way in which the fishery resources are exploited. Within this resource utilization regime it is shown how more modern fishing technology, or improved fishing efficiency, influences fish abundance and profitability. The model formulation follows in section two while a numerical illustration is offered in section three. Section four concludes the paper.

2. Model

We consider a simple biomass model ('a fish is a fish') exploited instantaneously and simultaneously by a fixed number of n identical fishermen. The population growth may hence be written as:

$$(1) \qquad X_{t+1} = X_t + F(X_t) - nh_t$$

where X_t is the stock size at time t, h_t is the individual harvest, and $F(X_t)$ is the natural growth function, assumed to be density dependent in a standard manner (see below).

Harvest is governed by the generalized Schaefer function, $h_t = qe_t^{\alpha} X_t^{\beta}$, with e_t as individual effort use and q as the productivity (efficiency) coefficient. This parameter represents the technology factor in the model, and a larger q is throughout said to represent more efficient or, synonymously, more modern fishing technology. β may be referred to as the stock elasticity and α as the input elasticity. The case $\alpha = \beta = 1$ is frequently used in the literature and coincides with the standard Schäfer harvesting function (again see, e.g., Clark 1990). However, for many fish stocks, β may be substantially lower than one ('schooling stocks'), and in many instances, there is good reason to assume a decreasing effort effect so that α is

[2] 'Restricted open-access' is synonymous with the more used term 'unregulated common property' (see, e.g., Baland and Platteau 1996 and Susilowati et al. 2005).

also less than one. As follows, $0 < \alpha < 1$ is assumed to hold. For a given harvest price and effort cost, p and c, respectively, the current individual profit is $\pi_t = pqe_t^{\alpha} X_t^{\beta} - ce_t$. Maximization for a given stock $X_t > 0$ yields $e_t = (\alpha pq / c)^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$. Because of lack of any strategic interaction among the exploiters, the number of fishermen does not influence the individual effort use[3][4]. Substituted into the harvest function gives $h_t = q(\alpha pq / c)^{\alpha/(1-\alpha)} X_t^{\beta/(1-\alpha)}$. Hence, irrespective of the price-cost ratio and other parameter values, harvest will always take place as long the stock size is positive. This is due to the fact that the marginal income, when $X_t > 0$, approaches infinite for a close to zero effort use.

The dynamics of the fish stock is completed when the harvest locus is inserted into the stock growth equation (1):

(2) $$X_{t+1} = X_t + F(X_t) - nq(\alpha pq / c)^{\alpha/(1-\alpha)} X_t^{\beta/(1-\alpha)}.$$

This is a first-order nonlinear difference equation where the dynamics generally depends on the initial size of the fish stock as well as the parameterization of the model. However, typically there will be no oscillations, and the steady state will be approached monotonically. See the classical May (1975) paper but also the numerical section below. It is also seen that the parameters of the model have the standard predictions as a higher price–cost ratio p / c shifts up the harvest locus and hence reduces the population growth. More effective technology and a higher q work in a similar manner.

The steady-state stock is found when $X_{t+1} = X_t = X^*$:

[3] In renewable harvesting models, strategic interaction is usually channelled through the resource stock resulting in reciprocal cost externalities. Under myopic harvesting where the stock is treated as exogenous by the exploiters (as here), this type of strategic interaction is hence ruled out. However, there may also be strategic interactions through various markets where the product market for fish may be of particular relevance. However, this possibility is not explored in this paper as the harvest price is assumed to be fixed and given.

[4] If the number of fishermen is small which typically is the case when considering small-scale common-pool resources (see also above), we may imagine that each fishermen takes own harvest effect into account in the harvest decision. The profit function may then be rewritten as $\pi_t = pqe_t^{\alpha}(X_t - qe_t^{\alpha} X^{\beta})^{\beta} - ce_t$. It is easily recognized that this effect shifts down the harvest locus (see main text below), but it will not change the outcome of model qualitatively.

(3) $F(X^*) = nq(\alpha pq/c)^{\alpha/(1-\alpha)} X^{*\beta/(1-\alpha)}$.

Natural growth is represented by the standard logistic function $F(X_t) = rX_t(1 - X_t/K)$, with r as maximum specific growth rate and K as carrying capacity (the maximum number of fish that the environment can support in the long run). The steady state $X^* > 0$ determined by equation (3) will then be unique.

The current maximum individual profit is $\pi_t = pq(\alpha pq/c)^{\alpha/(1-\alpha)} X_t^{\beta/(1-\alpha)} - c(\alpha pq/c)^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$, which may be written as $\pi_t = (\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^{\alpha})^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$ after a few rearrangements. The total rent at time t is accordingly:

(4) $\prod_t = n(\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^{\alpha})^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$

which is positive for any positive stock size. It is seen that more efficient harvesting technology q yields a higher total rent for any *given* stock size. This direct, short-run, effect, however, is counterbalanced by an indirect, long-run, effect as the stock at time t is contingent upon previous harvest activity where more efficient harvest technology slows down population growth (Eq. 2). The net result of these two effects is generally ambiguous, but at least in the beginning, when starting from an arbitrary initial stock value X_0, the direct, short-run, effect will dominate.

At the steady state, we may, however, infer more. The equilibrium rent is $\prod^* = n(\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^{\alpha})^{1/(1-\alpha)} X^{*\beta/(1-\alpha)}$. When combined with Eq. (3), we find after a few rearrangements:

(5) $\prod^* = (1-\alpha)pF(X^*)$.

The equilibrium rent is hence simply proportional to the equilibrium natural growth rate. Accordingly, when the biomass grows according to a single-peaked growth function like a logistic function, the steady-state rent will be ‘small’ for a high exploitation pressure and a ‘low’ stock value X^*, as well as for a ‘low’ exploitation pressure and a ‘high’ stock value.

The rent will be at its maximum when $F'(X^*) = 0$, or $X^* = X^{msy} = K/2$ (*msy* = maximum sustainable yield population).

Through Eq. (3), it is seen that a higher q always increases the harvesting pressure and works in the direction of a lower X^*. Therefore, depending on the price–cost ratio p/c and the number of exploiters n, more efficient harvest technology will either lower or increase $F(X^*)$ and hence will either lower or increase $\prod^*$. More specifically, in a situation with high exploitation pressure, channeled through a high price–cost ratio (p/c is low) and many harvesters (n is high) or both, we may find that more modern technology yields a lower equilibrium rent. The above-mentioned indirect, long-run, effect then dominates in the steady state. In the opposite case of a low price–cost ratio and few harvesters, more modern technology will produce a higher equilibrium rent, and the above-mentioned direct, short-run, effect dominates. See also Figure 1.

Proposition*: Fishing technology has a two-sided profitability effect under myopic exploitation. Under high exploitation pressure, more efficient harvest technology dissipates the equilibrium rent. Under low exploitation pressure, more efficient technology increases the equilibrium rent.*

Figure 1 about here

The fact that more efficient (and costless) technology may reduce the profitability of a fishery is a counterintuitive result. However, it can be explained by the myopic nature of the fishery. The various steady states, as well as the transition paths, are of a second best type, and hence exploiters may be better off with less efficient fishing technology, both individually and collectively. This possible outcome is in line with the results from the classic externality paper by Lipsey and Lancaster (1956)[5]. Therefore, the above proposition also prevails when there is only one harvester ($n = 1$) with (though somewhat unrealistic) myopic resource utilization. It

[5] The general theorem for the second best states that 'if there is introduced into a general equilibrium system a constraint which prevents the attainment of one of the Paretian conditions, the other Paretian conditions, although still attainable, are, in general, no longer desirable' (Lipsey and Lancaster 1956, p. 11).

contrasts with what is found in the sole-owner model (or social planner model) or in a common property regime where the fish stock, in various ways, is priced[6].

3. Numerical illustration

In the numerical examples, we work with the simple constant-return-to-scale situation $(\alpha + \beta) = 1$ and $\alpha = 0.5$. The individual myopic profit-maximizing harvest is then $h_t = aX_t$, where $a = pq^2/2c$, and the dynamics (2) is $X_{t+1} = X_t + F(X_t) - naX_t$. Therefore, the steady state condition (3) is found through $F(X^*) = naX^*$, or $X^* = K(1 - na/r)$ when applying the logistic natural growth function. The current rent (4) is $\prod_t = nbX_t$, where $b = pa/2$, while the equilibrium rent (5) follows simply as $\prod^* = (p/2)F(X^*)$.

The logistic growth function is given with parameter values $r = 0.5$ and $K = 5,000$ (in, say, tonnes) while the harvesting price is assumed to be 8.6 (in, say, mill NOK per tonne). For the given cost parameter c and number of harvesters n (together with the given fish price), the productivity parameter q is scaled such that the benchmark exploitation pressure is $na = 0.25$. Figure 2 yields the stock expansion path when $X_0 = 1000$. In this figure, two other expansion paths for other q-values are also depicted: the 'high'-efficiency growth path of $na = 0.30$ and the 'low'-efficiency growth path of $na = 0.20$.

Figure 2 about here

Figure 3 demonstrates the accompanying rent paths, $\prod_t$. As expected, the most efficient technology growth path yields the highest rent during the first period before the benchmark case takes over. At this takeover point, the indirect, long-run, profitability effect starts to dominate the direct, short-run, effect (section 2 above). At the steady state, the growth path with the lowest q-value also yields a higher rent than the most efficient technology case.

Figure 3 bout here

[6] In an open access fishery, however, a positive productivity shift may under certain conditions result in an inverted U-shaped profit curve (like Figure 1) before a new zero rent situation is reached. Such a transitional dynamics pattern is explored in Anderson (1986, Ch.2).

Finally, Table 1 shows the steady states of the different growth paths. In addition, the present-value (PV) rents are shown (calculated over a period of 50 years with a constant discount rent of 5 percent). As the benchmark case is constructed such that $X^{*} = X^{msy} = K/2 = 2{,}500$ and hence yields the maximum equilibrium natural growth, both the high- and low-technology efficiency scenarios yield a lower equilibrium profit (cf. also Figure 2). Therefore, this is the numerical demonstration of the above proposition.

4. Concluding remarks

This paper formulates a fishery harvest model where a fixed number of fishermen exploit the fish stock in a myopic profit-maximization manner: that is, the fishermen maximize short-term profit while taking resource abundance as given. Fishery stock growth paths are compared for various degrees of technological efficiency, and the two-sided effect on fishery rents is demonstrated. When natural growth is governed in a standard density-dependent manner, this two-sided effect is found to have a very simple steady-state interpretation, which leads to the above proposition.

The present simple model demonstrates that more modern technology may be a ‘bad’ when exploitation takes place within an institutional setting where the fishermen do not price the fish stock (a zero shadow price) and we are in a second best situation. This happens *even* if the number of fishermen is fixed and there is hence no inflow and outflow of fishing effort due to changes in profitability. Therefore, modern fishing equipment may threaten the ‘sustainability’ as well as the profitability of a fishery when being exploited in a restricted open-access (or unregulated common property) manner. As about 90% of the world’s fishermen and half of the fish consumed each year are captured by small scale, inshore fisheries which often are common pool resources (Ostrom 1990, p. 27), the ‘technology threat’ may be a real life situation in many fisheries and local communities in developing countries, as well as other places. Susilowati et al. (2005, p. 842), analyzing the mini-purse seine fishery of the Java Sea, for example, finds that ‘gains in *private* technical efficiency may…pose a *social* problem under…unregulated common property through the raising of catch rates, increases in ‘effective’ effort and fishing capacity…and further reductions in the resource stock’.

Literature

Abramovitz, M. 1956: Resource and output trends in the United States since 1870. American Economic Review 46, 5-23

Anderson, L. 1986: The Economics of Fisheries Management. The John Hopkins University Press, Baltimore

Baland, J. M. and J. P. Platteau 1996: Halting Degradation of Natural Resources. Clarendon Press, Oxford

Clark, C. 1990: Mathematical Bioeconomics. Wiley Interscience, New-York

Eggert, H. and R. Tveteraas 2007: Productivity development in Icelandic, Norwegian and Swedish fisheries. Paper presented at the 15th EAERE conference, Thessalonika

FAO 2003: World Agriculture Towards 2015/2030. FAO, Rome

FAO 2005: Review of the State of World Marine Fishery Resources. FAO Fisheries Technical Paper 457. FAO, Rome

Gordon, H. S. 1954: The economic theory of a common property resource: The fishery. Journal of Political Economy 62, 124-142

Homans, F. R. and J. Wilen 1997: A model of regulated open access resource use. Journal of Environmental Economics and Management 32, 1-21

Lipsey, R. G. and K. Lancaster 1956: The general theory of second best. The Review of Economic Studies 24, 11-32

May, R. 1975: Biological populations obeying difference equations: stable points, stable cycles, and chaos. Journal of Theoretical Biology 86, 511-524

Ostrom, E. 1990: Governing the Commons. Cambridge University Press, Cambridge

Skonhoft, A. and J. T. Solstad 2001: Exploiting a local common: Egoistic vs. altruistic behaviour. Marine Resource Economics 16, 39-49

Susilowati, I., N. Bartoo, I. Omar, Y. Jeon, K. Kuperan, D. Squires and N. Vestergaard 2005: Productive efficiency, property rights, and sustainable resource development in the mini-purse seine fishery of the Java Sea. Environment and Development Economics 10, 837-859

Figure 1: *Equilibrium rent and harvesting efficiency*

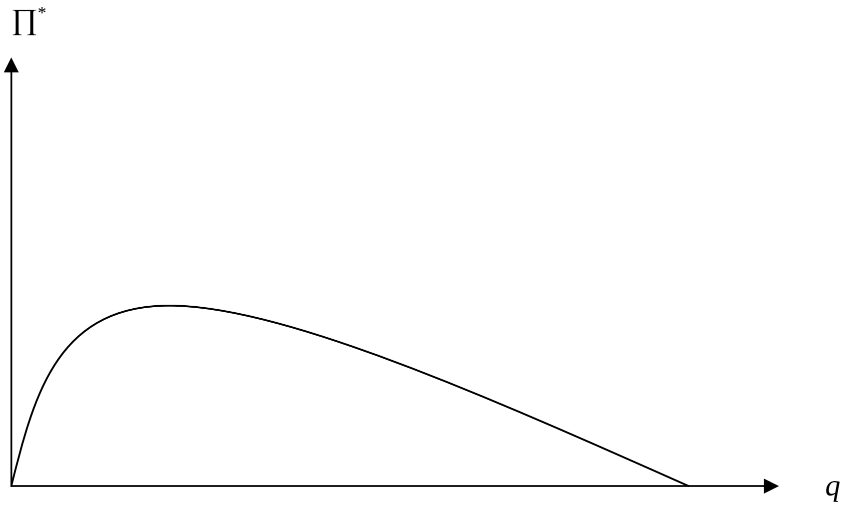

Figure 2: *Stock growth paths.*

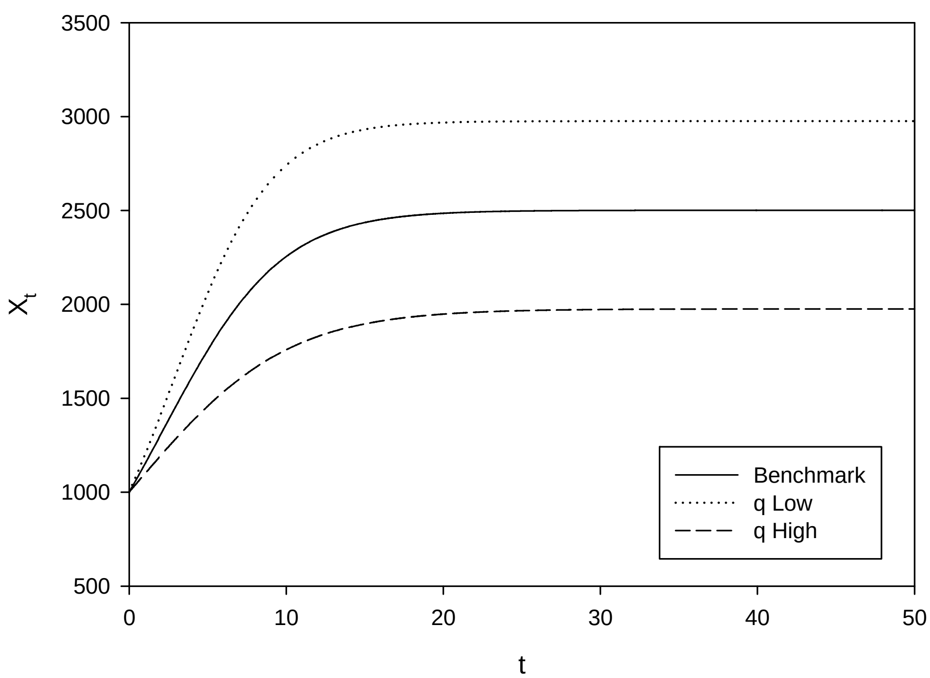

Figure 3: *Rent paths*

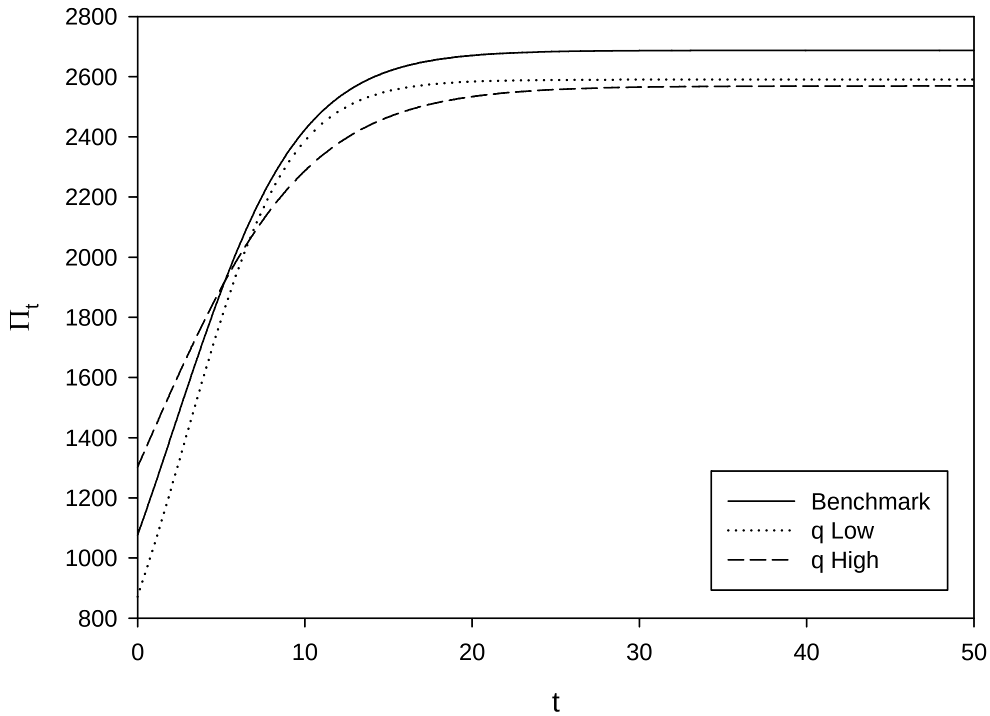

Table 1: *Harvesting efficiency and steady-states. Stock size (X^*), natural growth $F(X^*)$, rent (Π^*), and present-value profit (PV).*

	na	X^*	$F(X^*)$	Π^*	*PV*
Benchmark	0.25	2500	625	2687	43237
q low	0.20	2975	602	2590	41358
q high	0.30	1976	597	2569	42205