

## **The mixed blessing of more modern fishing technology**

*Keywords:*

Fisheries, small-scale, myopic exploitation, technology, rent

**ABSTRACT**

This paper formulates a simple biomass growth model of a fishery. The property rights regime is of the unregulated local common property type with a fixed number of fishermen and where the fish stock is exploited in a myopic profit-maximizing manner. Within this resource management setting it is demonstrated that more modern fishing technology has a two-sided profitability effect, and where the direct, short-run, positive effect is counterbalanced by a negative, long-run, indirect effect that slows down the stock growth and increases the harvesting costs. 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. This is the mixed blessing of modern fishing technology.

## 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, to demonstrate how and to what extent modern and more efficient harvesting technology may be a disaster not only for 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. Various studies indicate that productivity growth over the last few decades has been significant. Hannesson (2007) presents a calculation of the total productivity growth of a typically large scale fishery (Norway) for the last few decades while FAO (2003), among others, provides a more general overview of technical changes, also including small-scale fisheries.

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

---

<sup>1</sup> It can easily be demonstrated that the utilization approaches the costless harvesting case when efficiency approaches infinite: that is, the stock approaches the point where natural growth equalizes the rate of discount. Therefore, following this model, extinction will only be possible for a 'high' discount rate and a 'low' intrinsic growth rate of the fish stock. As shown by Murray (2007), however, extinction can also happen in the sole-owner model due to biological uncertainty as the owner may overestimate the natural growth of the stock in the presence of steadily more efficient harvesting technology.

In an *unregulated* fishery with unclear property rights and where the fishermen neglect to take into account their harvesting effect on the fish stock growth, the picture may be quite different. The so-called open-access fishery has for many years served as the benchmark of an unregulated fishery (e.g., Gordon 1954, Homans and Wilen 1997), but within such an exploitation regime, improved fishing technology has normally no long-run effect on the fish rent as the equilibrium rent, *by definition*, equalizes zero. In the short-run, however, more effective technology yields a positive rent in the transitional phase before a new zero rent equilibrium is reached (e.g., Anderson 1986, Ch.2). On the other hand, in unregulated fisheries allowing for a positive rent, the introduction of new technology, or a general trend in the direction of more efficient equipment, may erode profitability.

In what follows, an unregulated fishery is examined. Contextually, the sort of resource management we have in mind is a local inshore fishery in a typical development country setting. It may fit the FAO (2007, p. 7-8) definition of a small-scale fishery ‘...broadly characterized as a dynamic sector employing labour intensive harvesting...to exploit marine and inland water fishery resources... (where the)...activities...are often targeted on supplying fish and fishery products to local and domestic markets, and for subsistence consumption...’. In such a small-scaled fishery it is assumed that the number of fishermen (or vessels) flowing in (an out) of the fishery caused by changing profitability opportunities is small, or even negligible. This may be due to a possible license system that restricts the entrance of new fishermen. We abstract from any further regulations, or enforcement (but see section three), which typically is the case in such small scale fisheries (see, e.g., Pomeroy et al. 2009 with examples from Vietnam). The exploitation scheme may vary due to circumstances (e.g., Bromley 1991 for a general discussion), but here we focus on a situation where the fishermen lack any long-term view on the resource utilization. Within this framework it is assumed that they aim to do it as ‘as good as possible’ approximated by short term, or myopic, profit maximization. The exploitation hence takes place within the management setting described by, among others, Baland and Platteau (1996), as an *unregulated local common property* regime. It fits to the notion of a local common because the number of exploiters is fixed, and it fits to the notion of unregulated exploitation because it lacks any long term view on the resource utilization. It may also be quite similar to Ostrom’s (1990) notion of a small-scale local common-pool resource, but where economic, cultural and economic changes have changed the way in which the fishery resources are exploited. Unregulated resource

management schemes like the present one are studied in numerous papers, see, e.g., Brander and Taylor (1998).

Within this setting it is, from a theoretical point of view, demonstrated how more modern fishing technology, or improved fishing efficiency, may be a mixed blessing not only for the fish abundance, but also for the profitability of the individual fisherman and the local community. The possible mixed blessing of more efficient fishing technology is discussed, among others, by Whitmarsh (1990), Squires (1992) and Murray (2007). The main contribution of the present analysis is that the relationship between new technology and profitability is made clearer, and it is shown under what circumstances more modern technology may dissipate the rent within the framework of an unregulated common property regime. The driving force is all the time the presence of externalities due to the short-sighted exploitation of the fish stock. In Levhari and Mirman (1980) externalities are created in a situation where the users have a long term view on the resource exploitation. Here, on the other hand, it is channeled through the myopic nature of the resource exploitation as the fishermen do not price the fish stock<sup>2</sup>.

The rest of the paper is structured as follows. The model is formulated in the next section where technological improvement is introduced in the simplest way through a costless shift in the productivity parameter in the harvest (production) function and where different *levels* of technology is examined. The two-sided effect of more modern technology, one positive short-term effect and one negative long-term effect, is demonstrated. While we here look at different levels of the technology, section three formulates an extension where technological improvement *grows* steadily over time. Section four concludes the paper.

## 2. Model

We consider a single fish stock exploited instantaneously and simultaneously by a fixed number of  $n$  identical fishermen. The population growth may hence be written as:

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

---

<sup>2</sup> Notice, that such myopic exploitation also can be given a broader interpretation. Berck and Perloff (1984), for example, analyses a fishery where myopic profit acts as an adaptive estimate of future profit.

where  $X_t$  is the stock size (measured in biomass, or number of fish) 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 ('catchability') coefficient. This parameter represents the technology factor in the model, and a larger  $q$  is throughout said to represent more efficient, or more modern fishing technology. For simplicity, any investment activity related to more efficient technology is disregarded, and changes through different levels of  $q$  is hence synonymously with technological change of the so-called Hicks neutral and disembodied type.  $\beta$  may be referred to as the stock elasticity and  $\alpha$  as the input elasticity. The case  $\alpha = \beta = 1$  is frequently used in the literature and coincides with the standard Schaefer harvesting function (again see, e.g., Clark 1990). However, for many fish stocks,  $\beta$  may be substantially lower than one ('schooling stocks'), and in many instances, it is not unrealistic to assume a decreasing effort effect so that  $\alpha$  is also less than one<sup>3</sup>. As follows,  $0 < \alpha < 1$  is assumed to hold. In addition, we have  $\beta > 0$ . For given harvest price and per unit 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<sup>4</sup>, the number of fishermen does not influence the individual effort use directly, but it will influence it *indirectly* (see below)<sup>5</sup>. 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

---

<sup>3</sup> The scale properties of a fishery are examined, among others, by Hannesson (1983). The result from his findings as well as the results from other studies are mixed, and vary substantially across models and types of fisheries.

<sup>4</sup> In renewable harvesting models, strategic interaction is usually channelled through the resource stock (e.g., Levhari and Mirman 1980). 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 (e.g., Koulovatianos and Mirman 2007). However, this possibility is not explored in this paper as the harvest price is assumed to be fixed and given.

<sup>5</sup> If the number of fishermen is 'small' which typically is the case when considering small-scale common-pool resources, we may imagine that each fishermen takes *own* harvest effect into account in the harvest decision. The profit function may then be rewritten as  $\pi_t = pqE_t^\alpha (X_t - qE_t^\alpha X_t^\beta)^\beta - cE_t$ . It is easily recognized that this effect shifts down the harvest locus (see main text below), but it will not qualitatively change the outcome of model.

is due to the fact that the marginal profit, when  $X_t > 0$ , always will be positive even for a small effort use (because  $\alpha < 1$ ).

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

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

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 as harvesting stabilizes the dynamic path (cf. the classical May 1975 paper). It is also seen that the parameters of the model have the standard predictions as a higher price–cost ratio  $p/c$ , for a given stock size  $X_t$ , shifts up the harvest locus and hence reduces next periods population growth. More efficient technology and a higher  $q$  work in a similar manner.

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

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

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 at time  $t$  is

$$\pi_t = pq(\alpha pq/c)^{\alpha/(1-\alpha)} X_t^{\beta/(1-\alpha)} - c(\alpha pq/c)^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)} , \text{ which may be written as}$$

$$\pi_t = (\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^\alpha)^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)} \text{ after a small rearrangement. Notice that the}$$

individual profit at time  $t$  is not directly related to the number of fishermen  $n$ . However, it is *indirectly* influenced by  $n$  through previous periods fishing activity, cf. the above equation

(2). The total rent at time  $t$  becomes:

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

which is positive for any positive stock size<sup>6</sup>. 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 a given initial stock value  $X_0$ , the direct, short-run, effect certainly will dominate.

At the steady state, we may, however, infer more. The equilibrium rent is

$\Pi^* = n(\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^\alpha)^{1/(1-\alpha)} X^{*\beta/(1-\alpha)}$ . When combined with Eq. (3), we find after a few rearrangements that the rent may be related to the (endogenous) population size as:

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

The equilibrium rent is hence simply *proportional* to the equilibrium natural growth.

Accordingly, when the biomass grows according to a single-peaked growth function like the standard 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  $\Pi^*$ . More specifically, in a situation with high exploitation pressure, channeled through a high price–cost ratio ( $p/c$  is high) 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.

---

<sup>6</sup> In this equation, profit increases linearly with the number of fishermen  $n$ . However, notice again the indirect effect as  $n$  influences  $X_t$  through previous periods fishing activity (see also main text below).

**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 is explained by the stock externality which here works through a myopic exploitation of the fish stock. The various steady states, as well as the transition paths, are therefore of the so-called second best type, and hence the fishermen 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)<sup>78</sup>. It contrasts what is found in the social planner model (sole owner model) or in a common property regime where the presence of, say, social norms (cf. Ostrom 1990) means that the exploitation takes place in a regulated manner with a shadow price is attained to the fish stock. As mentioned, Squires (1992) and Whitmarsh (1990) suggest that technical improvement can be a mixed blessing if the fish stock is not priced. The above proposition supports their hypothesis and indicates under what circumstances this may happen.

It is possible to find an explicit expression for the equilibrium stock and rent when assuming constant return to scale (c.r.s.) harvesting with  $\alpha = \beta = 0.5$ . It is then possible to see how an improvement in technology is analytically different from an increase in, say, price or a decrease in the cost of effort. With c.r.s. the individual myopic profit-maximizing harvest becomes  $h_t = (pq^2 / 2c)X_t$ , and the dynamics (2) yields  $X_{t+1} = X_t + F(X_t) - n(pq^2 / 2c)X_t$ . Therefore, the steady state is found as  $F(X^*) = n(pq^2 / 2c)X^*$  through Eq. (3), or  $X^* = K(1 - npq^2 / 2cr)$  when applying the logistic natural growth function (see above). The

---

<sup>7</sup> 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).

<sup>8</sup> Therefore, the proposition also prevails when there is only one fisherman ( $n = 1$ ) combined (though then somewhat unrealistic) with myopic resource utilization.

current rent (4) is  $\Pi_t = (np^2q^2/4c)X_t$ , while the equilibrium rent follows as

$\Pi^* = (p/2)F(X^*)$  when using Eq. (5). Inserting for  $X^*$  it reads:

$$(6) \quad \Pi^* = (p^2nK/4c)q^2[1 - (np/2cr)q^2].$$

We find  $d\Pi^*/dq = 0$  when  $q = 0$  and  $q = \sqrt{cr/np}$  (cf. the above Figure 1). Therefore, the technological level that yields the highest rent is positively related to the cost-price ratio  $c/p$  and the productivity of the actual fish stock  $r$ , and negatively related to the number of fishermen  $n$ . In this c.r.s. fishery the maximum rent becomes

$$\Pi_{\max}^* = (p^2nK/4c)(cr/np)[1 - (np/2cr)(cr/np)] = pKr/8.$$

Figure 2 depicts two possible technology level – rent relationship. Panel b) shows what happens for different values of the harvest  $p$ . As seen, a higher price, for a given level of the technology, in general has a mixed effect on the equilibrium rent. But the maximum value increases for a higher  $p$ . The number of fishermen  $n$  (panel a) has also an unclear effect, and this will also be so for the effort cost  $c$  (not shown). These results follow the logic of the Lipsey and Lancaster (1956) paper.

Figure 2 about here

### 3 An extension

Above it has been demonstrated how different *levels* of the fishing technology may influence profitability and fish abundance in an unregulated fishery. Now, just as in Murray (2007) (see also Squires and Vestergaard 2009), we proceed to analyze a somewhat different situation where technological improvement, still in the costless Hicks neutral manner, *grows* steadily over time<sup>9</sup>. With  $\gamma > 0$  as the instantaneous growth rate, the efficiency level at time  $t$  then writes  $q_t = q_0e^{\gamma t}$ . We find the same optimal (myopic) individual effort as before except that  $q_t = q_0e^{\gamma t}$  replaces  $q$ . Therefore, the stock dynamics (2) changes to:

$$(7) \quad X_{t+1} = X_t + F(X_t) - nq_0e^{\gamma t} (\alpha pq_0/c)^{\alpha/(1-\alpha)} e^{\alpha\gamma t/(1-\alpha)} X_t^{\beta/(1-\alpha)},$$

while the rent evolves as:

---

<sup>9</sup>This is also the same modelling framework as in the above cited work by Abramovitz (1956) and numerous other theoretical and empirical growth studies.

$$(8) \quad \Pi_t = n(\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq_0/c^\alpha)^{1/(1-\alpha)} e^{\gamma t/(1-\alpha)} X_t^{\beta/(1-\alpha)}.$$

Depending on the initial fish abundance  $X_0$ , the stock  $X_t$  at time  $t > 0$  will either increase or decrease when new technology evolves. However, if initially growing, the stock will eventually decrease and be depleted in the long term as the harvest locus (right hand term of Eq. 7) steadily shifts up. Depending on the initial stock size, and parameter values, the rent may either increase or decrease in the very beginning as well. But in the long term the rent will be totally dissipated. Therefore, an ever increasing more efficient fishing technology together with myopic resource exploitation for sure will deplete the stock and destroy the economic conditions of the fishermen and the fishing community in the long term.

In reality, however, actions may be taken to prevent stock collapse and rent dissipating. In the present small scale fishery with a possible licence system (cf. the introductory section), regulation can take place through input control (fewer fishing days, fewer nets, less motor power, etc.) so that every fishermen is restricted to use, say,  $\bar{E}$  amount of effort at every point of time<sup>10</sup>. Another obvious action is to regulate harvest. It demands possible more enforcement capacity, and such capacity is often the crucial problem in small scale fisheries as considered here (again, see Pomeroy et al. 2008). Under an input regulating scheme, indicating that the institutional setting of this fishery also changes (cf. introductory section), the problem of the individual fisherman is to maximize profit, just as above, but now subject to the constraint  $E_t \leq \bar{E}$ . When imposed at  $t = 0$ , this constraint will typically bind in the very beginning. Sooner or later, when the stock has been sufficiently fished down, it will, however, no longer bind. The stock will then be further reduced and the rent will eventually be dissipated. Hence, under the prevailing situation where the fishing efficiency steadily improves, *fixed* input regulation has only a temporarily effect and will only delay stock depletion and rent dissipation.

---

<sup>10</sup> However, one possible problem preventing regulation is that more efficient technology may delay, or hide, a clear stock assessment signal. Frequently, fish abundance is assessed by catch per unit effort, or *CPUE*. For the individual fisherman, as well as for the whole fishery, we have  $CPUE_t = h_t / E_t = q_0 e^{\gamma t} E_t^{\alpha-1} X_t^\beta$ . Inserted for the optimal (myopic) effort this yields  $CPUE_t = q_0 e^{\gamma t} [(\alpha pq_0 e^{\gamma t} / c)^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}]^{(\alpha-1)} X_t^\beta$ , or simply  $CPUE_t = c / p\alpha$ . Therefore, under the present assumptions, *CPUE* yields no stock depleting signal. The same is also pointed out by Murray (2007, Ch. 2) in a different institutional setting with a solve-owner, but uncertain stock observations (see also introductory section).

Therefore, when utilizing input control in a situation where fishing technology gradually becomes more efficient and the number of fishermen is fixed, the only measure that can sustain the stock and rent in the long term is a steadily *tighter* input control; that is, every fishermen is restricted to use less and less effort. To sustain the stock level at, say,  $X^*$ , the stock equation (1)  $X_{t+1} = X_t + F(X_t) - nh_t$ , or  $X_{t+1} = X_t + F(X_t) - nq_0 e^{\gamma t} E_t^\alpha X_t^\beta$ , should hold as  $F(X^*) = nq_0 e^{\gamma t} E_t^\alpha X^{*\beta}$ . Steady state hence demands  $q_0 e^{\gamma t} E_t^\alpha$  to be kept fixed; that is, effort should be withdrawn at the constant yearly rate  $(dE_t / dt) / E_t = -\gamma / \alpha$ . Therefore, with  $\bar{E}_0$  as the initial effort level,  $\bar{E}_t = \bar{E}_0 e^{-\gamma t / \alpha}$  describes an input regulation path compatible with the sustained stock level  $X^*$ . In his sole-owner model, Murray (2007, Ch. 1) argues for the same degree of input withdrawal. A constant stock level, of course, means a constant catch. On the other hand, the rent  $\Pi_t = n[pq_0 e^{\gamma t} (\bar{E}_0 e^{-\gamma t / \alpha})^\alpha X^{*\beta} - c\bar{E}_0 e^{-\gamma t / \alpha}] = n[pq_0 \bar{E}_0^\alpha X^{*\beta} - c\bar{E}_0 e^{-\gamma t / \alpha}]$  will certainly grow over time. Accordingly, with input regulation where successive fishing effort is withdrawn, the fishermen will experience a double dividend of improved (costless) efficiency; less effort accompanied by higher profit!

#### 4. Concluding remarks

This paper studies a fishery where a fixed number of fishermen exploit a fish stock in a myopic profit-maximization manner. Such scheme may typically illustrate the exploitation of an unregulated local common property. Fishery stock growth paths are compared for various levels 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 saying that more efficient harvest technology dissipates the equilibrium rent under an already high exploitation pressure while it increases the equilibrium rent under low exploitation pressure. A high exploitation pressure typically occurs when the harvest is valuable combined with low effort costs, or when the already existing fishing equipment is effective. This result stands in sharply contrast the social planner (or sole owner) situation where improved harvesting technology unambiguously improves the rent, but reduces the stock. Our proposition is demonstrated in the most simply way by allowing for exogenous, cost free productivity growth.

Therefore, following our theoretical model, more modern fishing equipment may threaten the ‘sustainability’ as well as the profitability of a fishery when being exploited in an 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, and also FAO 2007), the ‘technology threat’ may be a real life situation in many fisheries and local communities in the developing world. Such a situation is possible described in Susilowati et al. (2005, p. 842), analyzing the mini-purse seine fishery of the Java Sea where they conclude 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’.

If fishing efficiency grows steadily over time, regulations must certainly take place to prevent stock depletion and rent dissipating. To sustain a given stock level, the model demonstrates that fishing effort should be gradually withdrawn from the fishery. The fishermen may then experience a double dividend of improved efficiency; less effort accompanied by higher profit.

### **Acknowledgements**

The shaping of section three of this paper has benefitted substantially from presentations and discussions at the Helsingør June 2008 workshop ‘Technical Change in Renewable Resource Economics’ organized by Niels Vestergaard and Dale Squires. I also thank three reviewers and Ola Flaaten for critical and constructive comments on an earlier draft of this paper.

### **REFERENCES**

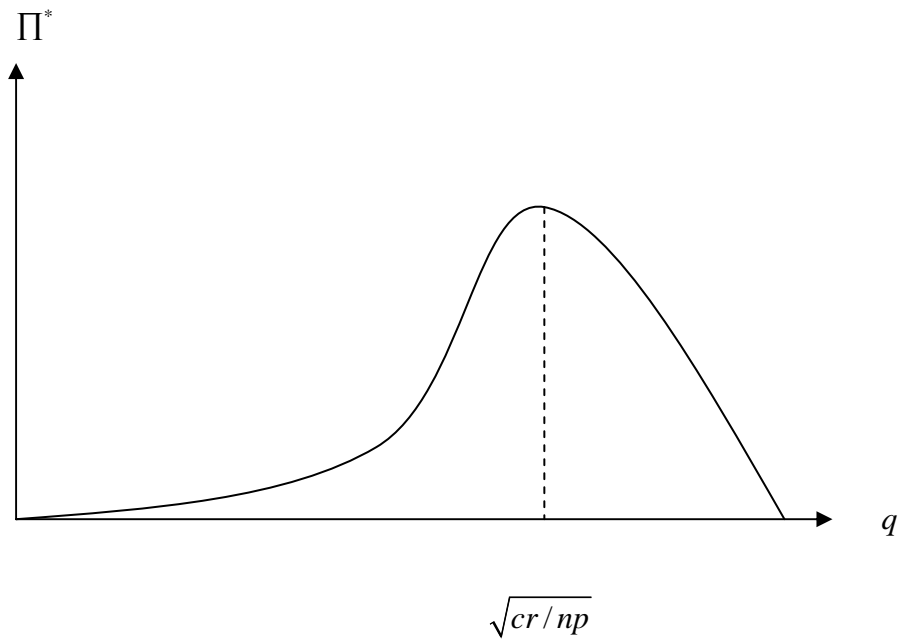
- Abramovitz, M., 1956. Resource and output trends in the United States since 1870. *American Economic Review* 46, 5-23
- Anderson, L., 1986, *The Economics of Fisheries Management*. The John Hopkins University Press, Baltimore
- Baland, J. M. and J. P. Platteau, 1996. *Halting Degradation of Natural Resources*. Clarendon Press, Oxford
- Berck, P. and J. Perloff, 1984. An open-access fishery with rational expectations. *Econometrica* 52, 489-506

- Brander, J. and M. Taylor, 1998. The simple economics of Easter Island: A Ricardo-Malthus model of renewable resource use. *American Economic Review* 88, 119-138
- Bromley, D., 1991. *Environment and Ecology*. Basil Blackwell, Oxford
- Clark, C., 1990. *Mathematical Bioeconomics*. Wiley Interscience, New-York
- 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
- FAO 2007: *Increasing the contribution of small-scale fisheries to poverty alleviation and food security*. FAO Fisheries Technical Paper 481. FAO, Rome
- Gordon, H. S., 1954. The economic theory of a common property resource: The fishery. *Journal of Political Economy* 62, 124-142
- Hannesson, R., 1983. Bioeconomic production function in fisheries: Theoretical and empirical analysis. *Canadian Journal of Aquatic Sciences* 40, 969-982
- Hannesson, R., 2007. Growth accounting of a fishery. *Journal of Environmental Economics and Management* 53, 364-376
- Homans, F. R. and J. Wilen, 1997. A model of regulated open access resource use. *Journal of Environmental Economics and Management* 32, 1-21
- Koulovatianos, C. and L. Mirman, 2007. The effects of market structure on industry growth: Rivalrous non-excludable capital. *Journal of Economic Theory* 133, 199-218
- Levhari, D. and L. Mirman, 1980. The great fish war: an example using a dynamic Cournot-Nash solution. *Bell Journal of Economics* 11, 322-334
- 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
- Murray, J., 2007: *Constrained Marine Resource Management*. Unpublished Ph.D. Dissertation, Dep. of Economics University of California San Diego
- Ostrom, E., 1990. *Governing the Commons*. Cambridge University Press, Cambridge
- Pomeroy, P. K. Nguyen and H. Trong, 2009. Small-scale marine fisheries policy in Vietnam. *Marine Policy* 33, 419-428
- Squires, D., 1992. Productivity measurement in common property resources: an application the Pacific coast trawl fishery. *Rand Journal of Economics* 23, 221-236

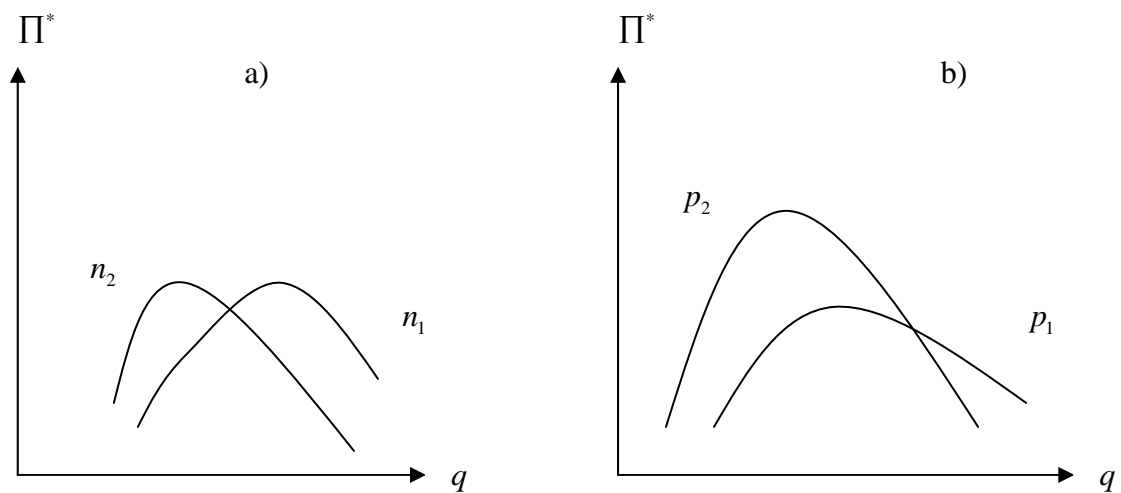
Squires, D. and N. Vestergaard, 2009. Technical change and the commons. Working Paper, Dep. of Economics University of California San Diego

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

Whitmarsh, D., 1990. Technological change and marine fisheries development, *Marine Policy* 14, 15-22



**Figure 1- Equilibrium rent and level fishing efficiency**



**Figure 2- Equilibrium rent and level fishing efficiency. Panel a) Different number of fishermen,  $n_2 > n_1$ . Panel b) Different fishing price,  $p_2 > p_1$ .**

