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Loss of economic rents in the global fishery[**]

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Abstract

Most fisheries around the world are severely lacking in private property rights in the underlying natural resources or their close complements (e.g. harvesting volume). Therefore, according to standard property rights theory, these fisheries should be highly wasteful of potential economic rents from these resources. The available global data, as compiled and interpreted by the FAO, confirm this prediction. More detailed evidence from individual fisheries, both the typical common property ones and those that have become subject to reasonably effective private property rights such as ITQs, recounts the same story.

This raises the question of the global economic waste or, more politely put, global rent loss, due to this inappropriate institutional framework of most fisheries world-wide. This question is particularly poignant due to the fact that a large portion of the global fishery is conducted by dirt poor people in the developing world who would really benefit from added income.

This paper builds on the theory of fisheries rents and global fisheries data primarily collected by the FAO to obtain an estimate the global fisheries rent loss and to assess reasonable lower and upper confidence bounds for this loss. It is found that this eminently avoidable rent loss probably constitutes a large fraction of the global development aid every year.

Keywords: Economic rents, fisheries rents, rents loss, loss of fisheries rents, global fisheries rents loss.
JEL classification: Q, Q2

0. Introduction

Global fisheries, it is well known, are subject to severe problems of economic inefficiency. One indication is the biological overexploitation of many of the world's most valuable fish stocks (FAO 2006). Another is general poor profitability of the world's commercial fisheries and the high level of subsidization the world's fishing industry has required (Milazzo 1998). The fundamental source of these problems is also well known. It is the common property arrangement of most global fisheries, i.e. lack of private property rights in the harvesting of fish and the underlying resources (Scott 1955, Harding 1968, Arnason, 2005). What is not so well known is the extent of this inefficiency. What is the total amount of the economic loss due to global fishery inefficiency? Is it a significant number on the global scale of things?

The objective of this paper is to present estimates of the economic inefficiency in the global ocean fishery. Economists traditionally measure the net economic benefits from a nature resource as the fishery by economic rents. Rents are not equal to profits — the difference is fixed costs and so-called intra-marginal profits — but usually similar and sometimes identical. Given this, global fisheries inefficiency may be measured as the difference between maximum rents obtainable from the fisheries and the actual rents currently obtained.

The paper is organized as follows: is necessary to briefly review the theory of economic rents and that of fisheries rents in particular. This is done in the first section of the paper which explain the concept of economic rents and how it can be extended to cover fisheries rents and, indeed, natural resource rents in general.

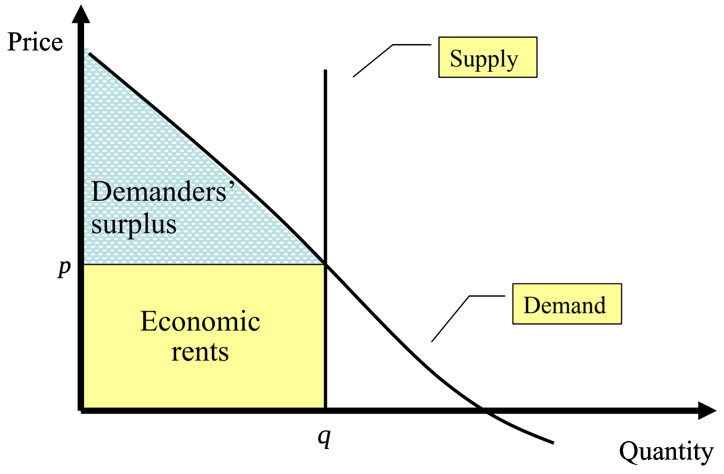
The remainder of the paper deals with the estimation of global fisheries rents loss. The approach is quite simple. A simple aggregative model of the global fishery is specified. The unknown parameters of this model are estimated by fitting the model to a set of available observations on the global fishery. Note that this is fitting and not statistical estimation; equipped with the estimated parameters the model exactly replicates the observations. With this estimated global fisheries model in hand, it is relatively straight-forward to calculate rents under any harvesting policy. The imprecision in the estimated global fisheries model, i.e. the uncertainty about the real global fishery, is partially accounted for by sensitivity analysis of the results and stochastic simulations

Section 2 sets out the basic fisheries model to be used. Section 3 describes how the model parameters are estimated on the basis of this model and some global fisheries data. Section 4 presents point estimates of the global fisheries rents loss and explores the sensitivity of the results to the model specifications. Section 5 extends the analysis by deriving confidence intervals for the global rents loss estimates on the basis of stochastic specification of key model components. The main numerical results of the paper are summarized in the conclusions.

1. Economic rents

In economics, the concept of economic rents is often illustrated with the diagram in Figure 1 (Alchian 1987). In this diagram, there is a demand curve and a supply curve for some economic good. The supply curve is vertical to suggest fixed supply (i.e. independent of the price). The market-clearing price is p. However, since the supply of the good is assumed fixed, the corresponding supply, q, would be forthcoming even if the price were zero. Hence, the entire price, p, may be regarded as a surplus per unit of quantity. The total surplus or economic rent attributable to the limited factor is measured by the rectangle $p \cdot q$.

Figure 1
Economic Rents



It is informative to observe that the economic rents depicted in Figure 1 also represent rental profits to the owner of the good — this is what the owner would gain from renting a resource such as land of quantity q to the demander. Indeed, this is the reason why it has been characterized as rents in the economic literature.

At the same time it is important to realize that the economic rents do not represent the total economic benefits of the supply q. This is measured by the sum of economic rents and the demanders' surplus represented by the upper triangle in the diagram. Thus, if the demanders are producers buying or renting q from the owner at price p, their profits would be the demanders' surplus. Total profits from the supply q, would be sum of economic rents and the demanders' surplus. Thus, in the case depicted in Figure 1, profits would be greater than economic rents. Some authors refer to the demanders' surplus in Figure 1 as intra-marginal rents (see e.g. Coglan and Pascoe 1999 for fisheries and Blaug 2000 more generally).

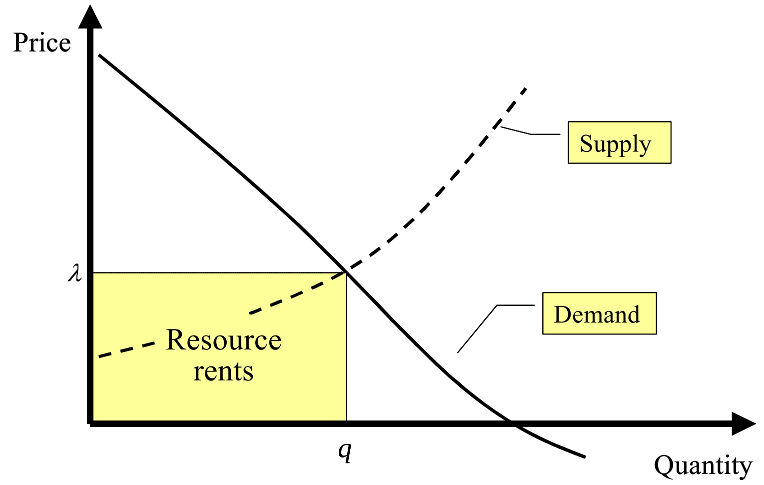
When it comes to fisheries rents, the diagram in Figure 1 is not entirely satisfactory. The reason is that in fisheries — as probably in most natural resource uses — the supply is not fixed by nature. At each point of time it is possible to extract more or less from the resource stock, provided of course it is positive. This raises the question as to how the quantity of supply is actually set. At one extreme, it may be determined by free access to the resource (equivalent to common property) in which case there will be no economic rents. At the other extreme it may be set by an owner of the stock or a fisheries manager who want to maximize economic benefits from the fishery. In between these two extremes, the various fisheries management regimes restrict the quantity of harvest (extraction) at different levels.

It can be shown (see appendix 1) that in all these cases there will be a supply curve for extraction from the fish stock and it will normally not be vertical as depicted in Figure 1. This supply does not reflect real costs in the sense of monetary outlays but represents the degree of present value profit maximization that is undertaken by the resource owner or the fisheries manager. The actual supply is where this supply curve intersects the demand curve. At this point of supply, there will be a level of economic rents. For optimally managed fishery, this supply curve and the corresponding fisheries rents are as illustrated in Figure 2. Less than perfectly managed fisheries will give rise to harvest supply curves below the one illustrated in Figure 2 and actual supply between q and $q°$. In an open access or totally unmanaged fishery, this supply curve will coincide with the horizontal axis. The supply will be $q°$ and the fisheries rents (but not necessarily profits) are identically zero.

As the supply curve in Figure 2 is drawn, the actual supply is q and the resource rents are defined by the multiple $\lambda \cdot q$. Note that there is no cost, in the usual sense, associated with supplying q. The supply price, λ, is merely an imputed or notional price. It represents the opportunity cost of reducing the size of the resource, sometimes referred to as a user cost (Scott 1955). This user cost is the result of the maximization of the present value of profits and is generated by the concern that "oversupply" now might hurt future profits. Thus, it is very similar to the user costs a monopolist might calculate for his own current supply. The difference is that in the natural resource context, the imputed user costs stem from the scarcity of the resource. In the traditional monopolist situation it comes from the perceived downward slope of the demand curve – scarcity of demand.

Figure 2

A Resource Extraction Industry: Resource Rents



Now, as is obvious from Figure 2, λ is equivalent to the demand price for the quantity q. But this demand price must be the marginal profits (additional profits of having one more unit) of q. Denote this by the symbol Π_q, which may be recognized as the first derivative of Π with respect to q, where Π, of course, denotes profits. Thus, we have the very useful relationship:

$$Rents = \lambda \cdot q = \Pi_q \cdot q\,.$$

On the basis of this relationship we can calculate fisheries (and other) rents if only we know the profit function the variables on which it depends at q and the quantity q. This relationship forms the basis for the estimation of rents and rents loss which follows.

2. Estimating global fisheries rents: The basic model

The approach to estimating global fisheries rents is based on the following aggregative fisheries model:

(1) $\dot{x} = G(x) - y$ (Biomass growth function).

(2) $y = Y(e,x)$ (Harvesting function).

(3) $\pi = p \cdot Y(e,x) - C(e)$ (Profit function).

The five variables of this model, i.e. x, y, e, π and p represent biomass, harvest, fishing effort, profits and landings price, respectively. The first four are endogenous — determined within the fishery, and the fifth, price, exogenous — determined by market conditions outside the fishery. The derivative, $\dot{x} \equiv \partial x/\partial t$ measures the change in biomass at a point of time.

The model comprises three elementary functions basic to <u>any</u> bio-economic fisheries model: the natural growth function, $G(x)$, the harvesting function $Y(e,x)$, and the cost function, $C(e)$. These functions are assumed to have the usual regularity properties (see e.g. Clark 1976).

Rents are going to be calculated in equilibrium (Arnason 2006). This implies that in the rent calculations, expression (1) simplifies to:

(1') $y = G(x)$.

It is assumed (as seems reasonable and in accordance with empirical estimates) that the harvesting function is monotonic and bounded in fishing effort. This suggests that it may be possible to rewrite this function as:

(4) $e = E(y,x)$

Given these two simplifications, (biological) equilibrium revenues, costs, profits as well as rents in the fishery may be written as a function of biomass only. More precisely:

(5) $Rev(x) = p \cdot G(x)$, (Equilibrium revenues).

(6) $C(x) = C(E(G(x),x))$, (Equilibrium costs)

(7) $\pi = p \cdot G(x) - C(E(G(x),x))$, (Equilibrium profits)

(8) $R(x) = \left(p - C_e(E(G(x),x)) \cdot E_y(G(x),x)\right) \cdot G(x)$, (Equilibrium rents)

Equations (5) and (6) provide us with expressions for equilibrium profits and rents for any level of biomass. Maximizing these functions will yield maximum sustainable profits and rents for the fishery. Knowing the current (equilibrium) biomass (or, for that matter, profits, costs or revenues), knowledge of these equations also allow us to calculate current rents. Thus, on the basis of (5) to (8), calculating rents loss is straight-forward.

Now, let us adopt the following specifications of the harvesting and cost functions:

(9) $Y(e,x) = q \cdot e \cdot x^b$,

(10) $C(e) = c \cdot e + fk$.

The harvesting function is a generalization of the Schaefer (1954) one. The parameter q is usually referred to as the catchability coefficient. The parameter b reflects the degree of schooling behavior of the species in question. Normally $b \in [0,1]$. b close to one would indicate little schooling and a lower b suggests increasing tendency toward schooling. For species such as herring b has been estimated between 0.1 and 0.2 (Bjorndal 1987).

The cost function is linearly increasing in effort with marginal effort costs being equal to the constant, *c*. This reflects the assumption that the fisheries inputs can be obtained at fixed costs — an economically reasonable assumption especially for a cost function supposed to apply in biological equilibrium. The fixed costs, *fk*, are included for generality. They will surely disappear in stock equilibrium (i.e, the long run).

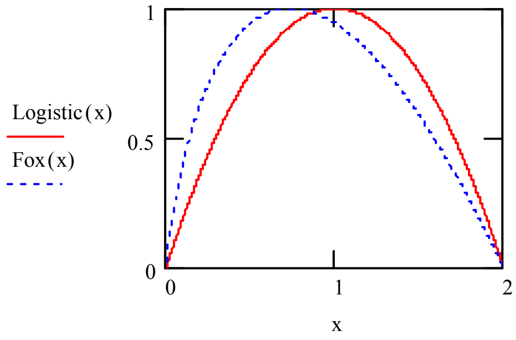
For the natural biomass growth function, we adopt two alternatives, (i) the logistic function (Clark 1976) and (ii) the Fox (1970) growth function[1]:

(11) $G(x) = \alpha \cdot x - \beta \cdot x^2$, (Logistic)

(12) $G(x) = \alpha \cdot x - \beta \cdot ln(x) \cdot x$ (Fox)

As can be readily seen, the Fox growth function consists of a slight modification of the second term of the logistic function. This leads to a biomass growth function and a sustainable yield functions which, unlike the corresponding functions for the logistic, are skewed to the left. A comparison of the two functions for the same maximum sustainable yield and virgin stock biomass is illustrated in Figure 3.

Figure 3
Logistic and Fox biomass growth functions



Under the above functional specifications we have four equations for the economic outcomes of the fishery:

(13) $Rev(x) = p \cdot G(x)$,

(14) $C(x) = \dfrac{c}{q} \cdot G(x) \cdot x^{-b} + fk$,

(15) $\pi = \left(p - \dfrac{c}{q} \cdot x^{-b}\right) \cdot G(x) - fk$, (Equilibrium profits).

(16) $R(x) = \left(p - \dfrac{c}{q} \cdot x^{-b}\right) \cdot G(x) = \pi + fk$, (Equilibrium rents).

Where, of course, *G*(*x*) stands for the biomass growth function adopted for the fishery. This could be the logistic or the Fox as specified in expressions (11)-(12). It could also be any other function.

3. Estimation of model parameters

There are many ways to estimate the parameters of expressions (11)-(16). Which one is selected depends on (i) the fisheries situation, (ii) the amount of data available to the researcher and (iii) the ingenuity of the researcher. Since expressions (11)-(16) include seven parameters, at least seven independent units of information are needed. This information

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[1] The Fox biomass growth function here is actually derived from Fox's (1970) basic specification of a sustainable yield function. The latter is thought to represent the global fisheries situation, where higher yield-lower unit value fisheries have replaced lower yield- higher unit value fisheries (fishing down the food chain), better than the symmetric logistic function.

might for instance widely known facts about the fishery e.g. the MSY (maximum sustainable yield), profitability, schooling behaviour etc. In addition some information about the initial state of the fishery is needed. With more pieces of information (observations), as discussed in section 3, statistical estimation techniques may be brought to bear and improved estimates be obtained.

As an example consider the following information about a fishery in some base year *t**.

Table 1 **Data for parameter estimates**	
Maximum sustainable yield	MSY
Virgin stock equilibrium	X_{max}
Biomass growth in year $t*$	$\dot{x}(t*)$
Landings in year $t*$	$Y(t*)$
Price of landings in year $t*$	$P(t*)$
Fishing effort (fleet) in year $t*$	$E(t*)$
Profits in year $t*$	$\Pi(t*)$
Fixed cost ratio in year $t*$ ($fk/TC(t*)$)	$\varepsilon(t*)$
The schooling parameter	b

Given these data, it is straight-forward to verify that the parameters of (11)-(16) can be estimated as follows:

Table 2 **Formulae to calculate model parameters**	
Parameters	Formulae
Logistic function	
$\hat{\alpha}$	$\hat{\alpha} = 4 \cdot \frac{MSY}{X_{max}}$
$\hat{\beta}$	$\hat{\beta} = 4 \cdot \frac{MSY}{X_{max}^2}$
Biomass in base year, $\hat{x}(t*)$	$\hat{x}(t*) = \frac{\hat{\alpha}}{2\hat{\beta}} \cdot \left(1 \pm \left(1 - \frac{4 \cdot \hat{\beta} \cdot (Y(t*) + \dot{x}(t*))}{\hat{\alpha}^2} \right)^{0.5} \right)$
Fox function	
$\hat{\alpha}$	$\hat{\alpha} = MSY \cdot ln(X_{max}) \cdot \frac{exp}{X_{max}}$
$\hat{\beta}$	$\hat{\beta} = MSY \cdot \frac{exp}{X_{max}}$
Biomass in base year, $\hat{x}(t*)$	$\left(\alpha - \beta \cdot \ln(\hat{x}(t*))\right) \cdot \hat{x}(t*) = \dot{x}(t*) + Y(t*)$
Catchability, $\hat{q}$	$\hat{q} = \frac{Y(t*)}{E(t*) \cdot \hat{x}(t*)^b}$

Cost parameter, $\hat{c}$	$\hat{c}=\dfrac{(P(t^*)\cdot Y(t^*)-\Pi(t^*))\cdot(1-\varepsilon)}{E(t^*)}$
Fixed coasts, $\hat{fk}$	$\hat{fk}=(P(t^*)\cdot Y(t^*)-\Pi(t^*))\cdot\varepsilon$

Let us consider the global ocean fishery in the year 2004 (*t**=2004). Our empirical assumptions concerning this fishery are listed in Table 3

Table 3 **Empirical Assumptions**		
	Values	**Units**
Maximum sustainable yield	100	m. metric tonnes
Virgin stock equilibrium	400	m. metric tonnes
Biomass growth in year *t**	0	m. metric tonnes
Landings in year *t**	82	m. metric tonnes
Price of landings in year *t**	0.95	US$/kg
Fishing effort (fleet) in year *t**	15	m. gross tonnes
Profits in year *t**	-5	b. US$
Fixed cost ratio in year *t**	0.	Ratio (no units)
The schooling parameter	0.85	Elasticity (no units)

In a later section, we'll do a sensitivity study of the results for other values values of these coefficients.

Given the data in Table 3, the following model coefficients can be derived as explained in section 3.

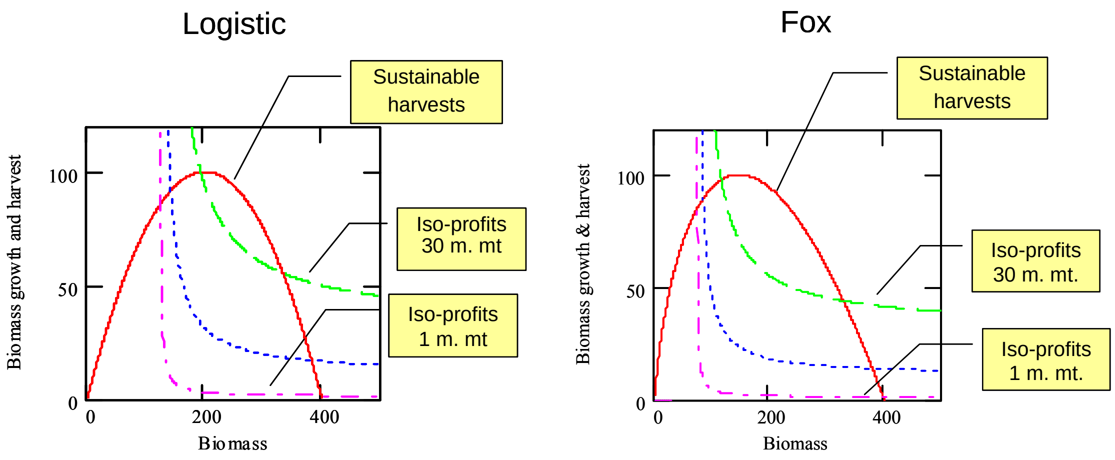
Table 4 **Implied model coefficients**		
	Logistic	Fox
Biomass growth parameter, α	1.0	4.072
Biomass growth parameter, β	0.0025	0.68
Biomass, *x*(2004)	115.1	68.2
Catchability, *q*	0.097	0.151
Schooling parameter, *b*	0.85	0.85
Marginal costs parameter, c	5.527	5.527
Fixed costs, *fk*	0	0

We may illustrate the essence of this global fisheries model in (biomass, biomass growth/harvest)-space with the help of the biomass growth curves and a set of iso-profit (constant profit) curves. For our model the iso-profit curves (in harvest units) are defined by

$$y=\frac{profits+fk}{(p-\frac{c}{q}\cdot x^{-b})}.$$

These curves are downward sloping as a function of biomass as illustrated in Figure 4. Obviously the higher the profits the further out in the diagram the iso-profit curves are.

Figure 4
The global fishery: Illustration



The biomass growth or sustainable harvest curves define points which are biologically sustainable. Sustainable profits (at any level of profits) occur where the iso-profit curves intersect the sustainable revenue curves. Maximum sustainable profits (which in this case coincide with maximum rents) occur where the highest iso-profit curves just touch the sustainable revenue curves.

As may be inferred from Figure 4, describing the global ocean fishery situation by the Fox-biomass growth function seems to offer higher sustainable profits than the logistic alternative. The reason is that if global fish biomass growth is better described by the Fox function, then current biomass must be lower than under the logistic specification and, therefore, *ceteris paribus*, catchability must be higher. As a result, rebuilding the biomass level will lead to higher profits.

4. Estimating global fisheries rents: Empirical estimates

Table 5 summarizes the main results for the two biomass growth functions and the basic empirical assumptions listed in Table 1. As reported there, the rents loss is estimated to be between 45.4 and 56.6 billion US$ depending on whether the underlying biomass growth function is taken to be the logistic one or the Fox one.

Table 5
Main results

	Current		Optimal		Difference	
	Logistic	Fox	Logistic	Fox	Logistic	Fox
Biomass	115.1	68.2	264.0	212.4	148.9	144.1
Harvest	82.0	82.0	89.8	91.4	7.8	9.4
Effort	15.0	15.0	8.1	6.4	-6.9	-8.6
Profits	-5.0	-5.0	40.4	51.6	45.4	56.6
Rents	-5.0	-5.0	40.4	51.6	**45.4**	**56.6**

These results are of course not very precise. To get some idea about how dependent they are on the basic empirical assumptions of our model we conduct a simple sensitivity analysis. Basically we alter some of our basic empirical assumptions by ±10% and ±20% and recalculate the resulting rents loss.

The main results are that doing this the global fisheries rents loss ranges **between 28.9 and 72.8 billion US$** depending on the empirical assumptions made. The greatest sensitivity of estimated rents loss is to the presumed MSY (with its impact on the estimates of the biological growth parameters especially the intrinsic growth rate), the presumed price of landed fish and the initial quantity of landings.

The sensitivity results are further illustrated in the following two Figures. Note that the higher (in absolute terms) the slope of the sensitivity curves, the higher the sensitivity of rents loss to the variable in question.

Figure 5
Sensitivity of rents loss to changes in empirical assumptions: Logistic function

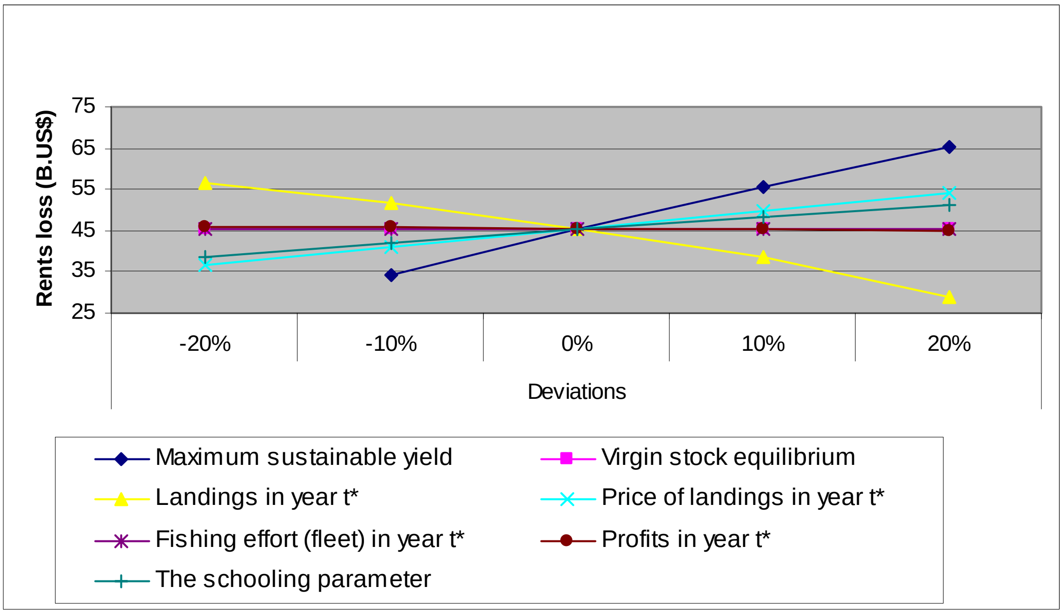
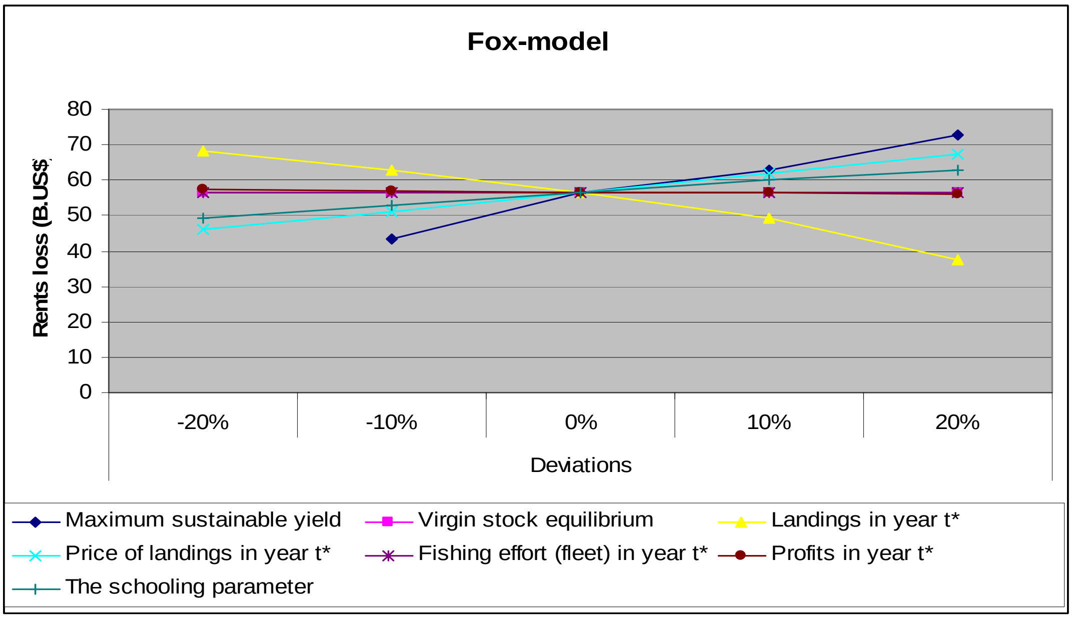


Figure 6

Sensitivity of rents loss to changes in empirical assumptions: Fox model



5. Estimating global fisheries rents: Confidence intervals

In order to obtain a more complete picture of the uncertainty regarding the rents loss estimate we now conduct a simple stochastic analysis of the situation. The procedure is as follows: First we specify stochastic distributions for some of the most important components of the model, the most important being the ones to which the rents estimates are most sensitive to. Then using Monte Carlo simulations (Fishman 1996), i.e. drawing repeatedly from these distributions, we obtain distributions of estimates of rents loss. On the basis of these distributions it is straight-forward to calculate confidence intervals for the estimated rent loss.

Three model components; price of landings, biomass growth and costs, are specified as being stochastic. It would of course be more natural to specify stochastic distributions for the basic assumptions of the fishery. That, however, would lead to quite complicated distributions for the actual model inputs that are numerically more difficult to deal with. For this reason the simpler route of this paper is taken. The actual stochastic specifications are as follows:

Price

$$\tilde{p} = p\cdot(1+u_1),\ \ u_1 \sim N(0,\sigma_p),$$

where $\tilde{p}$ represents the stochastic price, p the point estimate and u_1 is a normally distributed random variable with mean zero and standard deviation σ_p. It is easy to check that this specification implies that

$$\tilde{p} \sim N(p, p\cdot\sigma_p).$$

So the stochastic price is heteroscedastic with variance increasing in price.

Biomass growth

$$\tilde{G}(x) = G(x) \cdot e^{u_2}, \; u_2 \sim N(0, \sigma_G),$$

where $\tilde{G}(x)$ represents the stochastic biomass growth function, $G(x)$ the estimated function and u_2 is a normally distributed random variable with mean zero and standard deviation σ_G. It is readily seen that this specification implies that

$$\tilde{G}(x) \sim LN(G(x), \sigma_G),$$

where *LN* means that the distribution is log-normal.

Costs

$$\tilde{C}(x) = C(x) \cdot (1 + u_3), \; u_3 \sim N(0, \sigma_C),$$

where $\tilde{C}(x)$ represents the stochastic cost function, $C(x)$ the estimated cost function and u_3 is a normally distributed random variable with mean zero and standard deviation σ_C. It is easty to check that this specification implies that

$$\tilde{C}(x) \sim N(C(x), C(x) \cdot \sigma_C).$$

So, the stochastic costs are heteroscedastic and the variance increases with costs.

In what follows we will assume the following standard deviations for these three distributions:

$\sigma_p = 0.05$ (5% standard deviation)
$\sigma_G = 0.05$ (5% standard deviation)
$\sigma_C = 0.10$ (10% standard deviation)

The following three figures provide an illustration of the resulting probability distributions.

Figure 7 depicts the distribution of the price of landings. As can be seen the distribution is approximately normal. Measures of kurtosis and skewness do not diverge significantly from the normal. The sample average is 0.95 (US$/kg) and the standard deviation is 0.047.

Figure 7
Distribution of price
(σ_p=0.05, 2000 replications)

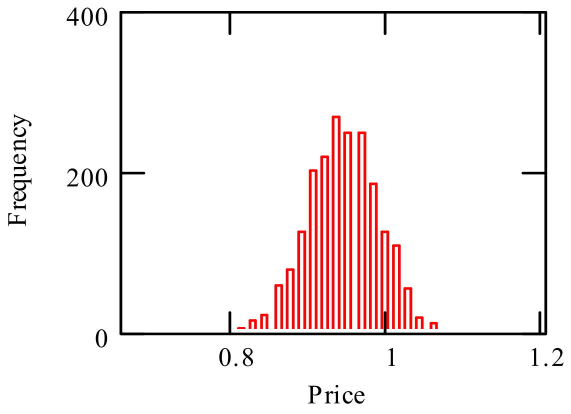
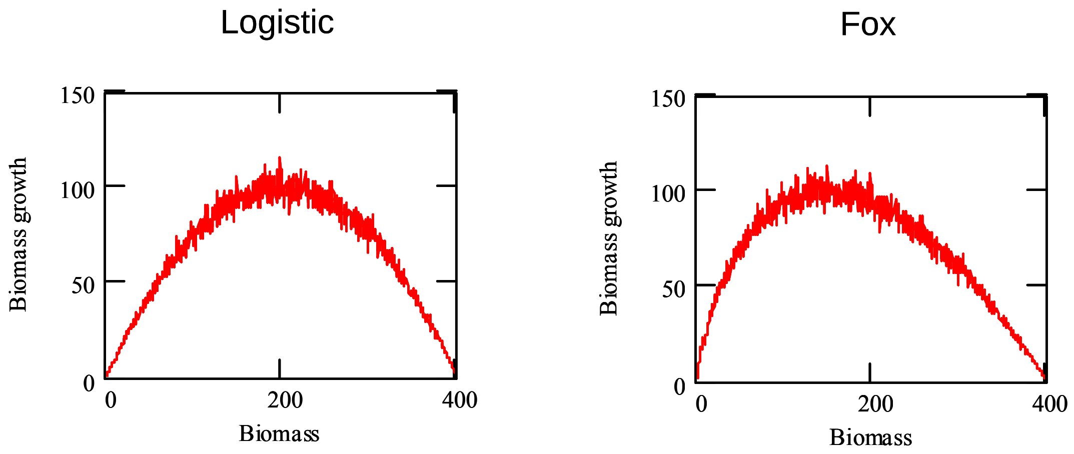


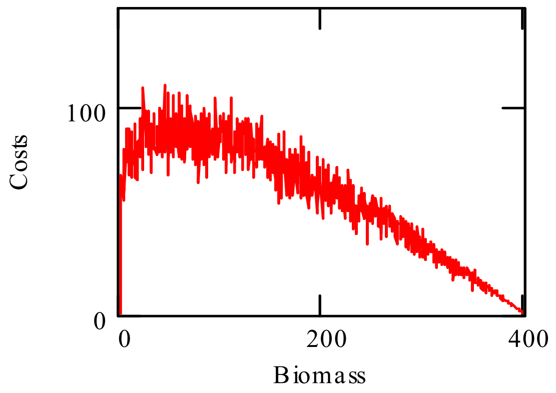
Figure 8 depicts an example of the stochastic fluctuations around biomass growth for the logistic function on the one hand and the Fox on the other. The figure is drawn so that for each biomass level there is one draw from the stochastic distribution of biomass growth. So in a sense Figure 8 is a collection of one possible realization of biomass growth for biomasses over biomass ranges from zero to the virgin stock (400 m. mt.). The confidence interval of actual biomass growth can be inferred from these curves.

Figure 8
Stochastic biomass growth functions
(σ_G=0.05)



Finally, in Figure 9, an example of the stochastic fluctuations around the cost function at different biomass levels. This figure is derived in the same way as the corresponding figure for biomass growth can be interpreted in the same way.

Figure 9
Stochastic cost function
(σ_C=0.1)



It is readily seen from Figures 9 and 10 that actual biomass growth and fishing costs may, according to the specifications adopted, deviate quite significantly from the expected value. One a particular biomass level has been adopted, e.g. the one that maximizes expected profits, these stochastic movements will imply a corresponding distribution of biomass growth and costs and consequently rents and rents loss.

We now turn to the task of estimating rents loss under uncertainty. As already explained the procedure is one of Monte-Carlo simulations employing the stochastic distributions of the price of landings, biomass growth and harvesting costs. 2000 independent draws are taken from each distribution.

Under uncertainty the standard procedure with some theoretical justification (Von Neuman Morgenstern 1944) is to maximize the expected value of rents. This will in general differ from maximizing the rents of the expected value of the independent variables. In this case, however, where the random variables appear for the most part linearly in the objective function — it is only in biomass growth where the random variable enters in a nonlinear way — the difference is very small. The rent maximizing biomass levels with and without uncertainty is listed in Table 6.

Table 6
Rent maximizing levels of biomass
(m. mt, 2000 replications)

	Non-stochastic	Stochastic
Logistic growth function	263.8	263.9
Fox growth function	212.3	212.5

The key outcomes out the simulations regarding rents loss are as given in Table 7.

Table 7
Estimated rents loss: Main results
(B. US$)

	Non-stochastic	Stochastic			
	Rents loss	Expected rents loss	Standard deviation	95% confidence interval	90% confidence interval
Logistic	45.377	45.529	3.761	[32.1,53.0]	[39.5,51.8]
Fox	56.587	56.778	4.721	[47.4,66.2]	[49.2,64.6]

As can be seen in Table 7, there is very little difference between the estimated nonstochastic rents loss, i.e. the calculated rents where the model and its parameters is presumed to be known with certainty, and the expected or mean rents loss under uncertainty. The reason is that most of the randomness specified is symmetric and enters linearly in the profit function. Only the biomass growth stochasticity is nonlinear or non-symmetric. However, it is not large enough compared to the others for the expected profit function to significantly deviate from the non-stochastic one.

The 90 and 95% confidence intervals for the rents loss are quite wide, reflecting the degree of uncertainty about the model specifications that was postulated. If the logistic biomass growth function applies, the annual global fisheries rents loss is found to be **between 32.1 and 53 b. US$ with 95% confidence**. Corresponding numbers for the Fox biomass growth function are **47.4 to 66.2 b. US$**. Combining the logistic and Fox results in a naïve way[2], we might say that there is a **95% probability that the global rents loss is between 39.5 and 64.6 b. US$** annually.

There is a substantial difference between estimates of the global rents according to the whether the logistic or the Fox biomass growth functions are taken to represent the global fisheries biology. This difference, moreover, is statistically highly significant. The essential reason for this difference is, as already explained, that if the Fox model is taken to apply then current biomass must be more overexploited than under the logistic specification and, therefore, there is more to be gained by reduced harvest rates.

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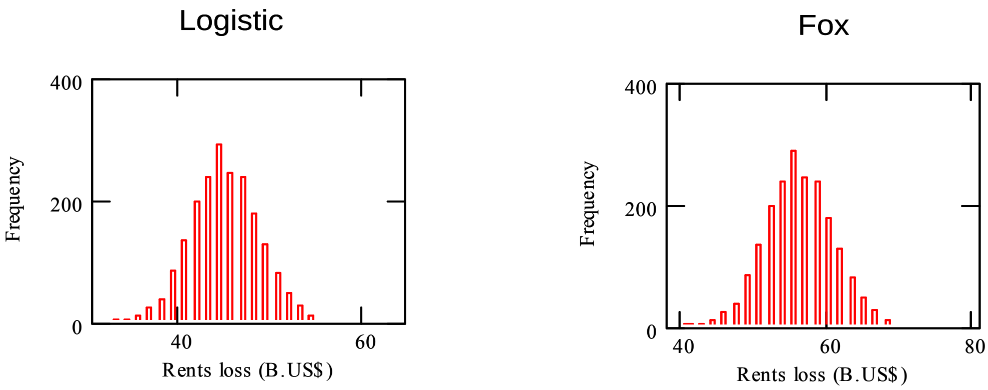
[2] There is a 5% probability that rents are less than 39.5 b. US$ according to the logistic function specification. However, there is only a 50% chance that the logistic applies. Hence, there is only a 2.5% probability that the rents loss is actually under 39.5. Similarly for the upper bound.

Further information about the respective rents loss estimates is provided in the following histograms.

Figure 10
Estimated rents loss: Histograms



6. Conclusions

Apparently reasonable probability distributions for key components of the global fisheries model lead to 95% confidence intervals for the global rents loss of **[32.1,53.0**] b. US$ for the logistic biomass growth specification and **[47.4,66.2]** b. US$. for the Fox biomass growth specification. Giving equal probability to the two specifications suggests a combined 95% confidence interval of **[39.5,64.6]** b. US$. Sensitivity analysis produces rents loss results in a similar range.

These results constitute evidence in support of previous estimates of the of the global rents loss (Garcia and Newton. 1997, Arnason 2006). According to all three studies the rents loss in the global ocean fishery could easily be in the neighbourhood of 50 b. US$, a number representing about half of the aggregate value of landings annually. An added contribution of the current study is an estimate of a 95% confidence interval of some ±7.5 b. US$.

The reader is warned against putting too much faith in these estimates, however. They are based on a very simple modeling approach. They do not incorporate much data about the global fishery. The assumed probability distributions for model components are quite ad hoc. They merely appear reasonable. It is entirely possible that a more careful study would produce rents loss estimates outside these confidence bounds.

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Appendix 1
The supply curve of harvest

Consider a fishing industry characterized by the instantaneous profit function:

(1) $\Pi(q,x)$, defined for $q,x\geq 0$,

where q denotes the volume of harvest and x the stock of the resource both at time t. The profit function is taken to have the usual (differentiability and concavity) properties (Varian 1984).

The resource evolves according to the differential equation:

(2) $\dot{x}=G(x)-q$, defined for $x\geq 0$,

where $G(x)$ is the renewal function of the natural resource having the usual properties (Clark 1976). As the $\Pi(q,x)$ function, the function $G(x)$ is assumed to be as differentiable as needed.

Consider now a fisheries manager (or a fisheries management regime) who seeks to maximize the profits in the fishing industry. Formally this problem can be expressed as:

$$\underset{\{q\}}{Maximize}\ V=\int_0^{\infty}\Pi(q,x)\cdot e^{-r\cdot t}dt\ ,$$

$$\begin{aligned} Subject\ to\text{: } & \dot{x}=G(x)-q \\ & x(0)=x_0 \\ & x,\, q\geq 0. \end{aligned}$$

The necessary (and in this case sufficient) conditions for solving problem (I) include (Pontryagin et al. 1962):

(3.1) $\Pi_q - \lambda \leq 0,\ q\geq 0,\ (\Pi_q - \lambda)\cdot q = 0,$

(3.2) $\dot{\lambda} - r\cdot\lambda = -\Pi_x - \lambda\cdot G_x,$

(3.3) $\dot{x} = G(x)-q,$

(3.4) Appropriate transversality conditions (for infinite time).

Expressions (3.1)-(3.4) describe the behaviour of a profit maximizing fishing industry. If the industry (or rather individual firms in the industry) takes prices as exogenous and these prices are “true” in the economic sense (as is usually assumed), conditions (3.1)-(3.4) also represent a social optimum.

Condition (3.1) is clearly a demand function. It represents the demand for harvests by the fishing industry when the biomass is x and the price is λ. This function, thus, corresponds exactly to the demand functions in Figures 1 and 2 in the main text.

The supply function is somewhat more involved. Fundamentally, it is defined by the differential equation (3.2). This equation relates the supply price of the resource, i.e. λ, to the harvest level (as well as biomass, x, and the rates of change of both x and λ). So, the supply is a dynamic relationship meaning that it moves over time. This is of course as expected: profit maximizing economic behaviour must reflect the underlying dynamics of the fish stock. More formally, this supply function may be seen as the solution to the differential equation system (3.2)-(3.4).

In equilibrium, however, the supply is given by:

$$\lambda = \frac{\Pi_x(q,x)}{(r - G_x(x))}.$$

This function interestingly has the usual properties of a supply curve (for a fixed biomass level) being increasing in quantity, i.e. the extraction rate, q.

Thus, for the optimally managed fishery, there will at each point of time exist a supply function. The "owner" of the resource (his role sometimes being played by fisheries manager) will at each point of time restrict supply of harvest. If this supply is actually binding for the fishers, their marginal net benefits of using the resource will exceed the marginal costs of doing so. As a result rents, more specifically fisheries rents, will emerge.

It is straight-forward to check that the same applies, i.e. there will be a supply function of harvests, even when the fishery is not optimally managed. Basically a sub-optimally managed fishery can be described as an optimally managed one with the appropriate additional constraints imposed.