Impact of management scenarios and fishing gear selectivity on the potential economic gains from Namibian hake

Ussif Rashid Sumaila

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Summary

This paper develops a model for Namibian hake, which incorporates the biology, gear selectivity and the economics of the hake fisheries in a framework that allows the analysis of fishing gear impacts on the potential economic gains from the resource. The objective is to produce quantitative results on the key variables of the fishery, namely economic rent, standing biomass and catch levels, that will support the optimal sustainable management of one of Namibia's most valuable fishery resources. Outcomes for three management scenarios are produced, (i) command; (ii) cooperative; and (iii) non-cooperative. For each of these, results are presented for two different assumptions of the economic setting under which the managers of the fishery operate, that is, a fully economic setting and a setting with cost-less labor inputs. As would be expected, different management scenarios and assumptions about the economic setting impact on the results derived from the model in significant ways.

ISSN 0804-3639

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WP 1999: 3

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ISSN 0804-3639
ISBN 82-90584-36-9

Indexing terms

Fishery management
Hake
Game theory
Cooperatives
Economic aspects
Namibia

Introduction

The objective of this study is to undertake bioeconomic analysis of Namibia's hake fishery to support optimal sustainable management. The management of Namibian hake consists of two main processes. First, a process of determining the annual total allowable catch (TAC), and second, a process that allocates the TAC among a number of license holders who employ different fishing gears to exploit hake. These two steps are carried out by the Ministry of Fisheries and Marine Resources, Namibia (MFMR), using inputs from scientists, industry and management. It is anticipated that the results of this study will provide insights that would help enhance the work of the MFMR with respect to both the determination and allocation of the TAC for hake.

The study focuses sharply on three important characteristics of the hake fisheries. One, the fact that wetfish and freezer trawlers, the two main vessel types used to exploit the resource, have different fishing grounds and consequently target upon different age groups of the hake stock. Two, the fact that the two vessels land hake in forms that influence the price they receive per unit weight of their catch. Three, each vessel group has its own cost structure, and hence land hake at different costs per unit weight.

The work in this paper fits into the general literature on the economics of shared stocks (see for instance, Munro 1979, Levhari and Mirman 1980, Fischer and Mirman 1992, Sumaila 1997a,b, and Armstrong 1998). Sumaila (1997a) is a study of the North-East Atlantic cod in the Barents Sea. This is a fishery located in the Northern hemisphere, which has been very well studied. On the other hand, the present paper studies the Namibian hake fishery, which is based in the less developed South. This fishery has not been well studied, especially with respect to bioeconomic analysis, and therefore serves as a greater challenge to the modeler.

For instance, while there are many studies that look into the selectivity patterns of the coastal and trawler vessels active in the Barents Sea (see for example, Armstrong et al., 1991 and Larsen and Isaksen, 1993) there is hardly any that has looked closely at the selectivity patterns of the wetfish and freezer trawlers active in Namibia's EEZ. In comparison to Sumaila (1997b), this paper is more ambitious because it incorporates stock recruitment and dynamics, and seeks to advice not only on how much of a predetermined TAC should be allocated to the two vessel groups (as was the objective in Sumaila, 1997b) but also on the overall size of the TAC. To my knowledge this work is the first computational game theoretic model developed and applied to a fishery in sub-Saharan Africa.

In the next section, I briefly discuss the hake fishery. Section 3 presents the bioeconomic model, including the data used for the computations. The numerical results of the study are presented in section 4. One key finding is that a management strategy for hake that seeks to protect either the juvenile or mature part of the stock from exploitation make good economic sense. This results may indeed be one explanation for the recent surprise decline in Namibian hake stocks, which followed the introduction of a policy of 60:40 share of the hake TAC to the wetfish and freezer fleets, respectively. Finally, section 5 summarises the main results, and concludes the paper.

The Namibian hake fishery

The hake stocks are one of the three most important fish species of the highly productive Namibian EEZ. The others are horse mackerel and pilchard. The main reason for the high productivity of the Namibian EEZ is the Benguela upwelling system prevalent in the coastal zone of Namibia and other Southern African countries.

Among the species of hakes inhabiting the Namibian EEZ, that is, *Merluccius capensis* (also known as cape hake), *Merluccius paradoxus* (deep-water hake) and *Merluccius pollis*, only the former two are of major importance to the fishery. These two species are so identical in appearance that they are often treated as one and the same (Wysokinski, 1986). Both species are relatively long-lived, reaching ages of up to and over 9 years.

Hakes are usually found close to the bottom of the water during day-time but rise to intermediate water during night time, probably following their prey.

Hake catches reached a maximum of over 800 000 tons in 1972, averaging some 600 000 tons annually during the period from the late 1960's to mid 1970's. As expected these period of high catches was followed by lean years, with average catches of less than 200 000 tons from the mid 1970's to 1980. This, however, rose again and remained relatively stable between 300 - 400 000 tons for most of the 80's. It is stated in Hamukuaya (1994) that during those years of high catches there was a large proportion of young fish between the ages of 2 - 3 years old, probably accounting for the low catches in later years. Bonfil et al. (1998), shows that due to the high catches of hake, horse mackerel and pilchard attributable to the activities of distant water fleets prior to independence, Namibia inherited a fishery well below its productive potential.

It is worth mentioning that the fishing sector is an important part of the economy of Namibia, with the hake fisheries being an important part of this. According to the MFMR hake contributed about N$230 million or 7.4% of Namibia's estimated exports in 1994.

The model

The fishing fleets targeting hake

A variety of fishing vessels are used to harvest hake; differing in their gross registered tonnage (GRT), engine horse power (HP), processing equipment, and freezing capacity. However, the bulk of hake are landed by wetfish and freezer trawlers. For instance, in 1994 out of a total of 108 213 tons of hake landed, 99 152 tons were by wetfish and freezer trawlers. This is well over 90% of the total landings of hake that year. The rest is landed using monk/sole trawlers, longliners, and mid-water trawlers (see Moorsom, 1994 and Sumaila, 1997b). 1995 and 96 data show that the dominance of the bottom trawlers in the hake fisheries continuous unabated (Ministry of Fisheries and Marine Resources, 1996). As a result of the overwhelming dominance of the bottom trawlers in the demersal hake fishery, I focus my attention on these vessels and organise the wetfish and freezer trawlers into two separate and distinct entities assumed to be managed by two different bodies, from now on, to be known as Wetfish Industry Group (w) and Freezer Industry Group (f), respectively.[1] These two groups are assumed to interact under (i) command, (ii) cooperative and (iii) noncooperative environments, as explained later in the paper.

Recruitment and stock dynamics of Namibian hake

The Beverton Holt age-structured model forms the basis for modeling the biology of hake in this study. According to Punt (1988) this model corresponds closely to the stock biomass observed in ICSEAF Divisions 1.3 and 1.4 (which lie in the Namibian EEZ) from 1956 to 1985, the parameters of the model having been estimated using results of virtual population analysis.

Let the spawning biomass, B_t^s, be defined by the following equation:

1.

$$B_t^S = \sum_{a=0}^{a_{\max}} p_a w_a n_{a,t}$$

where a=0,1,...,$a_{\max}$, denotes age group a hake; a_{max} is the last age group; w_a stands for weight of hake of age a at the start of the year; t=1,2,...,T, is fishing years, with T denoting the last period, p_a stands for the proportion of age a hake that is mature, and $n_{a,t}$ represents the number of age a hake in year t.

The stock-recruit relationship, R_t, is given by:

2.

$$R_t = n_{0,t} = \frac{\alpha B_t^s}{\left(\alpha\beta + B_t^s\right)^{-\gamma}}$$

where $n_{0,t}$ is the number of recruits in year t; and α, β, γ are parameters of the extended Beverton Holt stock-recruit relationship (Punt, 1988).

From the above, the basic stock biomass can be represented by the equations below:

3.

$$\begin{aligned} n_{a,t} &= \theta n_{a-1,t-1} - h_{a,t}, \text{ for } 0 < a < A \\ n_{A,t} &= \theta n_{A,t} - \theta n_{A-1,t-1} - h_{A,t}, \; n_{a,0} \text{ given} \end{aligned}$$

The function $h_{a,t} = \sum_p q_{p,a} n_{a,t} e_t$ denotes the total harvest by both players of age group a hake in fishing period t; θ is the age independent natural survival rate; e_t is the fishing effort exerted on cod in period t, while q stands for the catchability coefficient of the hake harvesting vessels. The reader should note that the stock dynamics of the last age group of hake is given special treatment. This is meant to capture the fact that all age a_{max} hake do not die at the end of a given period.

On selectivity and catchability

To determine the appropriate catchability coefficients to apply in the model, I employ the method outlined in Appendix 1 of Sumaila (1997a). A key input to the method is gear selectivity[2]. For a well-studied fishery such as the Barents Sea cod fishery, it is easy to find these from the literature, this is not the case for the Namibian hake fishery. Therefore, to form an opinion on the selectivity patterns of w and f, I interviewed a number of fisheries people in Namibia (see acknowledgment). A clear consensus that came out of the interviews was that the wetfish trawlers (because their fishing grounds are close to the shore) target mainly young fish while the freezer trawlers target mainly mature fish, because they operate further into the sea. Using this background information, I decided to assume in the model that wetfish trawlers exploit age groups 1 to 6 hake, while freezer trawlers target age groups 5 to 9[3]. The selectivity pattern for hake reported in Punt and Butterworth (1991) is used to set a total overall selectivity for each age group. Hence, the sum of the selectivity by the two vessel groups on a given age group is equal to the selectivity for that age group reported in Punt and Butterworth (op.cit).

Economics of the hake fisheries

As mentioned earlier, the MFMR is assumed to manage the hake stock for the benefit of Namibia as a whole. It therefore acts as a sole owner who seeks to obtain maximum economic benefits from the resource without destroying the resource base. We determine an equilibrium outcome which I term the "command outcome" to depict the behaviour and actions of the MFMR. In this outcome, the MFMR decides both the TAC and its allocation to the two parties, in a manner which will ensure maximum total economic benefit from hake. Two other equilibrium outcomes to be computed are the noncooperative and cooperative. The former is determined to serve as a benchmark for comparison with the cooperative and command outcomes. In addition, it serves as the "threat point" when the Nash cooperative solution is determined (see Nash, 1953, Munro, 1979).

For two reasons, it is assumed in this paper that the price per unit weight of hake faced by both players are perfectly elastic. The first relates to the fact that Namibian supply of hake is not big enough to influence the international market for hake under normal circumstances. Secondly, the focus here is on the impacts of gear selectivity stemming from interactions at the level of the stock, not at the level of the market.

The harvest cost function of a given player p in period t, $C(p,t)$, is modeled as an "almost" linear function of its fishing effort, $e_{p,t}$ (see Sumaila, 1995):

5.

$$C\left(e_{p,t}\right) = \frac{k_p e_{p,t}^{1+b}}{1+b}$$

where $b = 0.01$, and $k_p/(1+b) \approx k_p$ is the cost of engaging one fishing fleet for one year.

Let the single period profit of player p be given by:

6.

$$\pi_{p,t} = \pi_p(n_t, e_{p,t}) = v_a \sum_{a=0}^{A} w_a q_{p,a} n_{a,t} e_{p,t} - C(e_{p,t})$$

where $n_{a,t}$ is the age- and period-dependent stock size in number of fish; w_a is the mean weight of fish of age a; and $q_{p,a}$ is the age and player dependent catchability coefficient, that is, the share of age group a hake being caught by one unit of fishing effort of player p.

The noncooperative scenario

Under this scenario it is assumed that there is no regulator coordinating the actions of the two fleets. Furthermore, there is no possibility for credible communication between w and f - the management of each fleet takes the actions of the other as given, and chooses its own strategies to maximize own discounted economic rent. That is, each player finds a sequence of effort levels, $e_{p,t}$, so as to maximize its discounted economic rent:

7.

$$\mathrm{M}_{\mathrm{p}}(n, e_p) = \sum_{t=1}^{\mathrm{T}} \delta_p^t \pi_p\left(n_t, e_{p,t}\right)$$

subject to the stock dynamics given by equations (2) and (3) above and the obvious nonnegativity constraints. In the equation above, $\delta_p = \left(1 + r_p\right)^{-1}$ is the discount factor. The variable n (n_t) is the post-catch stock matrix (vector) in number of fish; and r_p denotes the interest rate of player p.

The command scenario

Here, the commander (or regulator), which in this particular case is the MFMR, seeks to find a sequence of effort, $e_{p,t}$ and stock levels, $n_{a,t}$ to maximise a weighted average of the objective functionals of the two fleets denoted $Prof_{com}$. β and (1-β) indicate how much weight is given to the own objective functional of *w* and *f* by the commander. For a given $\beta \in [0,1]$, the cooperative management objective functional translates into maximise:

8.

$$\Pr of_{com} = \beta \mathrm{M}_1(n, e_1) + (1-\beta)\mathrm{M}_2(n, e_2)$$

subject to the same constraints expressed by equations (2) and (3). The important point to note here is that the MFMR chooses the β which produces the highest total economic rent. This then determines both the overall TAC and how much of this should be harvested by *w* and *f*, respectively. After determining these, the MFMR simply issues a directive, which we assume the fishers are under the obligation to comply with.

The cooperative scenario

Under this scenario too there is no commander, *w* and *f* work together freely and cooperatively to determine a TAC and its allocation to themselves. The key point to note at this junction is that the outcome agreed upon must be incentive compatible with their own interests (see Binmore 1992). In other words, the outcome and hence the payoffs to each player must be at least as much as what the player will receive if he decides not to cooperate.

The two players may choose to work for a cooperative "with" or "without" side payments arrangement. The latter refers to a situation in which all players want to participate in actual fishing, and thus will not accept any compensation not to do so. The former is the opposite of this, all possible solutions are considered, including the possibility of buying out a player. Given the definition of the command scenario in this paper, the solution to the cooperative "with" side payments is close to the "command" outcome. In both cases, the objective is to maximise the weighted average of the objective functionals of the two fleets under the appropriate constraints. The main difference between the two is in the way the gain from cooperation is shared. In the case of the command scenario, the commander decides this, while under cooperative with side payments, a rule based on an application of the Nash bargaining scheme (Nash 1953; Munro 1990) is used[4].

The solutions to the model are pursued numerically (see Flåm, 1993), rather than analytically for two reasons. First, the complex age-structured nature of the model makes it analytically difficult to solve (see Conrad and Clark, 1989). Second, the objective of the current paper is to produce quantitative rather than qualitative results.

Model data

The biological, economic and technological data are mostly taken from Punt and Butterworth (1991), Punt (1988), Sumaila (1997b) and the MFMR. Table 1 displays (i) the proportion mature of each age group, p_a, (ii) the average weight, w_a, (iii) the total selectivity for each age group, S_a, (iv) the initial numbers of each age group of fish, and (v) the catchability coefficients for each vessel type. The latter are calculated by splitting the total selectivity according to the observed targeting patterns of juvenile and mature hake by the two vessels; and using the framework in Appendix 1 of Sumaila (1997a),
The rest of the model parameters are given the values: α=6300 (million) $\beta = 0.16$; γ=1.0 (Punt 1988); a_{max}= 9 Punt and Butterworth (1991). Natural survival rate, θ, is assumed to be 0.81 per year. Price per kilogram for the landings of the wetfish (v_1=N$ 8.18) and freezer (v_2=N$ 7.38) trawlers are taken from Sumaila (1997b). The cost of employing the wetfish and freezer trawlers for one year are determined from data from the Namibian fishing industry to be N$12.29 and N$ 39.90 million, respectively. A discount factor of 0.952 (equivalent to a real interest rate of 5%) is assumed.

Table 1: Values of parameters used in the model. Maximum age, weight taken from Punt and Butterworth (1991).
Catchability coefficients derived, initial stock size and proportion mature estimated.

Age a (years)	Selectivity Sa	Catchability Coef. W	F	Proportion mature (pa)	Weight w(a) (kg)	Initial numbers (millions)
0	0	0	0	0	0.001	2
1	0.007	0.00672	0.0060	0	0.0345	1.3
2	0.032	0.00307	0.0162	0	0.0935	0.64
3	0.216	0.0207	0.0162	0	0.187	0.4
4	0.426	0.0384	0.0162	0.5	0.319	0.28
5	0.972	0.05759	0.0004	1	0.55	0.18
6	1.028	0.0580	0.0060	1	0.929	0.13
7	1	0	0.0162	1	1.445	0.1
8	1	0	0.0162	1	2.108	0.04
9	1	0	0.0162	1	2.542	0.03

The results

Payoffs in a fully economic setting

By a fully economic setting I refer to a situation in which the fisheries manager incorporates all the appropriate economic parameters and variables (prices, costs and discount factors) into the decision-making process on how to manage the resource.

Figure 1 displays graphically the discounted economic rent achievable under cooperation for different β-values. This graph shows how the payoffs obtained by using wetfish and freezer trawlers change with varying β-values, that is, with changing emphasis on the preferences of the wetfish fleet relative to those of the freezers.

The best discounted economic rent computed under the command, noncooperation and cooperation regimes are reported in table 2. This table shows that under the fully economic environment, the command and the cooperative with side payments outcomes give a total discounted economic rent of N$ 10.23 billion over the 25 year time horizon of the model. To achieve this, all the TAC should be taken by the wetfish trawler fleet (that is, when $\beta = 1$; see figure 1). Under this scenario, we see that protection of the mature stock by reducing the freezer fleet catch to zero turns out to be bioeconomically sensible. Following the sharing rule mentioned earlier, the wetfish and freezer fleets receive N$ 7.18 and N$ 3.05 billion dollars, respectively, in the cooperative with side payments scenario.

Table 2: Total discounted economic rent (N$billion) under the different management regimes and assumptions of the economic environment

Management	Command			Cooperative			Noncooperative		
regime	wetfish	freezer	total	wetfish	freezer	total	wetfish	freezer	total
Fully economic	10.23	0	10.23	6.18	0.96	7.14	4.63	0.50	5.13
Cost-less labor input	13.27	0	13.23	8.15	1.32	9.47	6.75	0.90	7.65
Equal price, fully economic	0	7.52	7.52	4.47	0.88	5.35	3.54	0.54	4.08

The Nash cooperative "without" side payments outcome brings in N$ 7.14 billion (when β=0.6, see figure 1), which is significantly more than the N$ 5.13 billion produced in the noncooperative environment. Of the total, the wetfish fleet pulls in N$ 6.18 billion (N$ 4.63 billion under noncooperation), and the freezer fleet brings in N$ 0.96 (N$ 0.50 billion under noncooperation). In comparison to the command and cooperative scenarios, the noncooperative outcome is very bad - it produces an economic rent which is only about 50% of what is achievable under the command scenario.

Payoffs in a cost-less labour input setting

The motivation for implementing this scenario comes from observations I made during my fieldwork: Key decision-makers in the MFMR were of the view that given the high unemployment level in Namibia, the government is more concerned with providing as many sustainable jobs in the fishing sector of the economy as possible. I interpret this point in this model to imply that the alternative cost of fishing labor inputs is taken to be zero by the fisheries managers.

In figure 2, the discounted economic rent determined under the cooperative scenario, for different β-values, are presented. In addition, table 2 reports the best results under cooperation, command and noncooperative scenarios, respectively.

From this table we see that the command outcome produces a payoff of N$ 13.27 billion. This happens when the wetfish fleet alone harvest the stock, that is, when the preferences of the wetfish fleet is given full weight by management (β =1). A payoff of N$ 9.47 (wetfish: N$ 8.15 and freezer: N$ 1.32) billion is realized under cooperation "without" side payments. Here, cooperation with side payments results in payoffs of N$ 9.56 and N$ 3.71 billion for wetfish and freezer trawlers, respectively. Finally, noncooperation leads to a total payoff of N$ 7.65 (wetfish: N$ 6.75 and freezer: N$ 0.90) billion.

The good outcomes achieved by the wetfish fleet relates to the fact that they enjoy a number of "private" advantages. First, their landings receive, on average, higher price per unit weight than those of freezer trawlers (see Sumaila, 1997b). Second, the proportion of labor cost to total fishing cost is higher for the wetfish than the trawler fleet. Thus, in the cost-less labor input scenario, the performance of the wetfish fleet improves further. Third, this class of fishing vessels appear to have an advantage in that they target juvenile fish and can, therefore, undermine the freezer fleet in a competitive situation.

To find out the impact of the higher price received by the wetfish fleet, the model is re-run under the assumption that landings by the wetfish fleet receive the same price per unit weight as landings by the freezer fleet. Figure 3 displays graphically the discounted economic rent achievable under cooperation in a fully economic setting. This graph shows that in this case it is optimal to let only the freezer fleet to do the catching. From table 2, we see that when both fleets face the same price, the command outcome give N$ 7.52 billion.

Standing biomass

Table 3 presents the average standing biomass and the harvest size and proportion, over the 25 year time horizon of the model. A comparison of the numbers under the two management scenarios reveal the following. One, the command or cooperative with side payments scenario produces the best possible health for the stock under both assumptions of the economic environment. Two, the noncooperative situation is terrible for the health of the stock, producing average standing biomass which are well below those attained in the command and cooperative with side payments scenarios. Three, the cooperative without side payments scenario is second best, as it mitigates against the biological waste shown to exist in the noncooperative scenario, but falls short of the *optimum optimorum* achievable under cooperation with side payments or the command scenario.

A comparison of the outcomes under the different assumptions of the economic environment indicates that: Under the command and cooperative scenarios, the same average standing biomass is achieved under the two economic environments. On the other hand, under noncooperation because lower cost of fishing labor inputs implies a greater “race” for the fish: lower cost pushes the equilibrium stock size lower. Hence, a policy that tends to assume away the cost of fishing will also tend to lower the average standing stock size. The reader should note that qualitatively the “no price difference” scenario produces results that are similar to those discussed in the above paragraphs (see table 3b).

Catch sizes and proportions

The average harvest and the proportion of the catch in the base case (no price difference) scenario are reported in table 3a (table 3b). It is worth noting that the harvest sizes for the various scenarios are good indicators of both the number of boats and labor required to land the harvest. In fact, one may assume a linear relationship between catch and these input variables. Hence, we do not discuss separately the labor required to take the landings predicted under the different scenarios.

Table 3: Average standing biomass, harvest (thsd tonnes) and proportion of harvest by the wetfish trawlers.

3a: Base case scenario

Management	Fully economic		Cost-less labour	
regime	biomass	harvest (proportion)	biomass	harvest (proportion)
Command	1330	129 (100%)	1330	141 (100%)
Cooperative	1300	85 (95%)	1300	96 (95%)
Noncooperative	917	87 (95%)	896	99 (95%)

3b: Equal price scenario

Management	Fully economic		Cost-less labour	
regime	biomass	harvest (proportion)	biomass	harvest (proportion)
Command	1690	79 (0%)	1330	122 (100%)
Cooperative	1280	73 (95%)	1300	85 (95%)
Noncooperative	938	80 (94%)	913	92 (94%)

A number of observations can be made from table 3a (table 3b). First, in the fully economic environment, an average harvest of 87,000 (80,000) tons is obtained under noncooperation. The average harvest under the command and cooperative without side payments scenarios are 129,000 (79,000) and 85,000 (73,000) tons, respectively. Second, the cost-less fishing labor input assumption results in higher harvest under all the scenarios. However, the gains in harvest under the noncooperative scenario comes at a biological cost - the average standing biomass is lower than in the fully economic scenario.

The optimal catch proportion for the wetfish trawlers ranges between 95 - 100%, except when the same price is assumed for the landings of the two vessel types. In which case a catch proportion of zero for the wetfish fleet is found to be optimal under the command and cooperative without side payments scenarios. These numbers are clearly different from the current policy of 60-40% in favor of the wetfish fleet.

Discussion and concluding remarks

The study shows that the choice and implementation of management strategies for hake can have huge effects on the bioeconomic benefits from the resource. To illustrate this point take the estimated average annual harvests predicted by the study: a wide range of between 73,000 to 141,000 tons depending on the management scenario and the assumptions underlying the economic environment. This calls for careful analysis on the part of the MFMR to guide its decision making process. Clearly, with proper data, models such as the one presented here can produce useful insights for practical management of the hake fisheries of Namibia.

An important conclusion that can be derived from the results of this study is that a management policy that seeks to protect either the juvenile or mature part of the stock from exploitation produces good bioeconomic outcomes. This is because in all cases the best outcomes are achieved either when only the wetfish or freezer trawlers are allowed to exploit the resource. This result is particularly interesting because it may well be one reason for the surprising decline in the hake stock size after about 3 years of the introduction of a policy of 60:40 division of the hake TAC between the wetfish and freezer trawlers.

Another point to be made from the findings of the paper is that cooperation whether it comes about through negotiations or enforced by a controller can lead to significant economic gains to both parties. Furthermore, the study shows that the need for good data, both biological and socio-economic, cannot be over-emphasized. In addition, studies to find out the selectivity patterns of the vessels used to exploit not only hake but other important species in Namibian waters, would be very useful.

Finally, it is worth mentioning that the study is, as with all modeling and computational exercises, partial in some sense. For instance, the current model does not explicitly capture inter- and intra-species interaction. The next in the series of papers planned on the hake fisheries of Namibia will model cannibalistic behavior by mature hake. This is important because there is evidence to show that Namibian hake does exhibit this behavior (Pitcher and Alheit, 1995).

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Notes

[1] The use of longliners to exploit hake is expected to increase with time, producing impacts on both the biology and economics of hake exploitation. In a counterpart paper, the model presented here is extended to analyse the bioeconomic effects of introducing this vessel type as a major participant in the fishery.

[2] Note that the *catchability* of a fishing gear is defined as the share of the total stock being caught by one unit of fishing effort. On the other hand, the *selectivity parameter* of a fishing gear is the probability of the gear to hit fish of a particular age group.

[3] Clearly, this is one of the assumptions in the current model that needs to be researched and improved upon in future applications of the model.

[4] The rule consist of two steps. First, each player must receive his threat point payoffs. Second, the surplus over the sum of the threat point payoffs of all players is split equally between the players. The rational for this sharing formula is that, to satisfy the individual rationality constraint (Binmore, 1982), players must be guaranteed their payoff under a noncooperative regime, after which the surplus should be shared equally because each party to the cooperative agreement contributed equally to its success.

Figure 1: illustrates the payoffs to wetfish, freezer fleets separately and jointly in the fully economic setting.

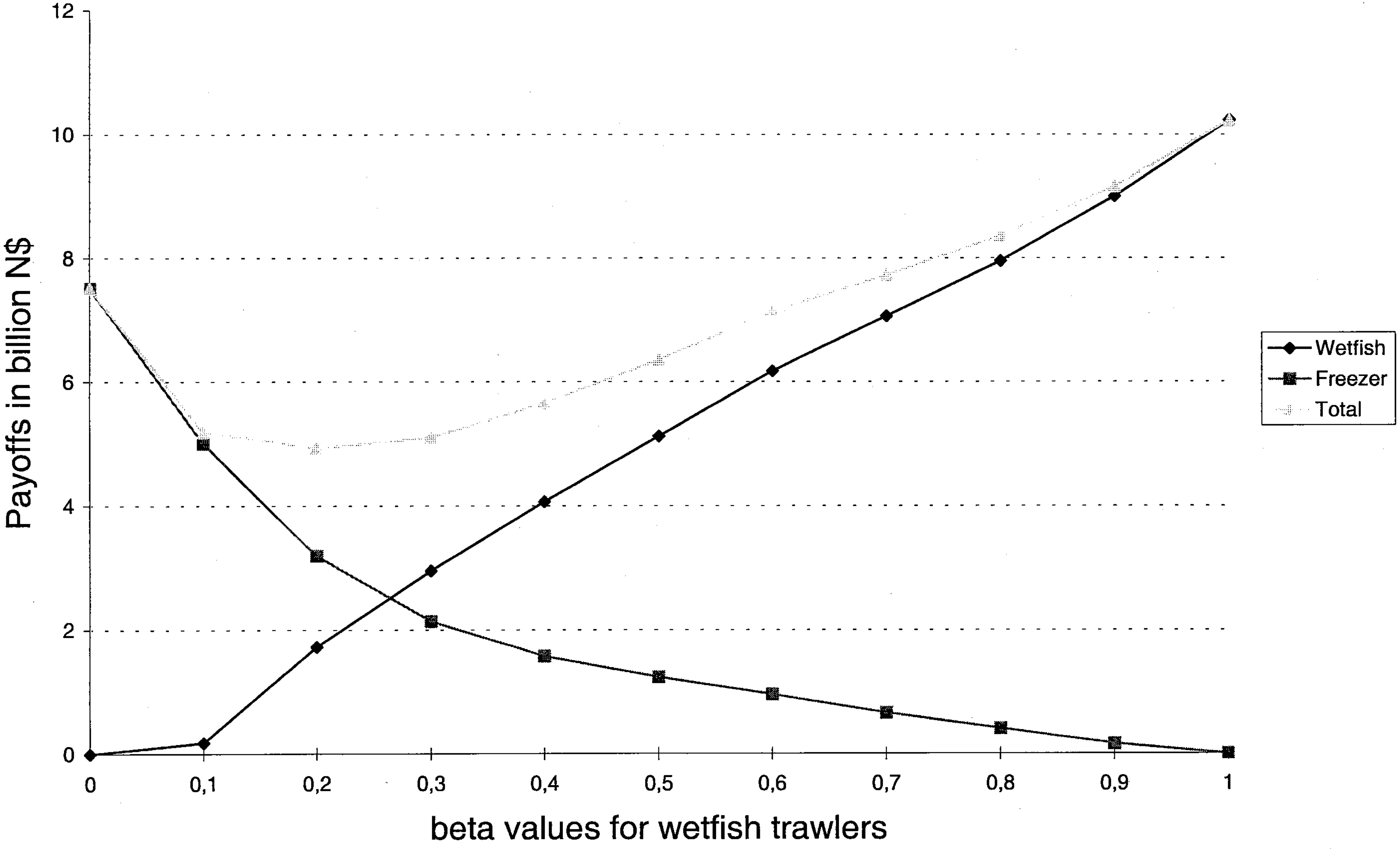

Figure 2: illustrates the payoffs to wetfish, freezer fleets separately and jointly in the cost-less fishing labour input setting.

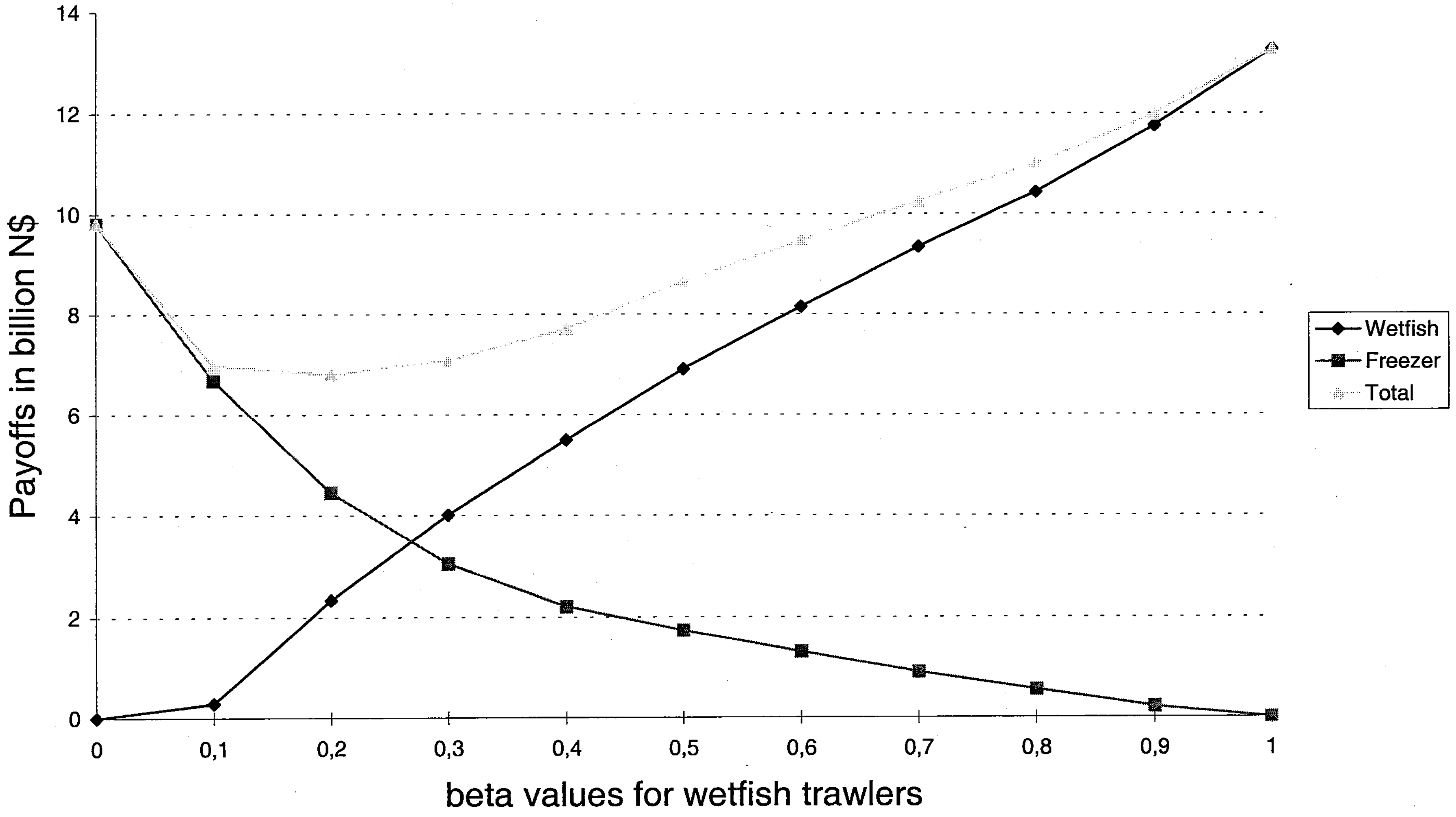

Figure 3 illustrates the payoffs to wetfish, freezer fleets separately and jointly, when both vessel types face the same price.