Assessing capacity in the United States Northwest Atlantic pelagic longline fishery for highly migratory species with undesirable outputs

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ABSTRACT

The Food and Agriculture Organization of the United Nations (FAO) and its member nations have embarked on an ambitious global plan to address excess capacity in fisheries. Under the International Plan of Action, its member nations have voluntarily agreed to assess and address excess harvesting capacity. To date, however, the assessment of capacity has ignored undesirable bycatch. In this paper, we present a method for estimating capacity, recognizing that reductions in undesirable outputs may also cause reductions in the capacity output. Our results indicate that the capacity output for sharks, tunas and swordfish would be reduced relative to observed outputs when reductions in the inadvertent capture of sea turtles would be required.

1. INTRODUCTION

Excess capacity has been recognized by the Food and Agriculture Organization of the United Nations (FAO) and its member nations as an issue of global concern. In addition, the FAO and its member nations have recognized the problem of incidental or inadvertent capture of unmarketable bycatch, most which is released or discarded at sea. There are several kinds of bycatch. First, there are species, such as sharks and other large fishes, sea turtles, seabirds and marine mammals, some of which are legally protected and others of which are perceived by the public as deserving of protection. Second, there are species that are not the object of tuna fisheries, but are the object of artisanal and recreational fisheries. Third there are juvenile tunas and billfishes that are so small that they are unmarketable. Fourth, there are species that are of little commercial value that are discarded at sea or landed and sold at low prices for the production of fish meal or pet food. To date, most assessments of capacity, have ignored the potential relationship between capacity output and bycatches. If bycatch reduction is an objective of capacity reduction programmes, failure to consider bycatches in the estimation and assessment of capacity will result in overestimating the capacity output. Alternatively, estimates of capacity output that exclude the potential for reducing undesirable outputs will be greater than estimates of capacity, which attempt to directly incorporate reductions in undesirable outputs.

In this paper, we expand the traditional data envelopment analysis (DEA) approach for estimating capacity to explicitly allow for the reduction or non-expansion of undesirable outputs. Instead of using the conventional output distance function approach described by Kirkley and Squires (1999) and Pascoe *et al.* (2003), we introduce the notion of a directional distance vector, which allows for the estimation of capacity relative to desirable outputs, while simultaneously allowing for reduction of undesirable outputs. We illustrate the methodology using set-level data obtained from gear experiments conducted by pelagic longline gear operations in the distant-water area off the northeastern United States . The results, although limited relative to depicting capacity representative of the entire fleet, indicate that capacity output, when estimated conditional on reducing undesirable outputs, is considerably less than estimates of capacity output that ignore reduction of the levels of undesirable outputs.

2. DEFINITIONS AND CONCEPTS

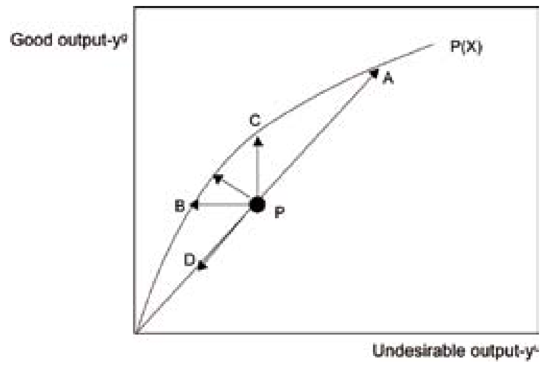
FAO has formally defined capacity as “the amount of fish (or fishing effort) that can be produced over a period of time (*e.g.* a year or a fishing season) by a vessel or a fleet if fully utilized and for a given resource condition”. This concept of capacity is utilized in this paper. As such, it is a technological-economic measure of capacity output (Kirkley, Morrison Paul and Squires 2002).

In contrast to previous assessments of capacity, however, we recognize two types of outputs in this paper. First, we consider the conventional notion of desirable or marketable outputs (*i.e.* legal commercially-landed product). In addition, we consider undesirable products, which cannot be marketed for the reasons mentioned above or which can be marketed only at at prices much less than those of the object species. Because of the inclusion of undesirable outputs, we modify the basic definition of capacity output to specifically include the notion of reducing or preventing the capture of undesirable outputs. Alternatively, capacity output is the amount of fish that can be produced over a period of time by a vessel or a fleet, if fully utilized, given resource conditions, and adjusted to reflect the potential reductions in undesirable outputs.

We also introduce an alternative notion of the distance function—the directional distance function. In previous DEA-based assessments of capacity, an output distance function was estimated to determine the potential expansion in outputs, given the fixed factors (*e.g.* vessel size and engine horsepower) of production. In the present study, a directional distance function is estimated, which explicitly allows for the expansion of desirable or good outputs and contraction of undesirable or bad outputs, subject to the constraints of the fixed factors.

To gain a better understanding of the differences in using the output *vs.* directional distance function approach, consider Figure 1. A production possibilities frontier (*i.e.*, maximum output levels for a given level of inputs) is depicted as P(X). One good and one bad output are produced in the example. The production level of the good output is depicted on the vertical axis, and, that of the bad output on the horizontal axis. Note that in this example good outputs cannot be produced without some level of bad outputs; this is referred to as the null-joint property. Let point P be a point representing levels of good and bad outputs. With the conventional approach of using the output distance function to estimate capacity, we seek to determine the maximum expansion of both good and bad outputs subject to the limitations imposed by the fixed factors (*e.g.* point A in Figure 1).

FIGURE 1
Range in directions for expanding (contracting) outputs



With the directional vector approach, however, we can determine expansions (or contractions) in the levels of good outputs and contractions or no changes in the levels of bad output. In other words, solutions can be determined that are in the direction of B (increase in good output and decrease in bad output), C (increase in good output and no change in bad output) or D (decrease in both good and bad outputs).[1] In this paper, we seek primarily expansions of good outputs and contractions of bad outputs in the direction between B and C. For comparative purposes, however, we also estimate capacity output for the case of contracting good output along with bad output (*i.e.* direction D).

3. THE PELAGIC LONGLINE FISHERY, THE GOOD AND BAD OUTPUTS AND THE DATA

The pelagic longline fishery of the Northwest Atlantic is a multi-species fishery, and the type of gear employed or the configuration of the gear can be changed from trip to trip to secure the best economic opportunity for that trip. The fishery operates between Maine and Florida, but the majority of the catch is taken in the Mid-Atlantic region.[2] The fishery targets primarily swordfish and tunas, but also captures and lands various sharks. There are approximately 171 United States -flag vessels active in the entire Atlantic and Gulf of Mexico fisheries. The targeted or desirable outputs are swordfish (*Xiphias gladius*), albacore tuna (*Thunnus alalunga*), yellowfin tuna (*T. albacares*), bigeye tuna (*T. obesus*), bluefin tuna (*T. thynnus*) and sharks. The undesirable outputs are loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles. In the analysis the two species of turtles are linearly aggregated (*i.e.* the total number of turtles caught is equal to the sum of the numbers of the two species caught).

The estimation and assessment of capacity in this fishery utilized data obtained from numerous at-sea experiments conducted in 2002 and 2003 that were designed to assess the performance of different hook sizes and types (J hooks *vs.* circle hooks), different types of bait and the use of lightsticks (Watson *et al.* 2005). The experimental data were obtained from the Northeast Distant Water area, which includes waters east of 60°W between 35°N and 55°N (Scott and Diaz, this volume, Figure 4a). This area has been closed to commercial fishing for several years. Thirteen vessels, which made more than 1 900 sets, participated in the experiment, but the data for only 251 of these were

[1] Lee, Park and Kim (2002) provide a comprehensive overview of selecting the direction of directional distance vectors in the estimation and analysis of technical efficiency.

[2] The majority of the catches of highly migratory species (HMS) are harvested by the pelagic longline fishery of the Gulf of Mexico.

usable, and the others did not meet the requirement that there be at least one good and at least one bad output for the set. The landings data are expressed as dressed weights and the sea turtle catches in numbers of animals caught. Information was available on the following inputs: (1) horsepower of engine, (2) length of vessel, (3) duration of soak, (4) duration of haul, (5) duration of set, (6) distance between gangions, (7) length of mainline, (8) number of hooks, (9) number of lightsticks, (10) number of floats and (11) number of radio beacons. For the purpose of estimating capacity output, engine horsepower and vessel length were considered to be the only limiting or fixed factors; all the other factors of production or inputs were considered to be variable inputs.

4. METHODOLOGY, DATA ENVELOPMENT ANALYSIS AND DIRECTIONAL VECTORS

Although there is no officially sanctioned or internationally accepted method for estimating capacity output in fisheries, the most widely used approach, to date, has been data envelopment analysis or DEA (Pascoe *et al.* 2003; Kirkley, Morrison Paul and Squires 2004). Furthermore, only the output-oriented version of DEA, or an output-only directional vector approach, have been used to estimate capacity in fisheries.[3] Since the details of the conventional output-oriented approach have been widely published in various FAO publications (*e.g.* Kirkley and Squires 1999; Pascoe *et al.* 2003), we present only the details of the directional distance function approach. The directional distance vector approach is quite similar to the traditional output-oriented DEA approach. We seek to determine the maximum expansion, but only for the good outputs, while conditioning the expansion on the same proportional reduction in bad outputs (*e.g.* if it is determined that the capacity output of tuna is 25.0 percent more than the existing level of observed landings of tuna, then the level of bad outputs is reduced by 25.0 percent).

With the traditional output-oriented model, capacity is estimated according to the model formulation and restrictions of Färe (1984) and Färe, Grosskopf and Kokkelenberg (1989). This is a mathematical programming problem, which seeks to determine the maximum proportionate expansion in all outputs, given no change in the fixed factors of production, but allowing for changes in the variable factors (*e.g.* fuel and labour) of production. The proportionate expansion is estimated by solving for the inverse value of an output distance function, which is done for every observation included in the analysis.[4]

The directional vector approach also seeks to determine the maximal expansion in good outputs, but subject to contractions of the bad outputs. In this study, we impose the condition that the proportionate maximal expansion of good outputs is also equal to the proportional maximum contraction of bad outputs (*e.g.* a 25-percent increase in good outputs relative to observed levels is accompanied by a 25-percent decrease in bad outputs relative to their observed levels).[5]

[3] The output orientation directional vector approach is the directional vector approach in which only outputs are allowed to increase, given that inputs are held constant, and reductions in bad outputs are not allowed. This approach yields the same estimates of capacity as does the more traditional output-oriented DEA approach.

[4] An output distance function is the mathematical distance between an observed output bundle (or output in a single output case) and the output bundle corresponding to the potential maximum or frontier output. The maximum potential output is a benchmark level of production determined by vessels of similar sizes. This is similar to the concept of efficiency ratings used to rank appliances of a particular type (*e.g.* water heaters). Initially, energy consumption is calculated for a group of appliances of similar sizes and price ranges; energy consumption of all except the most energy-efficient appliance are compared to the energy consumption of the most energy-efficient appliance, and a rating is assigned.

[5] This is not a requirement of the directional vector. It is possible to determine different levels of expansion for each good output and different levels of contraction for each bad output. This concept, which is described by Koopmans (1951) is referred to as the Pareto-Koopmans concept of efficiency

The following mathematical programming problem was specified and used to estimate capacity output such that good outputs and bad outputs are required to expand and contract, respectively, by the same proportion, β:

$$\vec{D}_O(x^{j'}, y^{j'}, u^{j'}; g) = \underset{\beta,z}{Max}\ \beta$$

s.t.

$$\sum_{j=1}^{J} z_j y_{jm} \geq y_{j'm} + \beta g_m, m = 1,....., M$$

$$\sum_{j=1}^{J} z_j u_{jk} = u_{j'k} + \beta g_k, k = 1,....., K$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{j'n}\ n = 1,....., N$$

$$\sum_{j=1}^{J} z_j = 1.0,$$

$$z_j \geq 0, j = 1, ..., J.$$

where $\vec{D}_O$ is the directional vector; x is a vector of fixed factors (vessel length and engine horsepower); y is a vector of good outputs (weights of desirable outputs of swordfish, tunas, and sharks; u is a vector of bad outputs (number of sea turtles); the g functions are the directions of the distance vectors (1.0 for good outputs and –1.0 for bad outputs); there are J observations, M good outputs, K bad outputs, and N inputs or fixed factors; β is the value of the directional distance vector, and equals 0.0 if the observed good (bad) output cannot be increased (decreased), and is >0.0 if the observed good (bad) output can be expanded (contracted) (the level of expansion (contraction) equals the value of β); and the constraint $\Sigma z_j = 1.0$ imposes variable returns to scale.

The equality constraint

$$\sum_{j=1}^{J} z_j u_{jk} = u_{j'k} + \beta g_k, k = 1,....., K$$

requires additional consideration. This constraint imposes what is referred to as weak subvector disposability. Weak subvector disposability, in constrast to strong subvector disposability, imposes the condition that it is not costless to catch and dispose of bad outputs; alternatively, in this formulation, it explicitly recognizes that labour must be reallocated to dispose of undesirable outputs, and reductions in bad outputs may cause reductions in good outputs. In the traditional framework for assessing capacity, strong disposability, or the conditional that there is no cost of disposing of undesirable outputs, is imposed on the technology. This is straightforward mathematical (linear) programming problem, and it is solved for each observation. The solution yields values of β, for which the percentage by which good and bad outputs, respectively, may be expanded and contracted.

5. RESULTS: ESTIMATES OF CAPACITY OUTPUT UNDER DIFFERENT ASSUMPTIONS

The previously discussed DEA model was estimated under the following basic assumptions: (1) both good and bad outputs could expand, and the cost of disposing of bad outputs is 0.0 (*i.e.* strong disposability is imposed); (2) good outputs could expand according to allowable capacity levels, while bad outputs must be reduced (subvector

TABLE 1
Summary statistics per set of pelagic longline experimental data

Statistic	Horsepower	Length	Swordfish	Albacore	Yellowfin	Bigeye	Bluefin	Shark	Turtles
Mean	465	20.7	433	8	2	44	10	257	1
N	251	251	251	251	251	251	251	251	251
Minimum	265	17.7	0	0	0	0	0	0	1
Maximum	850	25.9	2 003	123	186	509	222	1 201	18
Total			108 565	1 907	533	11 061	2 442	64 570	376

The weights for the desirable species are in kilograms, and the output of sea turtles is measured in numbers of turtles caught. N is the number of observations.

TABLE 2
Observed and estimated capacity output of desirable and undesirable outputs

Allowable expansion and contraction	Swordfish	Albacore	Yellowfin	Bigeye	Bluefin	Sharks	Turtles
Observed levels	108 565	1 907	533	11 061	2 442	64 570	376
Conventional approach: expand good and bad	256 193	2 836	631	21 224	3 292	144 507	1 012
Directional vector: expand good and contract bad	120 440	2 028	535	11 939	2 571	70 380	337
Directional vector: contract good and bad	94 152	1 625	399	9 577	1 928	53 810	255

The weights for the desirable species are in kilograms, and the output of sea turtles is measured in numbers of turtles caught.

weak disposability); and (3) both good and bad outputs must be reduced (global weak disposability). In the first case, the directional functions equal 1.0; in the second case, the directional distance of the good output equals 1.0, and the directional distance of the bad output equals -1.0; in the third case, the directional functions for the good and bad output both equal -1.0, thus forcing reductions in both the good and bad outputs. Estimation was accomplished using user-written code available in LINGO (2002).

Capacity was estimated using the 251 observations obtained from the experiments to assess options for reducing the bycatch of sea turtles in the pelagic longline fishery. Given the limited number of observations, the results should be viewed as representative only of the 13 vessels participating in the experiments, rather than of the entire pelagic longline fleet. The lengths of the vessels ranged from 17.7 to 25.9 m, and their engine horsepowers from 265 to 850 (Table 1). The average lengths and horsepowers for the entire pelagic longline fleet of the Northwest Atlantic and Gulf of Mexico pelagic fishery were 18.0 m and 441 horsepower. The landings of swordfish per set ranged from 0 to 2,003 kg, with an average of 433 kg, and the average landings per set of albacore, yellowfin, bigeye, bluefin and sharks were 8, 2, 44, 10 and 257 kg, respectively.

We next consider the potential expansions and contractions of desirable and undesirable outputs. The desirable outputs are swordfish, albacore, yellowfin, bigeye, bluefin and sharks, and the undesirable outputs are sea turtles. Based on the conventional approach for estimating capacity, we observe that the capacity output for swordfish, bigeye, and sharks is almost double or slightly more than double the observed levels of production; and capacity output is only slightly greater for albacore, yellowfin and bluefin (Table 2). There is, however, a 169-percent increase in the number of sea turtles captured. When good outputs are allowed to expand, but the undesirable outputs must be decreased or remain unchanged, capacity output is only slightly greater for all of the desirable outputs, and there is a decline in the number of sea turtles caught. If it is assumed that all products are complements (desirable and undesirable outputs must jointly increase or decrease) and the only way that the sea turtle catch can be reduced is to reduce the desirable outputs, capacity output is decreased to levels less than the observed levels. This last condition also yields the greatest reduction in the capture of sea turtles—from 376 to 255 turtles.

6. CONCLUSIONS

In this brief study, it was demonstrated that if managers desire estimates of capacity conditional on recognizing that the production of undesirable outputs should be reduced, the conventional DEA approach or the strict output-orientation produces greater estimates of capacity than do procedures designed to incorporate a reduction in undesirable outputs. The notion of a directional vector or directional distance function was introduced, and used to demonstrate a method for estimating capacity when there is a need to consider the reduction of undesirable outputs.

In this study, there were six desirable outputs and one undesirable one. The desirable outputs were swordfish, albacore, yellowfin, bigeye, bluefin and sharks, and the undesirable output was the number of sea turtles caught. Since only 251 observations for only 13 vessels were included in the data set, it is not possible to draw representative conclusions about the entire pelagic longline fleet, either in the Northwest Atlantic or the Gulf of Mexico.

This paper, thus, offers mostly an alternative methodology for estimating capacity, as opposed to an empirical study or examination of the capacity for an entire fleet. Fisheries management around the world, however, is increasingly emphasizing reductions in bycatches of protected and unmarketable species. The approach offered in this paper is one way to assess capacity while incorporating such concerns. In addition, as management agencies increasingly collect more data on discards, *etc.*, through logbooks, at-sea observers and other procedures, it will become increasingly easier to examine the relationship between capacity output and undesirable outputs.

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