ECONOMIC DISCUSSION PAPERS

Efficiency Series Paper 04/2001

Different Methods of Modeling Multi-Species Fisheries Using a Primal Approach

Antonio Álvarez y Luis Orea

Departamento de Economía

Universidad de Oviedo

Available online at: www.uniovi.es/economia/edp.htm

UNIVERSIDAD DE OVIEDO

DEPARTAMENTO DE ECONOMÍA

PERMANENT SEMINAR ON EFFICIENCY AND PRODUCTIVITY

DIFFERENT METHODS OF MODELLING MULTI-SPECIES FISHERIES USING A PRIMAL APPROACH

Antonio Álvarez[*] and Luis Orea

Efficiency Series Paper 4/2001

Abstract
The estimation of technical efficiency in fisheries has become a popular research topic among fisheries economists in the last decade. An interesting aspect of fishing activity is that even though in most fisheries boats specifically try to catch one or two species of interest, they end up catching several species (by-catch). The question is then how to correctly model this situation. In this paper we focus on the different methods to modeling multi-output technologies using a primal approach. In the empirical section we compare the results of the estimation of three of these models, namely the aggregate-output production function, the multi-output production function, and the distance function.

Key Words: Technical efficiency, multi-output technologies, fisheries.

---

[*] Corresponding author. E-mail: aalvarez@econo.uniovi.es.

1. Introduction

The estimation of technical efficiency in fisheries has become a popular research topic among fisheries economists in the last decade.[1] The specific nature of fishing activity raises some interesting modeling issues. In particular, even though in most fisheries boats specifically try to catch one or two species of interest, they end up catching several species, with the non-targeted species known as by-catch. The question is then how to correctly model this situation.

When dealing with multi-species fisheries, the literature has commonly accepted that the presence of by-catch implies that fishing is a multi-output activity. This situation has prompted some researchers to use non-parametric methods, such as Data Envelopment Analysis (DEA), which can easily accommodate several outputs (Coglan, Pascoe and Mardle, 1998). On the other hand, the empirical literature that follows a parametric approach has resorted to some sort of aggregation scheme for the outputs and then uses single-output production models.

In this paper we focus on the different models to deal with multi-output technologies using a primal approach. We review the models and discuss their respective advantages and disadvantages. In an empirical section we compare the results of the estimation of three of these models, namely the aggregate-output production function, the multi-output production function, and the distance function.

The paper is structured as follows. Section 2 reviews the different alternatives available to model multi-output technologies using a primal approach. Section 3 describes the data set and the empirical model. Section 4 contains the empirical models. Section 5 presents the estimation and results.

2. Multi-output production analysis

The traditional approach to modeling multi-species fisheries has been to use a dual function, and cost, profit and revenue functions have been estimated (see Chambers and Strand, 1998; Kirkley and Strand, 1988; and Salvanes and Steen, 1994).

The dual approach relies on the assumption of cost-minimizing or profit-maximizing

---

[1] See Alvarez (2001) for a survey of the literature.

behavior, which may not always hold. This behavior requires not only input and output prices to be observable and exogenous, but also concave product transformation curves. However, even if firms are minimizing costs (or maximizing profits), an additional problem associated with the dual approach is that in the absence of sufficient input price variation across firms it may not be possible to get significant econometric parameter estimates.

We now proceed to review and discuss the modeling of multi-output technologies using a primal approach. In particular we analyze the following four approaches:

- Specification of separate production functions for each output
- Aggregation of outputs into a single index
- Use of a multi-output production function
- Use of a distance function

For notational ease, the discussion that follows is based on the assumption that the *efficient* transformation of a vector of two inputs $x=(x_1,x_2)$ into a vector of two outputs $y=(y_1,y_2)$ can be represented by the general transformation function:

$$F(y_1, y_2, x_1, x_2, z) = 0 \qquad (1)$$

where z is a vector of variables that allows for shifts in the transformation function.

The implications of the previously described approaches are characterized not only in terms of the underlying transformation function but also in terms of the related multi-output cost function.

2.1. Specification of separate production functions for each output

A classical procedure in the study of multi-output firms is to estimate separate production functions for each output, taking as arguments the amount of each input used in producing output y_1 and y_2. That is:

$$\begin{aligned} y_1 &= f^1(x_{11}, x_{21}, z) \\ y_2 &= f^2(x_{12}, x_{22}, z) \end{aligned} \qquad (2)$$

where x_{kj} is the amount of input x_k allocated to production of output y_j (input x_{kj} affects the production of output y_j but not the production of y_l, where $l \neq j$).

Just, Zilberman and Hochman (1983) pointed out that, where input allocations are observed, econometric analysis of (2) generally leads to much better estimates of production function parameters than the single equation (1). Obviously, this approach requires information on how the inputs are allocated among the outputs. If this information is not available, the division of inputs may be based on strong arbitrary assumptions.[2]

However, the main problem here is that this specification is equivalent to imposing nonjointness of production of y_1 and y_2. A technology is said to be *nonjoint* if the input requirement set for $y=(y_1, y_2)$ can be written as the sum of separate input requirement sets for y_1 and y_2. The strong implications of assuming nonjointness can be characterized in a quite simple way by means of the properties of the cost function. Hall (1973) shows that a necessary and sufficient condition for nonjointness is that the cost of producing all outputs can be expressed as the sum of independent cost functions for each output. That is,

$$C(y_1, y_2, w_1, w_2) = C^1(y_1, w_1, w_2, z) + C^2(y_2, w_1, w_2, z) \qquad (3)$$

where w_j stands for the price of input j. The restrictiveness of nonjointness is apparent from (3). It implies that the marginal cost of producing an output is independent of the level of any other output. That is:

$$\frac{MC^1(y_1, w_1, w_2, z)}{\partial y_2} = 0 \qquad (4)$$

This equation indicates thatcosts cannot be reduced by supplying more than one output. Hence, it does not recognize the possibility of complementarities between every pair of outputs, i.e. the existence of economies of scope (Baumol *et al.*, 1982).

2.2. Aggregation of outputs into a single index

This approach was proposed by Mundlak (1963). He suggested aggregating the multiple outputs into a single output index, and then estimating an aggregate-output production function. The output index may be simply the sum of the outputs, the total revenue, or a multi-lateral superlative index (see Caves, Christensen and Diewert,

---

[2] Note that allocability implies that producers can decompose the total amount of one input into various parts and use these parts to produce various outputs separately. Thus, the fact that a researcher cannot distinguish between the amounts of one input used in producing various outputs is not sufficient to rule out allocability.

1982). The sum of all outputs (which is very common in fishing studies) does not hinge on any theoretical basis, and therefore it may result in non-credible estimates of technology parameters. The other two approaches avoid this problem, but they require output prices to be observable. While the revenue measure may be biased if output prices differ between firms, a multi-lateral superlative index avoids this problem.However, this is achieved at the cost of assuming revenue maximizing behavior and competitive output markets, which may not always apply in the fishing industry.

Although this approach recognizes that outputs are produced jointly, it imposes strong restrictions on the form of the transformation function. As Brown, Caves and Christensen (1979) point out, this method is equivalent to assuming that the transformation function (1) can be written as:

$$F(y_1, y_2, x_1, x_2, z) = -g(y_1, y_2) + f(x_1, x_2, z) = 0 \qquad (5)$$

This specification implies that the transformation function is separable in outputs and inputs.[3] Separability is an important assumption and essentially implies that one can significantly change the input mix without affecting the slope of the production possibility curve. Moreover, separability also implies that increasing, say, the amount of input x_1 allocated to produce output y_2 offers the producer the chance of increasing production of output y_1 instead of output y_2. This result may be quite restrictive in some industries.

Using a dual cost approach, Hall (1973) shows that separability implies that the cost of producing all outputs is multiplicatively separable. That is:

$$C(y_1, y_2, w_1, w_2, z) = H(y_1, y_2) \cdot \Psi(w_1, w_2, z) \qquad (6)$$

[3] An example of this relationship is the generalization of the Cobb-Douglas function proposed by Klein (1953) which can be written as:

$$y_1 y_2^{\delta} = \alpha_0 x_1^{\beta_1} x_2^{\beta_2}$$

Klein observed that this relationship would imply a convex rather than concave production possibility curve. This incorrect curvature for the output function would become a serious issue if economic optimization was required. A handful of papers have subsequently considered alternative approaches to avoid Klein's curvature problem. These include the constant elasticity of transformation (CET) function of Powell and Gruen (1968) and the generalized linear transformation function of Diewert (1971).

Hence, separability implies that relative marginal costs (or relative output prices) depend only on the output mix, so they are independent of the input prices.

2.3. Multi-output production functions

This approach addresses the problem of modeling multi-output technologies by regressing one output against the inputs and the other outputs. In our case, this implies estimating:

$$y_1 = f^1 (y_2, x_1, x_2, z) \tag{7}$$

or

$$y_2 = f^2 (y_1, x_1, x_2, z) \tag{8}$$

This approach does not require any assumption about separability and jointness. That is, it recognizes the possibility of complementarities between every pair of outputs (economies of scope). This has the advantages over the construction of aggregate output measures that it does not require data on prices and hence does not assume any optimizing behavior.[4]

The main problem with this method is that one output plays an asymmetric role. In practice, the results with regard to the technology are not independent of the output selected as the dependent variable. That is, if we change the output, we will likely obtain different parameters and therefore the properties of the technology may also change.

In addition, if we change the output, we are likely to get different efficiency scores since the efficiency measures are output specific. In this sense, the efficiency measures indicate the maximum feasible expansion of one output with the other outputs held fixed. These measures may lose much of their meaning if producers cannot increase the

---

[4] Note that the aggregate-equation representation - (5), (7) or (8) - includes aggregate inputs as an argument of the function as opposed to (2) which explicitly includes the allocation of each input among the outputs. As Beattie and Taylor (1985, Chapter 5) point out, some information is lost in using implicit functions or aggregate-equation representations. A similar point has been made by Just, Zilberman and Hochman (1983) who show that aggregate-equation representations (which involve only outputs and aggregate inputs) provide more restrictive representations of multi-product technologies than multiple-equation representations. They show that the use of aggregate-equations reflects not only technological relationships but also additional restrictions (see also Mittelhammer, Matulich and Bushaw, 1981).

production of one output without raising the production of other outputs.

2.4. Distance function

The distance function was introduced by Shepard (1953) and can be input or output oriented. An input distance function characterizes the technology by looking at the minimal proportional contraction of the input vector, given outputs, whereas an output distance function considers the maximal proportional expansion of the output vector, given an input vector. Since skippers cannot easily change their inputs, here we will focus on the output distance function.

The output distance function can be defined as:

$$D_O(x, y, z) = \min_{\Psi}\{\Psi > 0 : (\frac{y}{\Psi}) \in P(x, z)\} \qquad (9)$$

where P(x,z) is the set of feasible output vectors that are obtainable from the input vector x, given the vector z. As illustrated in Figure 1, given an input vector, x, the value of the output distance function, $D_O(x,y,z)$, places $y/D_O(x,y,z)$ on the outer boundary of P(x,z) and on the ray through y. This suggests that the distance function will take a value which is less than or equal to one if the output vector, y, is an element of the feasible production set.[5]

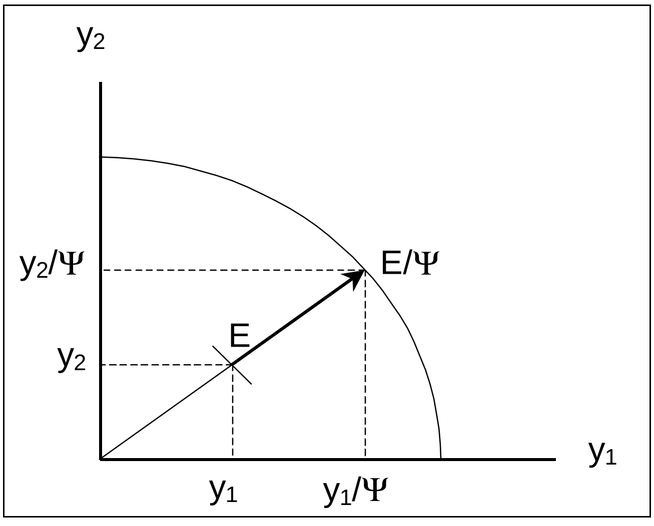

Figure 1. The output distance function

---

[5] However, this conclusion is only valid under the assumption of weak disposability of outputs. In other words, only under this assumption can the technology represented by the output set be modelled by the output distance function. The assumption of weak disposability of outputs is thus the "price" that must be paid if the technology is to be characterized by the output distance function (Färe and Primont, 1995).

The output distance function describes the technology as a transformation function. Moreover, it is related to the transformation function (1) by the following identity:

$$F\left(\frac{y_1}{D_O(x, y, z)}, \frac{y_2}{D_O(x, y, z)}, x_1, x_2, z\right) = 0 \qquad (10)$$

Färe and Primont (1995) show that an output distance function is non-decreasing, positively linearly homogeneous and convex in y, and decreasing in x. The distance function is also closely related to efficiency measurement. More specifically, the output distance function defined in (9) is the inverse of the output-oriented Farrell (1957) measure of technical efficiency.

The main advantage of the distance function over the joint production function is that estimation is possible without separability and jointness and data prices are not required. As every output plays the same role, this option also avoids the asymmetry problem of the estimation of a multi-product production function. That is, the efficiency measures are not output-specific but radial.

The main limitation of distance functions is that the property of linear homogeneity in outputs implicitly imposes that not only efficiency but also noise are radial. That is, the influence of noise upon one output is the same as that upon another output.

3. The data

Our data consist of daily observations for 11 vessels based on two ports located 15 miles apart in Northern Spain for one year (1999). Since some vessels do not go out fishing every day the data form an unbalanced panel data set. Four of the vessels use bottom nets while the rest carry out longline fishing.[6] The vessels' characteristics are summarized in Table 1.

Fishing trips do not take more than one day and when the vessels arrive in port all fish are auctioned in a local market.[7] With respect to output, there is a lot of by-catch with

---

[6] Netters lay the nets on some grounds and return to port. Next day they lift the nets, harvest the fish and lay the nets again on the same ground or on a different one. Longliners leave port earlier and cast the line with live bait, wait for several hours and lift the line before returning to port.

[7] However, during this year boats went out fishing on Saturdays even though the auction market was closed. In this case, the fish was stored and it was auctioned on Mondays.

captures making up one third of the total catch.[8] Some descriptive statistics of the output are also shown in Table 1.

Table 1. Descriptive characteristics of the fishing vessels and daily catches

	Unit	Mean	Coeff. of Variation	Min	Max
Fishing vessels					
Gross Registered Tons	Tons	21.3	0.34	16	32
Boat length	Meters	13.8	0.07	12.5	15.1
Engine power	Hp	169	0.14	128	200
Vessel age	Years	16	0.37	14	26
Daily catches					
Hake	Kg	79	0.67	0	407
By-catch	Kg	41	2.17	1	1247
Total catches	Kg	120	0.88	10	1247
Value	Pesetas	46905		16	582507

The large coefficients of variation indicate high variability in yields, especially in the case of by-catch. The value variable was created using the annual average regional prices of hake and by-catch which were common to all vessels.

4. Empirical model

In this section we discuss the specification issues of the main approaches to modeling multi-output technologies in the primal. Given that information on how the inputs are allocated among the outputs is not available, the three empirical models to be considered are a aggregate-output production function, a multiple-output production function, and an output-oriented distance function.

In the three models the common independent variables include boat (fixed) effects, time effects (quarter dummies), a dummy for the state of the sea, and a dummy for Mondays.

[8] During 1999 thirty other species where caught.

- Eleven dummies for boats: Vessel1 - Vessel11.
- Three dummies for quarters: Q1 – Q3.
  Q1 is Spring, Q2 is Summer and Q3 is Autumn and Winter.
- One dummy variable for the state of the sea: Sea
  This variable takes the value 1 if there is good weather and 0 otherwise.
- One dummy variable for Mondays: Dm.
  This variable takes the value 1 if the day was a Monday (0 otherwise).

The aggregate-output production function is specified as an additive model with only the above dummies as regressors. The multi-product function and the distance function were specified as translogs, with by-catch as the only continuous variable. By-catch was interacted with the dummies for quarters in order to find out if different seasons have a different effect on hake than on by-catch.

4.1. The aggregate-output production function

In this case, all catches were aggregated into value (V) using average prices for the whole region. In this way the weights are firm- and time-invariant. The function to be estimated can be written as:

$$\ln V_{it} = \alpha_i + \lambda_1 Q1_t + \lambda_2 Q2_t + \phi Sea_t + \delta Dm_t + v_{it} \quad (11)$$

where α_i are the fixed effects, λ_t are the time effects (the coefficients of the quarter dummies), Sea is the weather dummy variable, and Dm is the dummy for Mondays. Since Q3 is excluded, Autumn and Winter are the reference quarters. The random term v_{it}, which accounts for luck, is assumed to be symmetrically distributed with zero mean and constant variance.

The fixed effects, α_i, capture the effect of any unobserved (not included) variables, which are vessel-specific and time-invariant. Besides skipper skill, other variables such as vessel characteristics are included in the individual effect.[9]

4.2. The multi-output production function

We considered just two outputs: hake (y_1) and by-catch (y_2). The specification of this

[9] Deviations from the frontier function are accommodated in the fixed effects which can be redefined as an intercept parameter, α_0, minus and a non-negative efficiency term, u_i.

function is:

$$\begin{aligned}\ln y_{1it} = \; & \alpha_i + \lambda_1 Q1_t + \lambda_2 Q2_t + \phi Sea_t + \delta Dm_t + \beta_0 \ln y_{2it} \\ & + \frac{1}{2}\beta_{00}(\ln y_{2it})^2 + \beta_1 \ln y_{2it} Q1_t + \beta_2 \ln y_{2it} Q2_t + v_{it}\end{aligned} \tag{12}$$

4.3. The output-oriented distance function

The stochastic output distance function can be written in log terms as:

$$\begin{aligned}\ln 1 = \; & -\Big[\alpha_i + \lambda_1 Q1_t + \lambda_2 Q2_t + \phi Sea_t + \delta Dm_t + \beta_0 \ln y_{2it} + \frac{1}{2}\beta_{00}(\ln y_{2it})^2 \\ & + \beta_1 \ln y_{2it} Q1_t + \beta_2 \ln y_{2it} Q2_t + \delta_{12} \ln y_{2it} \ln y_{1it} \\ & + \gamma_0 \ln y_{1it} + \frac{1}{2}\gamma_{00}(\ln y_{1it})^2 + \gamma_1 \ln y_{1it} Q1_t + \gamma_2 \ln y_{1it} Q2_t\Big] + v_{it}\end{aligned} \tag{13}$$

where all distance function parameters are multiplied by –1 in order to be comparable with the previous functions, and v_{it} is a standard noise component that follows a symmetric distribution with zero mean.[10]

Obviously, equation (13) cannot be estimated as it stands since one would obtain the trivial solution (i.e. all distance function parameters equal to 0). Alternatively, equation (13) does not represent a distance function unless we include the parametric restrictions related with the property of linear homogeneity in outputs. This property is imposed by dividing the efficient unity value of the left-hand side of equation (13) by hake and normalizing by-catch using hake as a numeraire. The equation now becomes:

$$\begin{aligned}\ln y_{1it} = \; & \alpha_i + \lambda_1 Q1_t + \lambda_2 Q2_t + \phi Sea_t + \delta Dm_t + \beta_0 \ln y^*_{2it} \\ & + \frac{1}{2}\beta_{00}(\ln y^*_{2it})^2 + \beta_1 \ln y^*_{2it} Q1_t + \beta_2 \ln y^*_{2it} Q2_t + v_{it}\end{aligned} \tag{14}$$

where

$$\ln y^*_{2it} = \ln y_{2it} - \ln y_{1it} \tag{15}$$

5. Estimation and results

The three equations compared in this paper (11, 12 and 14) were estimated using the Within estimator.[11] The main advantage of this estimator is that it is consistent (when

[10] As in equation (11), deviations from the efficient unity value are accommodated in the fixed effects, α_i.

T$\rightarrow\infty$) even if the regressors are correlated with the individual effects. The parameter estimates are presented in Table 2, except for the coefficients of vessel dummy variables.

Table 2. Parameter estimates of the three empirical models

	Aggregate-output Production Function		Multi-output Production Function		Output-oriented Distance Function	
Variables	Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio
Q1	0,059	0,64	-0,579	-1,60	0,628	6,25
Q2	0,945	12,80	3,100	12,68	0,518	7,96
Sea	0,328	3,48	0,263	2,10	0,260	3,74
Dm	0,516	6,66	0,449	4,30	0,455	7,99
$\ln(y_2)$	-	-	0,286	2,86	-0,620	-31,21
$\frac{1}{2} \cdot (\ln y_2)^2$	-	-	-0,130	-4,34	0,008	1,40
$\ln(y_2)\cdot$ Q1	-	-	0,174	1,77	-0,113	-5,16
$\ln(y_2)\cdot$ Q2	-	-	-0,414	-5,36	-0,056	-3,14
R-squared	64%		76%		92%	

Some results are common to the three estimated functions. The coefficient of the state of the sea is positive and significant, indicating that good sea-conditions allow vessels to catch more fish. The coefficient of the dummy for Mondays is positive and significant, aswas expected given that fish caught on Saturdays is sold on Mondays. The dummy for the second quarter is always positive and statistically significant which suggests that vessels catch significantly more fish in summer than in other seasons.

The aggregate-output production function, however, does not allow us to know whether the increase in revenues in the second quarter is explained by an increase in catches of high-value (such as, hake) or low-value species. This information can be obtained from the multi-output production function or from the output distance function. Both approaches can tell us whether seasonal conditions affect hake in a different way than other species. As is illustrated in Figure 2, however, the multi-output production function measures the

[11] The estimations were carried out using the Gauss application TSCS.

shifts in the transformation functions in terms of hake (given the amount of by-catch), whereas the output distance function does it in terms of both hake and by-catch. This difference explains why the coefficients of by-catch and quarters (alone and interacting with quarters) are slightly different.

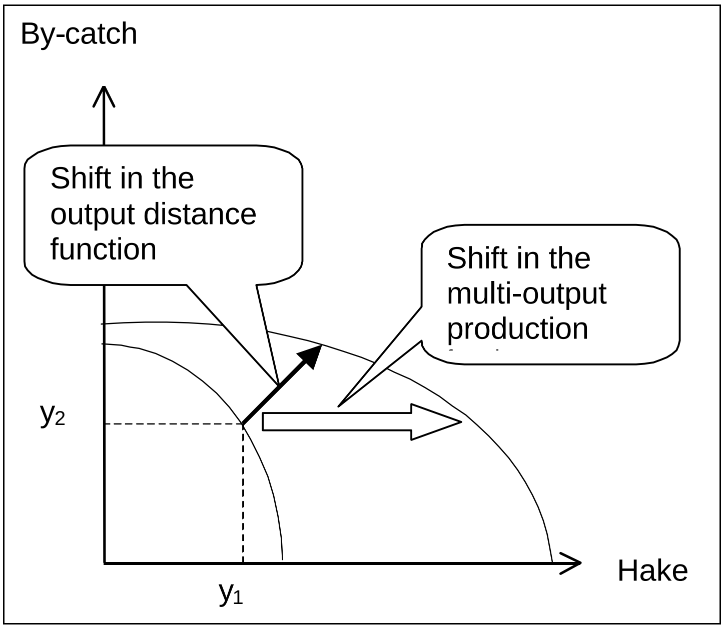

Figure 2. **Measuring shifts in the transformation function**

The coefficients of the interactions of by-catch with quarters are significant. This suggests that shifts are not neutral, that is, seasons affect hake and by-catch in different ways. The interaction of by-catch with the dummy for the second quarter is significant but negative, which indicates that in summer catches of hake increase more than catches of other species. In other words, the shift in the transformation function in summer is biased towards hakewhere this bias suggests that the rate of growth in hake catches is higher than the rate of growth in other species. The coefficient for quarter 1 is also significant and positive in the output distance function, which indicates that vessels catch more fish in spring. Again the interaction with by-catch is negative which tells us that the shift in the transformation function is hake-augmenting.[12] Overall these results suggest that the increase in catches estimated in the aggregate-output production function is mainly due to an increase in hake.

[12] It is noteworthy that the multi-output production function does not reveal, however, any shift in the transformation function in spring.

The R^2 value in both multi-product models is larger than the value obtained from the aggregate-output production function, implying that a multi-output production approach is an improvement over an aggregate-output production analysis.

When faced with the estimation of a multi-output technology, a critical issue is the *allocable* or *nonallocable* nature of factors of production. One input is nonallocable when producers cannot allocate that input into the production processes of each output, and allocable otherwise.[13] The implications of having nonallocable inputs for the estimation of the multi-output technology are important. In the nonallocable case, Beattie and Taylor (1985, Ch.5) note that instead of estimating a transformation function (from which one can get a family of production possibility curves) we can only estimate an output expansion path, which is a locus of attainable output combinations as nonallocable inputs increase. In this case, the production of various outputs is not of interest in a multi-output production analysis since we can use a traditional one-output production function to *completely* represent the technology.[14] In order to reject this possibility, we can test the null hypothesis that the rate of product transformation between hake and by-catch is statistically positive.

Focusing on the output distance function, the estimated coefficient of the by-catch output variable is significant, and has the expected negative sign. Note also that the second order coefficient of this variable is not statistically different from zero and that the interactions with quarter dummy variables also have the negative sign. Overall these results imply a negative relationship between hake and by-catch. Turning to the multi-output production function, we observe that the first-order coefficients are not all significant nor do they all have the correct negative sign. Although this appears to indicate a positive rate of transformation between hake and by-catch, the second-order

---

[13] A classic example of nonallocability is sheep production resulting in two outputs (mutton and wool) from a nonallocable input (feed).

[14] This result has two important implications. First, nonallocable inputs are not arguments in the transformation function, thus neither the multi-output production nor the output distance function have x_1 and x_2 as independent variables. This means that the parameters of a nonallocable input should not be statistically different from zero. Although one can test this hypothesis in order to know whether an input is allocable or not, this option is not available here because all inputs are time-invariant, so we cannot isolate them from the vessels' fixed effects. Second, if *all* inputs are nonallocable, the production of one output is positively related to the production of another output. Therefore, in order to check whether *all* inputs are allocable, one can test the null hypothesis that the rates of product transformation between any pair of outputs are statistically positive.

coefficient is significant and has the correct negative sign. In general, the results in Table 3 indicate that not all inputs are nonallocable, so we cannot use a traditional one-output production function to represent completely the technology.

6. The estimation of efficiency

If the output is in logs, technical efficiency indices for each vessel can be calculated in model (3) as the difference between the estimated individual effect and the maximum individual effect. (Schmidt and Sickles, 1984):

$$TE_i = \exp(\hat{\alpha}_i - \max \hat{\alpha}_j) \quad (16)$$

The technical efficiency scores for each vessel and the implied rankings are presented in Table 3 for the three models estimated in this paper. It can be seen that efficiency rankings do not differ substantially across models. This suggests that the choice of an aggregate-output or multi-output approach does not seem to be terribly crucial in this particular industry, especially if one is mainly interested in efficiency measurement.

Table 3. Technical efficiency indices and ranks

	Aggregate-output Production Function		Multi-output Production Function		Output-oriented Distance Function	
	T.E.	Rank	T.E.	Rank	T.E.	Rank
Vessel 1	12,1	5	0,6	8	22,2	5
Vessel 2	7,3	8	1,5	5	17,0	7
Vessel 3	10,6	6	0,7	7	21,2	6
Vessel 4	2,0	10	0,3	10	6,6	11
Vessel 5	9,1	7	1,0	6	13,7	8
Vessel 6	1,8	11	0,2	11	6,8	10
Vessel 7	2,5	9	0,3	9	8,1	9
Vessel 8	100	1	99,6	2	100	1
Vessel 9	93,8	2	100	1	97,0	2
Vessel 10	83,6	3	79,4	3	82,6	3
Vessel 11	64,4	4	60,3	4	63,0	4

Looking at the technical efficiency scores, the first seven indices belong to vessels which use longline fishing and which are substantially smaller than the those of vessels that use bottom nets. This result seems to indicate that longline vessels are less efficient than bottom nets vessels. It is noteworthy that this difference is higher in the multi-output production function model. This result is not surprising given that longline vessels focus mainly on other species, except in summer where they concentrate on hake. Since the efficiency measures in the multi-output production function model are output specific, we would be likely to get the opposite results if we chose by-catch as the dependent variable. As has already been pointed out, the scores from the output distance function are more useful because they do not impose the restriction that vessels can increase catches of hake without raising catches of other species.

7. Conclusions

This paper addresses the problem of modeling multi-species fisheries using primal approaches. As argued in section 2, the preferred approach is the estimation of distance functions because it does not impose restrictions on the technology (such as separability and nonjointness) and the efficiency scores do not rely on the output selected as the dependent variable.

In our empirical section we use a panel data set of daily catches for eleven vessels that fish off the northern coast of Spain. Three models, namely an aggregate-output production function, a multiple-output production function, and an output-oriented distance function, were estimated using the Within estimator. The results show that both multi-product models are an improvement over the aggregate-output production not only in terms of the R^2 statistic but also in terms of the rich information about the differences between hake and other species caught.

References

Alvarez, A., (2001), "Some Issues on the Estimation of Technical Efficiency in Fisheries", *Efficiency Series Paper 2/2001*, Univ. of Oviedo.

Baumol, W., J. Panzar and R. Willig, (1982), *Contestable Markets and the Theory of Industry Structure*, Harcourt Brace Jovanovich, San Diego.

Beattie, B.R. and C.R. Taylor, (1993), *The Economics of Production*, Krieger Publishing Company.

Brown, R.S., D.W. Caves, and L. R. Christensen, (1979), "Modeling the Structure of Cost and Production for Multiproduct firms", *Southern Economic Journal*, 46, 256-273.

Caves, D.W., L. R. Christensen, and W.E. Diewert, (1982), "Multilateral Comparisons of Output, Input, and Productivity Using Superlative Index Numbers", *Economic Journal*, 92, 73-86.

Chambers, R. and I.E. Strand, (1998), "A Dual, Bioeconomic Model of Short-Run Fisheries Production", Paper presented at IIFET IX, Tromso, Norway.

Coglan, L., S. Pascoe, and S. Mardle, (1998), "DEA Versus Econometric Analysis of Efficiency in Fisheries", Paper presented at IIFET X, Oregon State University.

Diewert, W.E., (1973), "Functional Forms for Profit and Transformation Functions", *Journal of Economic Theory*, 6, 284-316.

Färe, R., and D. Primont, (1995), *Multi-output Production and Duality: Theory and Applications*, Boston Kluwer Academic Publishers.

Farrell, M.J., (1957), "The Measurement of Productive Efficiency", *Journal of the Royal Statistical Society, Series A,* Part 3, 253-90.

Hall, R.E. (1973), "The Specification of Technology with Several Kinds of Outputs", *Journal of Political Economy*, 81(4), 878-892.

Just, R., D. Zilberman and E. Hochman, (1983), "Estimation of Multicrop Production Functions", *American Journal of Agricultural Economics*, 65, 770-780.

Klein, L.R., (1953), *A Textbook of Econometrics*, Row Peterson, New-York.

Mittelhammer, R.C., S.C. Matulich and D. Bushaw, (1981), "On Implicit Forms of Multiproduct-Multifactor Production Functions", *American Journal of Agricultural Economics*, 63, 164-168.

Mundlak, Y., (1963), "Specification and Estimation of Multiproduct Production Functions", *Journal of Farm Economy*, 45, 433-443.

Pascoe, S, J.L. Andersen and J. de Wilde, (2001), "The Impact of Management Regulation on the Technical Efficiency of Vessels in the Dutch Beam Trawl Fishery", *European Review of Agricultural Economics*, 68 (in press).

Powell, A.A. and F.H.G. Gruen, (1968), "The Constant Elasticity of Transformation Production Frontier and Linear Supply System", *International Economic Review*, 9, 315-328.

Salvanes, K.G. and F. Steen, (1994), "Testing for Relative Performance between Seasons in a Fishery", *Land Economics*, 70(4), 431-447.

Schmidt, P. and R.C. Sickles, (1984), "Production Frontiers and Panel Data", *Journal of Business and Economic Statistics*, 2, 367-374.

Shephard, R.W., (1970), *Theory of cost and production functions*, Princeton University Press, Princeton.