

Koundouri, Phoebe; Bjørndal, Trond; Pascoe, Sean

Working Paper

Output Substitution in Multi-Species Trawl Fisheries: Implications for Quota Setting

Nota di Lavoro, No. 30.2004

Provided in Cooperation with:

Fondazione Eni Enrico Mattei (FEEM)

Suggested Citation: Koundouri, Phoebe; Bjørndal, Trond; Pascoe, Sean (2004) : Output Substitution in Multi-Species Trawl Fisheries: Implications for Quota Setting, Nota di Lavoro, No. 30.2004, Fondazione Eni Enrico Mattei (FEEM), Milano

This Version is available at:

<https://hdl.handle.net/10419/117917>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

**Output Substitution in
Multi-Species Trawl Fisheries:
Implications for Quota Setting**

Trond Bjørndal, Phoebe Koundouri
and Sean Pascoe

NOTA DI LAVORO 30.2004

FEBRUARY 2004

NRM – Natural Resources Management

Trond Bjørndal, *CEMARE, Department of Economics, University of Portsmouth*
Phoebe Koundouri, *Department of Economics, University of Reading and*
Department of Economics and CSERGE, University College London
Sean Pascoe, *CEMARE, Department of Economics, University of Portsmouth*

This paper can be downloaded without charge at:

The Fondazione Eni Enrico Mattei Note di Lavoro Series Index:
<http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm>

Social Science Research Network Electronic Paper Collection:
<http://ssrn.com/abstract=504562>

The opinions expressed in this paper do not necessarily reflect the position of
Fondazione Eni Enrico Mattei

Output Substitution in Multi-Species Trawl Fisheries: Implications for Quota Setting

Summary

In most multi-species fisheries managed through output controls, total allowable catches (TACs) are set primarily on the basis of biological considerations, usually on a species by species basis. An implicit assumption of management is that fishers are able to adjust their product mix in line with these quotas. If this is not the case, then over-quota catch occurs, leading to either illegal landings or discards. In either case, the effectiveness of the TAC in conserving the resource is reduced. In this paper we show that in the case of multi-species fisheries that exhibit jointness in production, setting TACs on an individual species' basis is inappropriate. In particular, we quantify technical interactions through the estimation of a multi-output distance function for the UK North Sea beam and otter trawl fisheries, and find that in most cases, the potential of substitutability between the main and alternative species is relatively small. We argue that failure to quantify and integrate these technical interactions in the construction of management instruments for fisheries regulation, may result in increased discarding, illegal fishing and potentially lower than expected future yields.

Keywords: Multi-output fishery, Multi-output distance function, Elasticities of substitution, Efficiency

JEL Classification: Q22

This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation”, Venice, Italy, August 28-29, 2003, organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL).

The study has been undertaken as part of the Commission of the European Communities Fifth Framework programme project QLK5-CT1999-01295, “Technical efficiency in EU fisheries: implications for monitoring and management through effort controls”. The authors would also like to thank Subal Kumbhakar and the anonymous reviewers for their useful comments.

Address for correspondence:

Phoebe Koundouri
School of Business
Department of Economics
University of Reading
HUMSS Building
PO Box 218
Whiteknights, Reading
RG6 6AA, Berkshire
UK
Phone: + 44 (0) 118 378 7862
Fax : +44 (0) 118 975 0236
E-mail: p.koundouri@reading.ac.uk

The need for fisheries management has been accepted in most countries around the world, and relatively few completely unregulated fisheries exist within territorial waters of coastal states. Fisheries regulation varies considerably, ranging from basic limited entry to complex individual transferable quota programs. The failure of input controls to effectively regulate fishing activity as a consequence of input substitution (i.e. of unregulated inputs for restricted inputs) has resulted in many countries either fully adopting an output control system (e.g. New Zealand), or some combination of input and output controls.

Fundamental to the use of output controls is the establishment of a total allowable catch (TAC). This may be either fished competitively – a strategy often criticized by economists due to the incentive to race to fish and the consequent dissipation of resource rent – or allocated to fishers as individual quotas (transferable or non-transferable). While in theory TACs are set on the basis of the multiple objectives of fisheries management, in practice TACs are primarily set on the basis of biological considerations, namely the state of the fish stocks. In Europe, advice on TACs is provided by the International Council for the Exploitation of the Seas (ICES) based on stock assessments of the individual species. Although some recognition is given to some biological interaction (e.g. predator-prey relationships), TACs are set for species individually. Similar TAC setting procedures are employed in the USA and other countries using output controls.

In multi-species fisheries, the ability of the fisher to target individual species is generally assumed to be limited as output is characterized by joint production. The catch composition is a function of the type of gear employed and the relative abundance of the different species in the different areas or times fished. If the relative abundance of the different species does not

vary substantially from area to area, then the ability of the fisher to change their catch composition through changing fishing area is limited.

Management through TACs set on an individual species basis involves an implicit assumption that fishers are able to adjust their behavior sufficiently such that the catch composition reflects the set of TACs. If fishers are unable to adjust their catch composition, then there exists the likelihood of over-quota catch, leading to either illegal landings or discarding. In either case, the integrity of the TAC is violated, and the conservation objectives are not achieved. In contrast, setting TACs taking into account the likely output mix of the fishery may result in a more efficient use of the resource.

In this paper, the potential for fishers to alter their targeting behavior is examined using a multi-output distance function approach. This allows the estimation of the elasticity of substitution between various outputs. The analysis is applied to two fleet segments operating in the North Sea. In each case, the stocks of one or more species caught by these fleet segments is in decline, and TACs for these species have been set at a low level with the expectation that this will result in stock recovery. If fishers are unable to change their catch composition to avoid these species, it is likely that these TACs will be violated and the potential for a rapid stock recovery reduced.

The paper is organized as follows. The next section reviews previous studies involving the estimation production functions in fisheries and the treatment of multiple outputs. Then a description is provided of the methodology employed in the study, and the econometric specification of the model employed. After this, a description of the fishery examined and the data used in the analysis is presented. This is followed by the empirical results of the analysis,

including the estimates of the elasticities of output substitution. Finally, the policy implications of the analysis are presented.

Single vs multi-output production functions in fisheries

A production function defines the relationship between the level of inputs and the resultant level of outputs. It is estimated from observed outputs and input usage and indicates the average level of outputs for a given level of inputs (Schmidt). In fisheries, several studies have estimated production functions at either the individual boat level or aggregate fishery level (e.g. Hannesson, Bjørndal, Campbell and Lindner, Squires, Pascoe and Robinson). The objective of these studies was generally to estimate output elasticities associated with each input, and in some cases the potential for input substitution.

More recently, emphasis has shifted to the estimation of production frontiers. Interest in technical efficiency has largely driven this shift, although there are theoretical reasons why the estimation of production frontiers has advantages over the estimation of production functions (see Kumbhakar). Only limited attempts to estimate stochastic production frontiers for fisheries have been undertaken¹.

A common feature of these studies is the reliance on a single measure of output. This approach has been common for the estimation of production functions in most industries. However, unlike many other industries, many fisheries are characterized by joint production. Joint production occurs when firms produce several outputs at the same time. In fisheries, this is due to technological aspects of the production process, in particular technical interdependencies and non-allocable inputs. Resource jointness in fisheries can arise as a result of several reasons. In particular, many species are often found in the same geographical

area and will be harvested at the same time as a result of the limited selectivity of the fishing gear.

The use of a single composite measure of output under such circumstances imposes a number of restrictive assumptions. Adding up the weight of each output assumes that all species are equally important in the catch, which is clearly not the case as high volume species tend to be low value. This can be overcome through incorporating prices into the analysis, and several studies have used revenue as the output measure (e.g. Sharma and Leung, Pascoe and Cogan, Herrero and Pascoe). The use of total revenue as the output measure requires the assumption that output prices do not differ between firms, and changes in 'output' due to changes in price need to be compensated for. A further method that has been applied (e.g. Pascoe, Andersen and de Wilde) has been to weight the quantity of each output on the basis of its revenue share. This avoids the biases introduced through using prices only, but assumes revenue maximizing behavior and competitive output markets – assumptions that may not be realistic in many instances. Moreover, an aggregate production function imposes the restrictive assumption of separability in inputs and output on the transformation function. This implies that the input mix can be changed significantly without affecting the slope of the production possibility curve, and that marginal costs depend only on the output mix, and are thus independent of the input prices.

An alternative to single output measures is the use of multi-output measures. Several studies have been undertaken assessing technical efficiency and capacity utilization using Data Envelopment Analysis (DEA) in fisheries (see, for example, Feltoven; Pascoe, Cogan and Mardle; Tingley, Pascoe and Mardle; Vestergaard, Squires and Kirkley). A key feature of DEA is that it is directly able to incorporate multiple outputs into the analysis. However, as it

is non-parametric, it is sensitive to random error, and also does not provide estimates of the impact of individual inputs on the level of outputs, or the relationship between the outputs themselves.

Alvarez and Orea examined two methods for incorporating multi outputs in fisheries production functions and compared these with single output measures. The first method – the multi-output production function – involved regressing one (of two) outputs against the other output and set of inputs. The second method – the output oriented distance function – involved a normalized and restricted model that considers the maximal proportional expansion of the output vector given an input vector. Both methods were found to produce similar output elasticities associated with each input, and these were similar to those derived through the single output production function. Moreover, the specification of the multi-output production process overcame the problems associated with the implicit assumptions imposed through the different aggregation processes necessary to derive the single composite output measure.

Fousekis compared the multi-output distance function with the stochastic ray function approach. He found that that latter technique generally resulted in lower efficiency scores, although both methods produced consistent rankings of the efficiency scores. The different techniques also resulted in different estimates of the key production elasticities that are relevant for policies aiming at reduction of harvests through individual input controls.

A key criticism of the multi-output production function is that the output selected as dependent variable plays an asymmetric role, which affects the estimated parameters of the production technology as well as the relevant efficiency score. In contrast, in the output

oriented distance function, every output plays the same role, avoiding the asymmetry problem (i.e., the efficiency measures are not output specific but radial). Further, the output oriented distance function has advantages over the other methods in that estimation is possible without separability and jointness, and information on prices is not required. However, estimation of the distance function requires the assumption of linear homogeneity in outputs, implicitly implying that not only efficiency, but also noise is radial. That is, the influence of noise on one output is the same as that upon another output. This notwithstanding, the output-oriented distance function appears to be the most appropriate method for estimating multi-output production processes.

The Restricted Multi-Output Distance Function

The methodology employed in the study largely follows that used by Fare and Grosskopf; Grosskopf *et al.*; Coelli and Perelman and Morrison Paul *et al.*. These studies largely derive from the initial distance function theory developed by Shephard (1970). Given the existence of a production possibility frontier, the distance that any producer is away from the frontier is a function of the set of inputs used, \mathbf{x} , and the level of outputs produced, \mathbf{y} . For the output-oriented model, this can be expressed as

$$(1) \quad D(\mathbf{x}, \mathbf{y}) = \min\{ \theta : (\mathbf{y} / \theta) \in P(\mathbf{x}) \}$$

where $D(\mathbf{x}, \mathbf{y})$ is the distance from the firm's output set to the frontier, and θ is the corresponding level of efficiency. The output distance function seeks the largest proportional increase in the observed output vector \mathbf{y} provided that the expanded vector (\mathbf{y} / θ) is still an element of the original output set (Grosskopf *et al.*).² If the firm is fully efficient, so that it is

on the frontier, $D(\mathbf{x}, \mathbf{y}) = \theta = 1$, whereas $D(\mathbf{x}, \mathbf{y}) = \theta < 1$ indicates that the firm is inefficient.

The output distance function is homogeneous of degree one in outputs (Shephard 1970).³

Fishery models recognize that capital (the vessel) is usually a fixed factor, due to limited second hand markets and high adjustment costs. In this case a restricted profit function is appropriate, where the fishing vessel is assumed to maximize profits by choosing inputs and harvest level subject to the size of the vessel used in harvesting. Modeling fishermen behavior with profit functions, however, is appropriate only when the output quantities are choice variables. For fishing vessel in individual vessel quota (IVQ) regulated fisheries⁴ the harvest level is set by the individual quota and is no longer a choice variable, i.e., harvest is an exogenous or restricted factor. Hence the price-taking fishermen maximizes profits for a given harvest level H_{it} , or equivalently, minimizes the cost of harvesting the given quota, assuming the quota is the only fixed factor (Asche *et al.*).

The restricted profit maximization problem can be written as:

$$(2) \quad \Pi_{it}^R(p_t^P, p_t^S, p_t^C, p_t^A, p_t^O, p_t^K, p_t^E) = \max(p_t^P \cdot y_{it}^P + p_t^S \cdot y_{it}^S + p_t^C \cdot y_{it}^C + p_t^A \cdot y_{it}^A + p_t^O \cdot y_{it}^O) - C_{it}(Y_{it}, p_t^E, p_t^K)$$

where

$$(3) \quad C_{it}(Y_{it}, p_t^E, p_t^K) = \min p_t^E \cdot x_{it}^E + p_t^K \cdot x_{it}^K : H_{it}(Y_{it}, x_{it}^E, x_{it}^K) = 0$$

To anticipate the empirical estimation, the relevant variables are introduced. The vessel and time specific restricted profit function and the cost function are $\Pi_{it}^R(\cdot)$ and $C_{it}(\cdot)$, respectively. Outputs are plaice (y_{it}^P), sole (y_{it}^S), cod (y_{it}^C), anglerfish (y_{it}^A) and other (y_{it}^O); p_t^P , p_t^S , p_t^C , p_t^A and p_t^O , are the respective competitive market prices. Input price vectors for labour (days employed in fishing), x_{it}^E and capital x_{it}^K , are p_t^E and p_t^K , respectively. \mathbf{Y}_{it} is vessel (i) and time

(*t*)-specific aggregate harvest quantity. By solving for optimal levels of output, one can therefore find the potential rents in such a fishery.⁵

Given the advantages of the distance function discussed above, we model fishing behavior through a restricted multi-output distance function. The production technology is defined by output sets, $P(\mathbf{X}_{it}; \mathbf{H}_{it})$, which represents the set of all output vectors, \mathbf{Y}_{it} , which can be produced using the input vector, \mathbf{X}_{it} , given that individual fishermen decide the mix of input quantities for a given quota (which can be vessel (*i*) and time (*t*) specific). Quotas restrict the harvest level \mathbf{H}_{it} . That is,

$$(4) \quad P(\mathbf{X}_{it}; \mathbf{H}_{it}) = \{\mathbf{Y}_{it}: \mathbf{X}_{it} \text{ can produce } \mathbf{Y}_{it} \text{ given } \mathbf{H}_{it}\}$$

For each \mathbf{X}_{it} , the output set $P(\mathbf{X}_{it}; \mathbf{H}_{it})$ is assumed to satisfy the properties mentioned above. The output distance function is defined on the output set, $P(\mathbf{X}_{it}; \mathbf{H}_{it})$, as:

$$(5) \quad D_{it}^R(x_{it}^E, x_{it}^K, y_{it}^P, y_{it}^S, y_{it}^C, y_{it}^A, y_{it}^O; H_{it}) = \min \{\theta_{it}: (\mathbf{Y}_{it} / \theta_{it}) \in P(\mathbf{X}_{it}; \mathbf{H}_{it})\}$$

where $D_{it}^R(\cdot)$, the restricted output distance function, is non-decreasing in outputs and increasing in inputs, linearly homogeneous in outputs, $D_{it}^R(\cdot) = 1$ and $D_{it}^R(\cdot) = 1$ if \mathbf{Y}_{it} belongs to the “frontier” of the production possibility set; θ_{it} measures the proportional (radial) expansion of the output vector that brings the *it*th firm to the efficient frontier.⁶

Shephard (1953, 1970) has shown that the output distance function may also be obtained as a profit maximal profit function. This means that equation (5) can alternatively be written as:

$$(6) \quad D_{it}^R(x_{it}^E, x_{it}^K, y_{it}^P, y_{it}^S, y_{it}^C, y_{it}^A, y_{it}^O; H_{it}) = \max_{p^d} \{p_t^P y_{it}^P + p_t^S y_{it}^S + p_t^C y_{it}^C + p_t^A y_{it}^A + p_t^O y_{it}^O : \Pi_{it}^R(\cdot)\} \quad m=1, \dots, 6$$

Econometric Specification

In order to estimate the distance from the frontier, both the frontier itself and the relationship between inputs and outputs need to be determined. This requires some form of multi-output production function $P(\mathbf{x})$ to be specified. The most common functional form applied is the translog production function, as it does not impose restrictive assumptions regarding substitutability between inputs (and in this case outputs). This is particularly important in this study as a primary objective is to assess the elasticity of substitution between outputs.

The translog distance function with M ($m = 1, 2, \dots, M$) outputs and K ($k = 1, 2, \dots, K$) inputs, and for I ($i = 1, 2, \dots, I$) firms, can be given by (Grosskopf *et al.*, Coelli and Perelman, Morrison Paul *et al.*):

$$(7) \quad \begin{aligned} \ln D_i = & \alpha_0 + \sum_m \alpha_m \ln y_{mi} + 0.5 \sum_m \sum_n \beta_{mn} \ln y_m \ln y_{ni} \\ & + \sum_k \alpha_k \ln x_{k,i} + 0.5 \sum_k \sum_l \beta_{kl} \ln x_k \ln x_{li} \\ & + \sum_k \sum_m \beta_{km} \ln x_{ki} \ln y_{mi} \end{aligned}$$

In order to maintain the homogeneity conditions, a number of restrictions need to be imposed. These conditions involve the constraints $\sum_m \alpha_m = 1, \sum_n \beta_{mn} = \sum_m \beta_{km} = 0$, while symmetry restrictions require $\beta_{mn} = \beta_{nm}$ and $\beta_{kl} = \beta_{lk}$. The homogeneity restrictions can be imposed through normalizing the function by one of the outputs. This results in:

$$\begin{aligned}
\ln D_i / y_{li} = & \alpha_0 + \sum_m \alpha_m \ln(y_{mi} / y_{li}) + 0.5 \sum_m \sum_n \beta_{mn} \ln(y_m / y_{li}) \ln(y_{ni} / y_{li}) \\
(8) \quad & + \sum_k \alpha_k \ln x_{k,i} + 0.5 \sum_k \sum_l \beta_{kl} \ln x_k \ln x_{li} \\
& + \sum_k \sum_m \beta_{km} \ln x_{ki} \ln(y_{mi} / y_{li})
\end{aligned}$$

The level of inefficiency can be estimated from a stochastic frontier production function of the form $y = f(\mathbf{x}) + v - u$, where v is the error term, assumed to be $N[0, \sigma]$, and u is the one sided inefficiency term that may take one of several distributional forms. The level of efficiency is estimated as the exponent of the negative of the error term, i.e., $\exp(-u)$. Consequently, $\ln D_i = -u_i$, and the normalized equation can be expressed as

$$\begin{aligned}
-\ln y_{li} = & \alpha_0 + \sum_m \alpha_m \ln(y_{mi} / y_{li}) + 0.5 \sum_m \sum_n \beta_{mn} \ln(y_m / y_{li}) \ln(y_{ni} / y_{li}) \\
(9) \quad & + \sum_k \alpha_k \ln x_{k,i} + 0.5 \sum_k \sum_l \beta_{kl} \ln x_k \ln x_{li} \\
& + \sum_k \sum_m \beta_{km} \ln x_{ki} \ln(y_{mi} / y_{li}) + v_i + u_i
\end{aligned}$$

For estimation purposes, the negative sign on the dependent variable can be ignored (i.e., we use $\ln y_l$ rather than $-\ln y_l$). This results in the signs of the estimated coefficients being reversed, but is more consistent with the expected signs of conventional production functions (Coelli and Perelman), and provides a convenient means of qualitatively assessing the models.

In order to separate the stochastic and inefficiency effects in the model, a distributional assumption has to be made for u_i . Two main distributional assumptions that have been proposed are a normal distribution truncated at zero, $u_j \sim [N(\mu, \sigma_u^2)]$ (Aigner, Lovell and Schmidt), and a half-normal distribution truncated at zero, $u_j \sim [N(0, \sigma_u^2)]$ (Jondrow *et al.*). In addition, the inefficiency can also be considered to have a time invariant component, so

that $u_{i,t} = u_i \exp[\eta(T-t)]$ (Battese and Coelli), where T is the terminal time period (i.e., $u_{i,t} = u_i$ when $t=T$).

Following Grosskopf *et al.*, the Allen elasticities of substitution can be directly derived from the distance function, given by

$$(10) \quad A_{yy'}(x, y) = [D(x, y) * \frac{\partial^2 D(x, y)}{\partial y \partial y'}] / [\frac{\partial D(x, y)}{\partial y} * \frac{\partial D(x, y)}{\partial y'}]$$

where $A_{yy'}$ is the Allen elasticity of substitution between output y and y' . A negative value indicates the outputs are substitutes, while a positive value indicates complementarity. The size of the value is a measure of the strength of the substitute/complementarity relationship.

In order to estimate the values of the first and second order derivatives, the values of α and β relating to the output over which the production function was normalized need to be derived. This can be done by using the homogeneity restrictions that were imposed on the model. For the purposes of estimating the elasticity of substitution, the signs of the estimated coefficients need to be reversed.

The UK North Sea Demersal fishery

The North Sea contains a number of interacting multi-species fisheries of great importance to many countries (Figure 1). The North Sea is the major fishing area in European Community waters. Over half of the combined total allowable catches of all species in all EU waters are taken from the North Sea. Commercial activity in the region is mostly undertaken by fishermen from the UK, Denmark, the Netherlands, France, Germany, Belgium and Norway.

Transboundary stocks are shared between the EU and Norway. Based on the total allowable catches (TACs) and the guide prices for each species, the total value of the allowable catch in 1999 was estimated to be about 1.5 billion Euro (Table 1). This is an underestimate of the true value of landings as the guide prices are generally lower than market prices. However, it provides an indication of the order of magnitude of the value of the fishery.

This study focuses on two main fleet segments that make up the majority of the UK North Sea demersal fleet: the UK beam trawl and the English otter trawl fleet segments.

The UK North Sea beam trawl fleet targets primarily high value flatfish (particularly sole and plaice), but also catches a considerable quantity of cod and anglerfish. In addition, many other species are caught as bycatch in varying, but small, quantities. Most of the stocks exploited by the fleet are heavily over-fished, resulting in a substantial decrease in quota levels over recent years. In addition, the fishery has been targeted for decommissioning as it is considered to have considerable excess capacity. Fleet size has been almost halved between 1994 and 2000 as a result of the reduced North Sea quotas, pushing some boats into the English Channel and/or Celtic Sea, and decommissioning.

The English otter trawlers primarily target cod, haddock, saithe and whiting, but also catch plaice and nethrops. These species comprise 90 per cent of the catch by volume, and a greater proportion by value. In addition, a range of other species is caught as bycatch.

The key species caught by both groups are subject to quota controls under the European Common Fisheries Policy. Prior to 1998, quota was allocated to the producer organizations (POs) to which the trawlers belonged, based on the rolling track record of the member

vessels. This would increase or decrease with the actual catch of the individuals, although the POs were expected to attempt to keep the total catch within the allocation. Different POs ran different schemes, with some operating an individual transferable quota (ITQ) system (with trade limited to within the PO) and others operating a more competitive TAC system. For the fleet segments examined, most beam trawlers were managed under effectively an ITQ scheme, while most otter trawlers were managed under a pooled quota system. In 1999, the track record system was changed to a fixed quota allocation (FQA). Despite being ‘fixed’, these could be traded by individuals, either through an annual lease, or through more permanent arrangements (although the process for the latter was generally administratively complex, inhibiting ‘permanent’ transfers).

Despite being subject to quota controls, the quotas were not binding over the period examined. Since the introduction of the FQAs in 1999, the only binding quotas for North Sea species were for saithe and sole in 2000. For most species, quota uptake ranged between 70 and 90 per cent (DEFRA). An analysis of the available beam trawl logbook and quota allocation data for 2000 (see below) found that over 75 per cent of the vessels did not fill their quota allocation, with the remainder exceeding the allocation (presumably through quota leasing). Given the apparent abundance of quota and the apparent effectiveness of the quota leasing market, it was assumed for the purposes of this study that the quotas were not effectively constraining output.

The Available Data

Logbook production data and boat characteristics information from the central fleet registry for the beam and otter trawlers operating in the North Sea were used in the analysis. The data available for the otter trawl fleet relates only to the boats in the fleet registered to English

ports. Data on Scottish otter trawlers are held separately, and were not available for this analysis.⁷ The logbook data were available on a monthly basis over the 11 year-period 1990-2000.

Over the period, data were available for 58 beam trawlers, although only between 30 and 40 operated in any one year, and 152 otter trawlers, with between 100 and 120 operating in any one year. For both groups, only boats that were still registered in 2000 were included. As noted above, many boats had left the fishery as a result of decommissioning. The boats that left the fishery through the decommissioning scheme were most likely the least efficient, and their inclusion in the earlier years of the analysis (but not the later years) might have affected the results. Hence, for consistency, the target population was defined in terms of those boats that were registered in 2000. A second condition was imposed that the boats must have operated in the fishery in at least three of the 11 year data period.

The data set was also subject to further exclusions. For beam trawlers, boats that primarily targeted brown shrimp (*Crangon crangon*) were excluded. For these boats, the catch of the other species considered was negligible, and the fishing operation was considered sufficiently different to exclude from the analysis. Of the remaining vessels, not all boats recorded catch of the key species (plaice) in each year. As this formed the dependent variable in the model, boats that did not record landings of plaice were excluded for that year. Again, boats that did not have catches for at least three years after removing observations without plaice were excluded from the analysis. Similarly for the otter trawlers, boats that did not record landings of cod (the main species) were excluded. As with the beam trawl data, boats that did not have data for at least three years after removing observations without cod were excluded from the analysis. The key characteristics used in the analysis are presented in tables 2 and 3. In most

years, data were available for between 30 and 40 beam trawlers, and between 100 and 120 otter trawlers.

Catches of the key species used in the model varied over the period examined, largely as a result of changes in stock conditions. The key species were selected on the basis of both weight and contribution to total value and constituted 90 per cent of the value of total catch. The remaining species were aggregated into an 'other' category using a division index approach.

While several physical characteristics were available in the data set, e.g. length, vessel capacity units and width, only engine power (kW) was used in the model. Boat deck area (expressed as the product of length and width) was found to be highly correlated with engine power ($r=0.94$), while vessel capacity units are a composite measure of both boat size and engine power (and, thus, was also highly correlated with engine power). The number of days at sea was also used as a variable in the model, representing the level of capital utilization.

Stock information for the key species examined was available on an annual basis (ICES). Stock indexes were derived based on the total available biomass in each year (with the base year being 1990). Changes in the stock abundance over the period of the data are illustrated in Figure 2. As can be seen, the different species were subject to differing changes in stock abundance. For the 'other' species, average catch per day fished across the fleet was used to derive the stock index. This approach implicitly assumes that catch per day fished is proportional to the available stock abundance. Individual stock information on many of the species in the 'other' category was not available.

Accounting for variations in stock abundance in fisheries production functions is generally undertaken through either the direct inclusion of the stock, or through the use of dummy variables. A particular problem exists for the use of stock indexes in multi-output production functions in that each stock measure relates directly to only one of the outputs, although indirectly it may affect the output of the others by affecting fishing patterns. A composite stock variable cannot effectively capture the stock changes of the different species, which do not follow a consistent pattern. Use of dummy variables is also problematic, as a single annual dummy variable cannot adequately represent the different individual stock effects. A series of individual stock dummy variables run into the same problems as the stock indexes, in that they cannot be related to any particular stock. In this study, a further problem was experienced, in that the stock indexes were highly correlated. For example, for the beam trawl fishery, the sole and plaice stock indexes had a correlation coefficient of 0.90, while plaice and 'other' species had a correlation coefficient of 0.80. Initial attempts at incorporating the stock indexes fully into the translog framework resulted in a singular matrix due to the high level of multicollinearity.

To overcome these problems, the catches in each time period were normalized using the stock indexes, i.e., the catch in each time period was divided by the stock index in that time period. This allows the effects of changes in stock size on catch to be incorporated into the analysis, but imposes the implicit assumption of unitary output elasticity with respect to stock size. This assumption is most likely valid given the nature of the resources, in that they are widely dispersed, fairly uniform in density across their areas of distribution and exploited across their whole areas of distribution.

Empirical Results

The adjusted catches of each species were normalized by plaice and cod for the beam trawl and the otter trawl, respectively, in order to estimate the multi-output production frontier. The data were further normalized by the mean value of each variable, such that the average value of the normalized data was equal to one. This allows the output elasticities with respect to the outputs of the other species and the inputs to be determined directly from the results of the analysis as the α coefficients.

The models were estimated using FRONTER 4.1 (Coelli). A series of tests can be conducted to examine the specification of the models. These are tested through imposing restrictions on the model and using the generalized likelihood ratio statistic (λ) to determine the significance of the restriction. The generalized likelihood ratio statistic is given by $\lambda = -2[\ln\{L(H_0)\} - \ln\{L(H_1)\}]$, where $\ln\{L(H_0)\}$ and $\ln\{L(H_1)\}$ are the values of the log-likelihood function under the null (H_0) and alternative (H_1) hypotheses. The restrictions form the basis of the null hypothesis, with the unrestricted model being the alternative hypothesis. The value of λ has a χ^2 distribution with the number of degrees of freedom given by the number of restrictions imposed.

A key test is the one-sided generalized likelihood ratio-test for the existence of a frontier, i.e., $H_0: \gamma = 0$. As the alternative hypothesis is that $0 < \gamma < 1$, the test has an asymptotic distribution, the critical values of which are given by Kodde and Palm. If the hypothesis is accepted, then there is no evidence of technical inefficiency in the data and the production frontier is identical to a standard production function.

Several other standard tests are carried out on the specification of the production function and inefficiency distribution. As the basic model is assumed to have a translog functional form, the hypothesis that the correct functional form of the model is Cobb-Douglas can be imposed by removing the squared and cross product terms from the translog production function, i.e., $H_0: \beta_{i,k} = 0$ and re-estimating the model. Distinguishing between a half normal and a truncated normal distribution as the most appropriate assumption for the inefficiency distribution can be undertaken by running the model under both assumptions. The half-normal distribution is a special case of the truncated normal distribution, and implicitly involves the restriction $H_0: \mu = 0$. Similarly, the hypothesis that efficiency is invariant over time, i.e., $H_0: \eta = 0$ can also be tested. The model is estimated first assuming time variant inefficiency, then restricted by modeling the frontier as time invariant.

The results of the specification tests indicate that the translog is the most appropriate functional form, that inefficiency exists, and that the most appropriate distributional assumption for the inefficiency is a truncated normal distribution with time varying inefficiency (Table 4).

The results for the translog models with the appropriate distributional characteristics are presented in Table 5. Most of the coefficients were found to be significant at the 1 per cent level.

The α coefficients are indicative of the elasticity of the output of the species chosen as the dependent variable with respect to the output of the other species and the inputs. *A priori*, it would be expected that the signs of these coefficients would be negative for the outputs of the other species, assuming some degree of substitution, and positive for the inputs. This was

found to be the case for both gear types, with the exception of haddock in the otter trawl model. For both gear types, the output elasticity with respect to days fished was close to unity, while the output elasticity with respect to engine power was less than one. This suggests constant returns with respect to days fished, but diminishing returns with respect to boat size.

The Allen elasticities of substitution between the key species were estimated at the means of the various inputs and outputs (Tables 6 and 7), following the approach proposed by Grosskopf *et al.*. A negative value of the elasticity indicates a substitute, while a positive value indicates a complement. The results suggest that substitution of some species is possible, but this is largely limited to ‘bundles’ of species. For example, for the beam trawlers, while the main target species is plaice, it appears possible to target sole to some degree. However, increasing sole output also increases the catch of anglerfish and ‘other’ species. Similarly, the fisher could increase the catch of cod, but also ‘other’ species. For the otter trawlers, there appears to be two available strategies, with cod, whiting and plaice being one group, and haddock, saithe, nephrops and ‘other’ being an alternative bundle.

In most cases, the potential of substitutability between the main species and the alternative species is relatively small. For example, while cod and haddock - the two main species - are substitutes for the otter trawlers, the elasticity of substitution is small, so the practical potential for substitution is limited. Similarly, the elasticity of substitution between sole and plaice - the two main species - for the beam trawlers is small, indicating only limited substitution potential. These results have profound consequences for regulations of these fisheries.

The elasticity of substitution between the main target species of each fleet segment (sole and plaice for beam trawl, cod and haddock for otter trawl) were also estimated for each observation in the data set. From these estimates, the average elasticity of substitution for each boat over the period of the data was calculated. An apparent relationship exists between the elasticity of substitution between sole and plaice and boat size (expressed in terms of engine power) for the beam trawl fleet (Figure 3a). Larger boats tended to have a more negative elasticity of substitution, whereas smaller boats tended to have more of a complementary relationship between the species.⁸ As larger boats are more mobile, they are more able to change fishing grounds and take advantage of different relative abundance of the species. In contrast, the smaller boats are more restricted in their movement, tending to fish in a more limited number of fishing grounds and consequently less able to adjust their output mix. Less of a difference was observed in the otter trawl fleet (Figure 3b). Around one quarter of the boats had, on average, a positive elasticity of substitution, and these tended to be the smaller boats in the fishery. However, a greater number of smaller vessels had negative elasticities, although these were also highly inelastic.

The estimated distributions of efficiency for the two fleet segments differed substantially (Figure 4). Over two thirds of the beam trawlers were more than 70 per cent efficient on average over the period of the data. In contrast, over 90 per cent of the otter trawlers were less than 70 per cent efficient on average.

From the model results (Table 5), average individual otter trawl efficiency increased by around 2.3 per cent a year. The removal and replacement of less efficient otter trawlers over the time period resulted in a slight additional increase in average efficiency for the fleet segment as a whole, with an average rate of efficiency increase of around 2.6 per cent (Figure

5). In contrast, average individual efficiency of the beam trawlers decreased by 6.5 per cent a year (Table 5), while removal of the lesser efficient vessels (and introduction of more efficient vessels into the panel) resulted in an overall average decline in the efficiency of the fleet segment of around 1 per cent.

A decline in average individual vessel efficiency of Dutch beam trawlers operating in the North Sea was also observed over the same period (Pascoe *et al.*). This was attributed to increased crowding pressure, as TACs for sole and plaice were reduced while fleet sizes remained relatively constant. For the UK fleet, total beam trawl numbers effectively halved over the period examined, reducing the potential increase in crowding externalities. However, as overall international pressure on these shared stocks did not decrease at the same rate, this would still have negatively impinged on the efficiency of the UK vessels.

Policy Implications

Interactions between species in a fishery may be either biological, e.g. predator-prey, or technical, i.e., joint production. Technical interactions within fisheries have generally been assumed to exist, although the strength of the interaction has not been previously quantified. Fishermen have long argued that they have an inability to target individual species, and the results from this study support their anecdotal evidence. Most previous studies of production functions and frontiers in fisheries have generally applied a composite output measure on the assumption that applying a set of inputs to a given set of fish stocks, usually expressed as a composite stock measure, results in a given level of total output. Alvarez and Orea examined both multi-output production functions and multi-output distance functions for two species (one being a composite bycatch ‘species’), but did not extend their analysis to consider elasticities of substitution between the outputs.

Excluding the stock from the production frontier does not allow the effects of changes in stock size on targeting behavior to be examined. A high relative stock abundance of a species would result in its cost per unit capture decreasing (relative to the other species with lower stock abundances), and may encourage some change in targeting behavior, i.e., output substitution, if possible. However, high stock abundance resulting in high catches may also result in lower prices, so the incentives to change targeting behavior may be less than expected. In either case, these effects cannot be captured (and are effectively assumed to be zero) through the exclusion of stock. However, as the elasticity of substitution is a technical (rather than economic) measure, if these factors had influenced targeting behavior and had resulted in changes in output composition then they should have been identified through the interaction terms in the model. The fact that some substitution has been observed in the data may be a direct result of these factors.

The results of the study have implications for the continuing management of the fishery. In the European Union, as in most other countries, total allowable catches (TACs) are generally set on the basis of the status of the stock of the individual species rather than on the basis of the technical interactions between the species. This is particularly the case when stocks of some species are severely depressed, requiring substantial decreases in the allowable catch. In such cases, pressure is often placed on policy makers to increase the TACs of less biologically vulnerable species in order to reduce the impact of the reduced catch of the vulnerable species on fishermen's income.

In the case of the North Sea stocks, the technical interaction between haddock, cod and whiting, for example, has been recognized by fisheries scientists, and advice to policy makers

has been to control the catches of these species in relation to each other (ICES). The decline in the North Sea cod stock has resulted in substantial declines in allowable catches in a bid to avoid stock collapse and allow the stock to recover. In 2000, the North Sea cod stock was estimated to be roughly 20 per cent of the level of population of mature fish required for sound recruitment (the Bpa, or “Biomass according to the precautionary approach”). A “recovery program” was instigated with the aim of enabling the stock of mature fish to increase by 30 per cent a year until the Bpa level has been achieved. The TAC for cod in the North Sea was reduced from 81,000 tonnes in 2000 to 48,600 tonnes in 2001, and further reduced to 41,600 tonnes in 2002 (European Commission).

In contrast, North Sea TACs of both haddock and saithe were increased by 62 and 55 per cent respectively between 2001 and 2002. The increase in stock that is presumed to underly these TAC increases will result in an increased proportion of these species in the catch, *ceteris paribus*. However, stocks of these species are still considered low (ICES), and it is likely that the TAC increases are, in part, a means of ‘softening’ the impact of the decreased cod TACs. Given the limited substitutability between cod and haddock and also saithe, which is complementary to haddock, the disparity in the TACs may lead to increased discarding of over-quota cod, provided it is economically viable to continue fishing for haddock and saithe without the additional revenue derived from cod.⁹

For the beam trawl fleet, scientific advice for 2002 for the two main species was a 30 per cent reduction in the TAC of plaice and 20 per cent reduction in the TAC of sole in the North Sea (ICES 2001). Recognition was again given to the joint nature of the output of the two species in the scientific advice. Final changes in TACs were, in contrast, less than a 5 per cent decrease for plaice and 16 per cent for sole (European Commission). Again, given the limited

substitutability between sole and plaice, the incompatible TACs may result in increased discarding of sole. However, as sole is substantially more valuable on a per unit basis, it may not be economically viable for fishermen to land only plaice and discard sole, resulting in either the TAC for plaice not being filled, or providing incentives to land over-quota catch of sole illegally.

The results of the analysis also suggest that there is an apparent relationship between boat size and the ability to target individual species. This was more obvious in the beam trawl fleet, where the larger boats demonstrated a clear substitution relationship, while the smaller vessels in many cases had a complementary relationship. The ability to substitute catch for the otter trawlers was on average also relatively low, with the smallest boats also demonstrating complementarity. The majority of the otter trawlers were of similar size as the smaller beam trawlers, reinforcing this relationship between boat size and the ability to influence product mix.

An objection often raised in opposition of the use of individual transferable quotas (ITQs) is that quota tends to concentrate in the fishery in a smaller number of larger vessels. While this may have benefits in terms of economies of scale, the results of this study suggest that it is the larger vessels that are most able to adjust their product mix, and therefore be most able to respond to changes in the relative TACs. Restrictions on trade in quota that reduce concentration may be contributing to the other problem often associated with ITQs, namely over-quota catch and discarding. As the smaller vessels appear less able to adjust their catch mix, then changes in relative TACs will result in greater inconsistency between quota holdings and product mix unless the quota market is sufficiently flexible to allow fishers to adjust their quota holdings. The UK policy of fixed quota allocations inhibits the adjustment

of quota holdings. With limited ability to adjust both catch composition and quota holdings, incompatible TACs can only result in greater discarding or illegal landings.

The results of the study reinforce the need for fisheries managers to consider the technical interactions between species when setting the TACs. These interactions have been recognized by fisheries scientists, and have been generally assumed to exist by fisheries economists. However, this represents the first empirical analysis to quantify these interactions in the context of fisheries management. Failure to consider these interactions may result in increased discarding in the fishery, illegal fishing and potentially lower than expected future yields.

References

- Aigner D., C.A.K. Lovell and P. Schmidt. "Formulation and estimation of stochastic frontier production function models." *J. Econometrics* 6(1977): 21-37.
- Alvarez, A. "Some Issues on the Estimation of Technical Efficiency in Fisheries." Efficiency Series Paper 2/2001. Department of Economics, University of Oviedo, 2001.
- Alvarez, A. and L. Orea,. "Different Approaches to Model Multi-Species Fisheries Using a Primal Approach". Efficiency Series Paper 3/2001. Department of Economics, University of Oviedo, 2001.
- Anderson, L.G. "An economic analysis of highgrading in ITQ fisheries regulation programs". *Marine Resource Econ.* 9(1994): 209-226.
- Arnason, R. "On catch discarding in fisheries". *Marine Resource Econ.* 9(1994):189-207.
- Asche, F., T. Bjørndal and D.V. Gordon, Fishermen behaviour with individual vessel quotas: over-capacity and potential rent, paper presented at the XVth Annual Conference of the European Association of Fisheries Economists, Brest, France, 14-16 May, 2003.

- Battese, G.E. and T.J. Coelli. "Frontier Production Function, technical efficiency and panel data: with application to Paddy Farmers in India." *J. Productiv. Anal.* 3(1992): 153-169.
- Bjørndal, T. "Production in a Schooling Fishery: The Case of the North Sea Herring Fishery." *Land Econ.* 65(1989): 49-56.
- Campbell, H.F. and A.J. Hand. "Joint Ventures and Technology Transfer: the Solomon Islands Pole-and-line Fishery". *J. Devel. Econ.* 57(1998): 421-422.
- Campbell, H.F. and R.K. Lindner. "The production of fishing effort and the economic performance of license limitation programmes." *Land Econ.* 66(1990):55-66.
- Caves, D.W., L.R. Christensen and W.E. Diewert. "Multilateral comparisons of output, input and productivity using superlative index numbers". *Econ. J.* 92(1982):73-86.
- Coelli, T. "A guide to FRONTIER version 4.1: a computer program for frontier production function estimation." CEPA Working Paper 96/07. Department of Econometrics, University of New England, Armidale, Australia, 1996.
- Coelli, T. J. and Perelman, S. "Efficiency measurement, multi-output technologies and distance functions: with application to European railways". CREPP Working Paper 96/05, University of Liege, 1996.
- DEFRA. *UK Fisheries Statistics 2001*, Department of Environment, Food and Rural Affairs, London, 2001 (and earlier issues).
- European Commission Fishing TACs and Quotas 2002 As agreed by Council Regulation (EC) No 2555/2001 of 18 December 2001. Available from http://europa.eu.int/comm/fisheries/doc_et_publ/liste_publi/tac/tac2002_en.pdf
- Färe, R. and S. Grosskopf. "A distance function approach to price efficiency". *J. Public Econ.* 43(1990):123-126

- Felthoven, R.G. “Effects of the American Fisheries Act on capacity, utilisation and technical efficiency.” *Marine Resource Econ.* 17(2002): 181-206
- Fousekis, P. “Distance vs. Ray Functions: An Application to the Inshore Fishery of Greece”. *Marine Resource Econ.* 17(2002):251-268.
- Grafton, R.Q., D. Squires and K.J. Fox. “Private Property and Economic Efficiency: A Study of a Common-Pool Resource”. *J. Law Econ.* 43(2000): 679-713.
- Grosskopf, S., D. Margaritis and V. Valdmanis. “Estimating output substitutability of hospital services: A distance function approach”. *Europ. J. Op. Res.* 80(1995): 575-587
- Hannesson, R.. “Bioeconomic production function in fisheries: Theoretical and Empirical analysis.” *Can. J. Fish. Aquatic Sci.* 13(March 1983):367-375.
- Herrero, I. and S. Pascoe. Value versus volume in the catch of the Spanish South-Atlantic Trawl Fishery. *J. Agr. Econ.* 54(2003):
- ICES. *Report of the ICES Advisory Committee on Fishery Management, 2000*. ICES Co-operative Research Report 249. ICES, Copenhagen, 2001.
- Jondrow, J., C.A.K. Lovell, I.S. Materov and P. Schmidt. “On the estimation of technical inefficiency in the stochastic frontier production function model”. *J. Econometrics* 19(1982): 223-238.
- Kirkley, J., D. Squires and I. Strand. “Assessing Technical Efficiency in Commercial Fisheries: The Mid-Atlantic Sea Scallop Fishery”. *Am. J. Agr. Econ.* 77(November 1995): 686-697.
- Kirkley, J., D. Squires and I. Strand. “Characterizing Managerial Skill and Technical Efficiency in a Fishery”. *J. Prod. Anal.* 9(1998): 145-160.
- Kodde D.A. and F.C. Palm. “Wald criteria for jointly testing equality and inequality restrictions.” *Econometrica* 54(1986):1243-1248.

- Kumbhakar, S.C. "Specification and estimation of production risk, risk preferences and technical efficiency." *Am. J. Agr. Econ.* 84(February 2002) 8-22.
- Morrison Paul, C.J., W.E. Johnston, G.A.G. Frengley "Efficiency in New Zealand Sheep and Beef Farming: The Impacts of Regulatory Reform". *Rev. Econ. Statist.* 82(May 2000):325-37.
- Pascoe, S. *Bycatch Management and the Economics of Discarding*. FAO Fisheries Technical Report 370, FAO, Rome, 1998.
- Pascoe, S., J.L. Andersen and J. de Wilde. "The Impact of Management Regulation on the Technical Efficiency of Vessels in the Dutch Beam Trawl Fishery". *Europ. Re. Agr. Econ.* 28(June 2001), 187-206.
- Pascoe, S. and C. Robinson. "Input controls, input substitution and profit maximisation in the English Channel beam trawl fishery". *J. Agr. Econ.* 49(1998):16-33.
- Pascoe, S. and L. Coglan Contribution of unmeasurable factors to the efficiency of fishing vessels: an analysis of technical efficiency of fishing vessels in the English Channel. *Am. J. Agr. Econ.* 84(August 2002) 45-57.
- Pascoe, S., L. Coglan and S. Mardle. "Physical versus harvest based measures of capacity: the case of the UK vessel capacity unit system." *ICES J. Marine Sci.* 58(2001): 1243-1252.
- Schmidt, P. "Frontier production functions." *Econ. Rev.* 4(1986):329-334.
- Sharma, K.R and P. Leung. "Technical Efficiency of the Longline Fishery in Hawaii: An application of a Stochastic Production Frontier." *Marine Resource Econ.* 13(1998):259-274.
- Shephard, R. W. *Cost and Production Functions*. Princeton: Princeton University Press, 1963.
- Shephard, R. W. *Theory of Cost and Production Functions*. Princeton, Princeton University Press, 1970.

- Squires, D. "Fishing effort: Its testing, specification, and internal structure in fisheries economics and management." *J. Environ. Econ. Manage.* 14(September 1987):268-282.
- Squires, D. and J. Kirkley. "Skipper Skill and Panel Data in Fishing Industries". *Can. J. Fish. Aquatic Sci.* 56(November 1999), 2011-2018.
- Tingley, D., S. Pascoe and S. Mardle. "Estimating capacity utilisation in multi-purpose, multi-metier fisheries." *Fish. Res.* 63(2003): 121-134.
- Vestergaard, N., D. Squires and J. Kirkley. "Measuring capacity and capacity utilization in fisheries: the case of the Danish Gill-net fleet". *Fish. Res.* 60(2003): 357-368

Footnotes

¹ See e.g. Kirkley, Squires and Strand 1995, 1998; Campbell and Hand; Sharma and Leung; Grafton, Squires and Fox; Alvarez; Pascoe, Anderson and de Wilde, Pascoe and Cogan; Herrero and Pascoe.

² Production technology is defined by output sets, $P(\mathbf{x})$, which represents the set of all output vectors, \mathbf{y} , which can be produced using the input vector, \mathbf{x} , i.e., $P(\mathbf{x}) = \{\mathbf{y} : \mathbf{x} \text{ can produce } \mathbf{y}\}$. The properties of this set are summarised as follows: for each \mathbf{x} , the output set $P(\mathbf{x})$ is assumed to satisfy (i) $0 \notin P(\mathbf{x})$; (ii) non-zero output levels cannot be produced from zero level of inputs; (iii) $P(\mathbf{x})$ satisfies strong disposability of outputs: if $\mathbf{y} \in P(\mathbf{x})$ and $\mathbf{y}^* = \mathbf{y}$ then $\mathbf{y}^* \in P(\mathbf{x})$; (iv) $P(\mathbf{x})$ satisfies strong disposability of inputs: if \mathbf{y} can be produced from \mathbf{x} , then \mathbf{y} can be produced from any $\mathbf{x}^* = \mathbf{x}$; (vi) $P(\mathbf{x})$ is bounded (which is essentially a mathematical requirement that implies that we cannot produce unlimited levels of outputs with a given set of inputs); (vii) $P(\mathbf{x})$ is convex (which implies that if two combinations of output levels can be produced with a given input vector \mathbf{x} , then any average of these output vectors can also be produced; this assumption implicitly requires the commodities to be continuously divisible).

³ The properties of $D(\mathbf{x}, \mathbf{y})$ follow directly from the axioms on the technology set and play a major role in efficiency measurement: (i) $D(\mathbf{x}, \mathbf{y})$ is non-decreasing in \mathbf{y} and increasing in \mathbf{x} ; (ii) $D(\mathbf{x}, \mathbf{y})$ is linearly homogeneous in \mathbf{y} ; (iii) if \mathbf{y} belongs to the production possibility set of \mathbf{x} (i.e., $\mathbf{y} \in P(\mathbf{x})$), then $D(\mathbf{x}, \mathbf{y}) = 1$; and (iv) distance is equal to unity (i.e., $D(\mathbf{x}, \mathbf{y}) = 1$) if \mathbf{y} belongs to the “frontier” of the production possibility set.

⁴ A number of fisheries are regulated with individual vessel quotas (IVQs), setting an upper bound on output per species per boat, in addition to a TAC for the entire fishery. The IVQs may or may not be tradable.

⁵ Furthermore, since the TAC is given, if some vessels are to increase their output, others must reduce theirs. As argued by Asche et al. , one can also obtain optimal fleet size, and

therefore an indication of the overcapacity in the fishery. This is important information in fisheries managed with IVQs, as it will provide information about the extent to which one has been able to collect the resource rent and how much resource rent is dissipated due to overcapacity in the fishery.

⁶ The definition of the output distance function uses *min* (minimum) instead of *inf* (infinum), implying the assumption of the absence of the possibility that the minimum does not exist (i.e., that $\theta = +\infty$ is possible).

⁷ This was not a problem for the beam trawl fleet as all UK beam trawlers operate out of English ports.

⁸ This relationship was relatively weak statistically, with a correlation of $r=-0.13$. This increased to $r=-0.51$ if three of the large vessels with high positive elasticities were excluded.

⁹ The economic incentives to discard fish has been well established in the literature. See for example Anderson; , Arnason; Pascoe.

Figure 1. North Atlantic fishing grounds. The North Sea is represented by ICES Division IV.

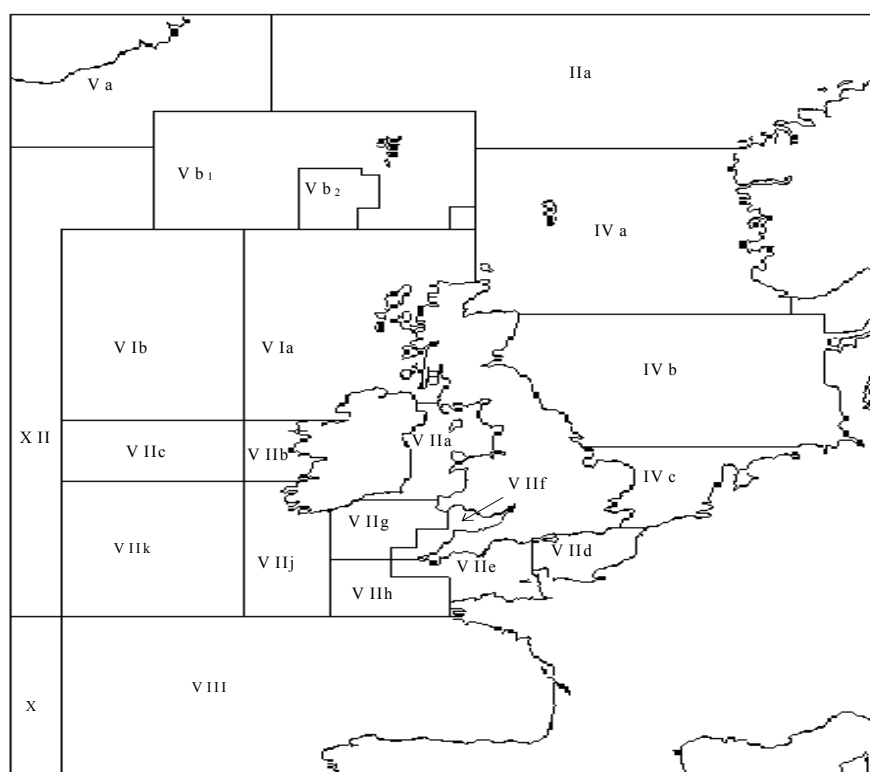


Figure 2: Relative stock indexes for a) beam trawl species and b) otter trawl species

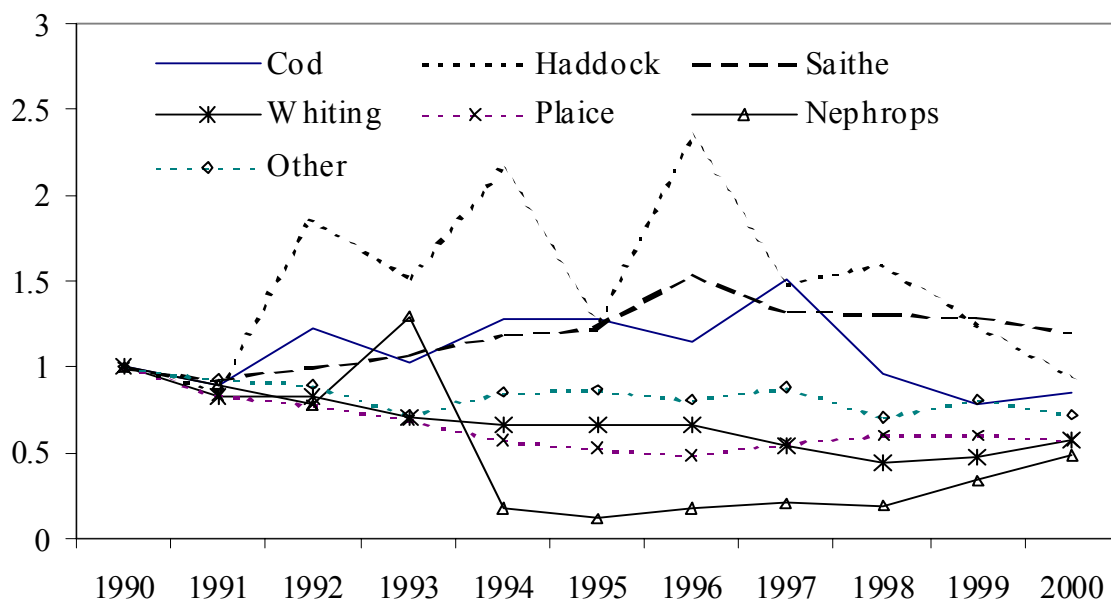
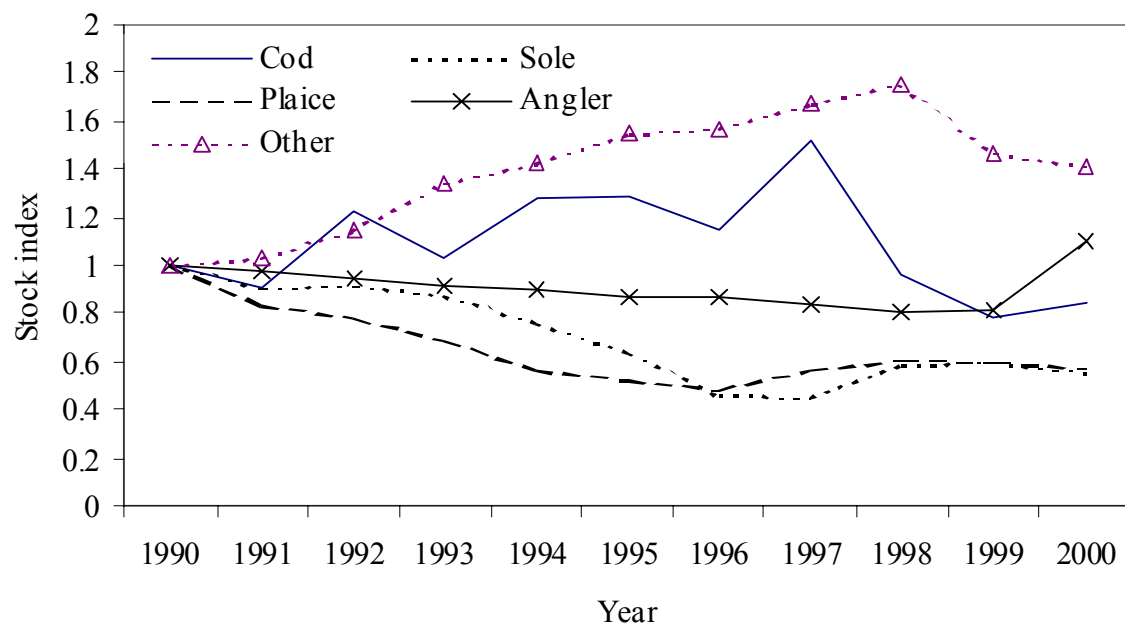


Figure 3. Individual operator's elasticity of substitution against engine power: a) sole and plaice, beam trawlers; and b) cod and haddock, otter trawlers

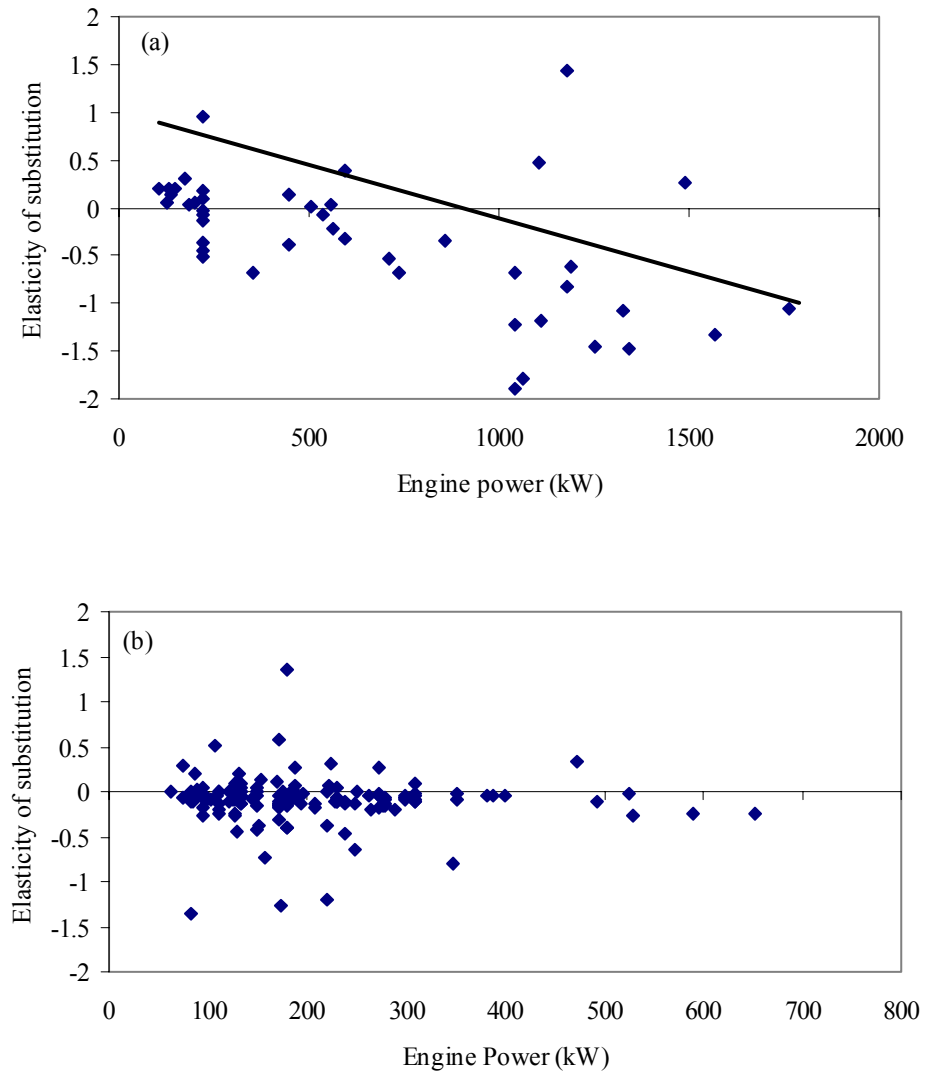


Figure 4. Distribution of average individual vessel efficiency over the period 1990-2000.

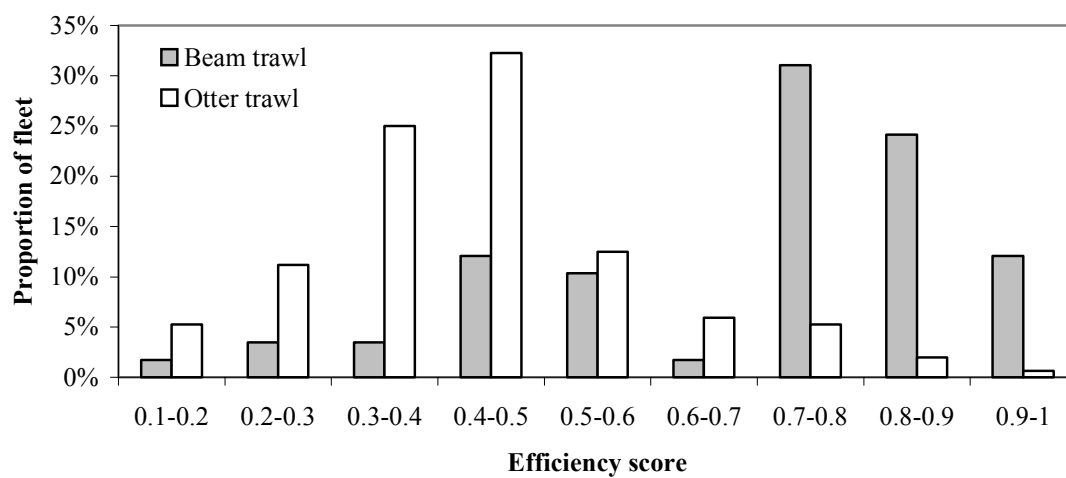


Figure 5. Average vessel efficiency over the period 1990-2000.

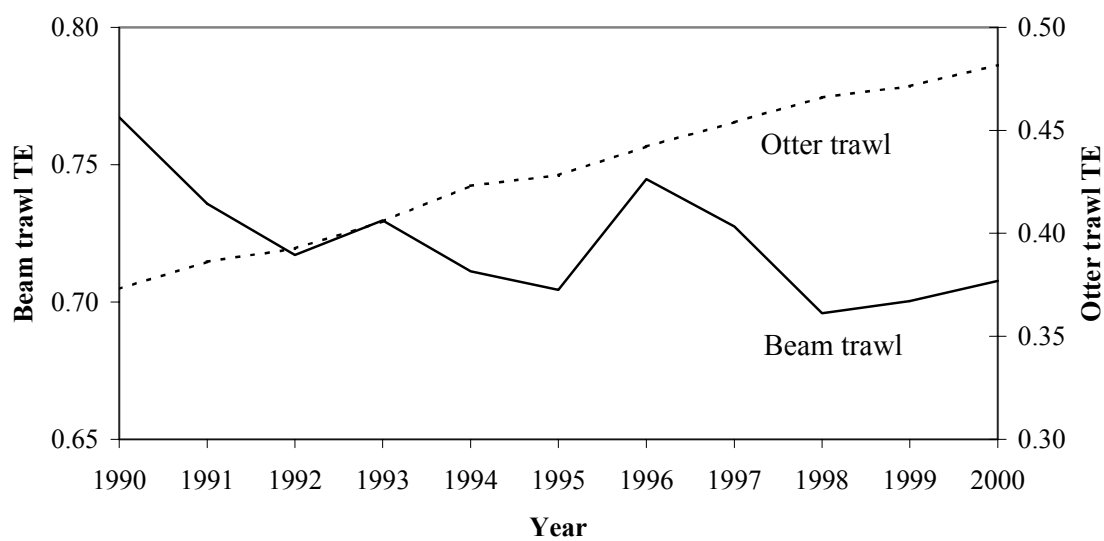


Table 1: TAC allocation for North Sea species^a (kt) and estimated value^b (mEuro), 1999

	Belgium	Denmark	France	Germany	Netherlands	Norway	UK	Total	Value
Demersal groundfish^c									
Cod	4.7	23.9	4.9	12.1	13.1	12.5	52.4	132.4	197.4
Haddock	0.8	5.2	5.8	3.3	0.4	14.9	56.0	88.6	90.9
Whiting	1.2	4.9	8.2	1.4	3.0	4.4	20.9	44.0	38.9
Saithe	0.1	2.3	13.3	6.5	0.0	57.2	4.5	110.0	84.7
Demersal flatfish									
Plaice	6.1	14.9	0.6	6.1	46.6	3.4	23.8	102.0	132.9
Sole	1.6	1.1	0.3	1.2	14.9	0.0	0.9	20.3	131.0
Invertebrates									
<i>Nephrops</i>	0.8	0.8	0.0	0.1	0.4	0.0	12.9	15.2	79.5
Other								1688.4	704.7
Total								2200.9	1460.0

a) Allocation by country based on historical shares of TAC

b) Values based on guide prices for 1999

c) includes ICES Division IIa for some species

Table 2. Average characteristics and catch (kg) of key species, beam trawlers

YEAR	Boats	Engine power (kW)	Days	Plaice	Sole	Cod	Angler	Other
1990	14	954	188	347,343	22,168	10,109	8,778	23,804
1991	27	791	156	194,968	15,038	6,711	6,430	20,054
1992	41	837	158	189,343	8,469	10,651	7,392	25,103
1993	43	815	178	191,841	7,247	14,440	10,688	35,899
1994	39	879	200	195,427	10,165	16,857	13,207	40,579
1995	41	842	196	187,727	9,697	13,557	12,184	38,977
1996	36	899	200	212,235	9,180	15,443	9,085	42,857
1997	38	891	191	238,279	4,163	14,526	11,150	44,008
1998	40	898	188	228,431	6,465	19,562	8,628	44,965
1999	39	898	181	190,520	7,168	13,918	6,175	37,716
2000	35	959	186	295,031	7,784	10,165	7,814	37,474

Table 3. Average characteristics and catch (kg) of key species, otter trawlers

YEAR	Boats	Engine power (kW)	Days	Cod	Haddock	Whiting	Saithe	Nephrops	Plaice	Other
1990	88	223	147	31,171	7,094	8,340	10,539	9,017	3,635	22,358
1991	96	217	140	28,662	6,209	7,959	13,992	7,739	3,701	19,590
1992	99	211	134	29,849	9,198	8,880	5,256	6,348	4,003	18,326
1993	111	217	141	30,841	12,666	9,964	11,149	11,199	2,651	15,493
1994	102	209	117	34,012	10,481	8,898	4,641	1,231	3,423	15,056
1995	110	212	118	36,883	11,484	8,036	10,946	859	4,140	15,572
1996	110	213	119	44,432	13,322	8,679	18,314	1,285	3,377	14,778
1997	124	206	121	38,443	14,757	11,264	13,019	1,493	4,411	16,330
1998	123	211	142	62,507	15,709	13,479	10,847	1,623	3,636	15,286
1999	119	216	120	30,794	13,379	11,332	15,770	2,486	3,316	14,693
2000	104	229	122	22,601	10,964	10,377	10,048	3,691	4,352	13,427

Table 4. Specification tests

	$L(H_0)$	$L(H_1)$	χ^2	Probability
Beam trawl				
$\gamma = 0$	-163.578	-100.621	125.915	<0.01% ^a
$\beta_{i,j} = 0$	-275.485	-100.621	349.728	0.00%
$\mu = 0$	-102.542	-100.621	3.841	5.00%
$\eta = 0$	-108.800	-100.621	16.359	0.01%
Otter trawl				
$\gamma = 0$	-687.097	-481.432	411.331	<0.01% ^a
$\beta_{i,j} = 0$	-810.856	-481.432	658.848	0.00%
$\mu = 0$	-490.692	-481.432	18.521	0.00%
$\eta = 0$	-495.743	-481.432	28.622	0.00%

a) based on the one sided distribution tables developed by Kodde and Palm (1986)

Table 5. MLE results for the two fleet segments

	Beam trawl				Otter trawl		
	Coeff	SE	t-stat		Coeff	SE	t-stat
Constant	0.731	0.081	9.054***	Constant	1.024	0.082	12.411***
Cod*	-0.036	0.024	-1.531	Haddock*	0.121	0.012	9.752***
Sole*	-0.233	0.016	-14.331***	Whiting*	-0.092	0.012	-7.338***
Angler*	-0.057	0.013	-4.265***	Saithe*	-0.064	0.008	-8.016***
Other*	-0.246	0.036	-6.750***	Nephrops*	-0.054	0.006	-9.064***
KW	0.654	0.069	9.470***	plaice*	-0.129	0.015	-8.561***
Days	1.018	0.053	19.061***	other*	-0.493	0.019	-26.379***
Cod* ²	-0.009	0.009	-0.988	KW	0.835	0.068	12.358***
Sole* ²	-0.012	0.003	-3.758***	Days	0.978	0.029	33.691***
Angler* ²	-0.012	0.003	-4.560***	Haddock* ²	0.009	0.003	3.529***
Other* ²	-0.034	0.008	-4.433***	Whiting* ²	-0.006	0.002	-3.582***
KW ²	-0.036	0.094	-0.383	Saithe* ²	0.002	0.001	1.604
Days ²	0.032	0.048	0.676	Nephrops* ²	-0.001	0.001	-1.047
Cod*sole*	0.008	0.012	0.639	Plaice* ²	-0.010	0.003	-4.000***
Cod*angler*	0.008	0.009	0.823	Other* ²	-0.016	0.005	-3.220***
Cod*other*	-0.013	0.016	-0.809***	KW ²	0.008	0.105	0.077
Sole*angler*	-0.006	0.006	-1.057***	Days ²	-0.011	0.026	-0.415
Sole*other*	-0.041	0.013	-3.220	Had*wht*	-0.015	0.004	-4.107***
Angler*other*	0.027	0.010	2.783	Had*saithe*	0.015	0.004	4.086***
Kw days	-0.041	0.058	-0.704	Had*nep*	0.003	0.002	1.821*
Kw cod*	0.000	0.036	0.008	Had*plaice*	-0.015	0.005	-3.086***
Kw sole*	0.168	0.024	6.904***	Had*other*	0.023	0.006	3.468***
Kw ang*	0.018	0.014	1.270	whit*saithe*	0.000	0.003	0.065
Kw other*	-0.241	0.045	-5.389***	Whi*neph*	0.003	0.002	1.219
Days cod*	0.040	0.036	1.108	Whi*plaice*	0.002	0.003	0.868
Days sole*	-0.057	0.021	-2.682***	Whi*other*	0.017	0.004	3.945***
Days ang*	-0.043	0.016	-2.679***	Saithe*nep*	0.000	0.001	0.446
Days other*	0.075	0.037	2.047**	saithe*plaice*	0.007	0.004	1.756*
σ^2	2.650	0.830	3.192***	Saithe*other*	-0.039	0.005	-7.811***
γ	0.974	0.008	115.683***	Nep*plaice*	0.007	0.003	2.111**
μ	-3.214	0.616	-5.221***	Nep*other*	-0.021	0.004	-4.845***
η	-0.065	0.014	-4.726***	plaice*other*	0.023	0.005	4.133***
				Kw days	-0.045	0.067	-0.671
				Kw had*	-0.095	0.024	-4.029***
				Kw whi*	0.050	0.020	2.542**
				Kw saithe*	0.005	0.013	0.340
				Kw neph*	0.037	0.013	2.775***
				Kw plaice*	0.023	0.026	0.862
				Kw other*	0.077	0.028	2.753***
				Days had*	0.046	0.011	4.321***
				Days whi*	-0.015	0.013	-1.154
				Days saithe*	0.022	0.008	2.789***
				Days neph*	-0.021	0.006	-3.251***
				Days plaice*	-0.020	0.017	-1.174
				Days other*	-0.037	0.018	-2.050**
				σ^2	0.240	0.025	9.539***
				γ	0.617	0.030	20.634***
				μ	0.770	0.067	11.427***
				η	0.023	0.004	5.604***

*** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level.

Table 6. Elasticity of substitution: beam trawl

	Plaice	Sole	Cod	Angler	Other
Plaice	-				
Sole	-0.373	-			
Cod	-0.291	-0.659	-		
Angler	0.465	0.346	-2.653	-	
Other	-1.808	0.513	1.026	-1.391	-

Table 7. Elasticity of substitution: otter trawl

	Cod	Haddock	Whiting	Saithe	Nephrops	Plaice	Other
Cod	-						
Haddock	-0.247	-					
Whiting	0.029	-0.570	-				
Saithe	-0.347	0.820	-0.016	-			
Nephrops	-0.247	0.214	-0.237	-0.053	-		
Plaice	0.281	-0.411	-0.083	-0.370	-0.448	-	
Other	-0.043	0.164	-0.163	0.542	0.345	-0.154	-

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

<http://www.feem.it/Feem/Pub/Publications/WPapers/default.html>

<http://www.ssrn.com/link/feem.html>

NOTE DI LAVORO PUBLISHED IN 2003

PRIV	1.2003	<i>Gabriella CHIESA and Giovanna NICODANO: <u>Privatization and Financial Market Development: Theoretical Issues</u></i>
PRIV	2.2003	<i>Ibolya SCHINDELE: <u>Theory of Privatization in Eastern Europe: Literature Review</u></i>
PRIV	3.2003	<i>Wietze LISE, Claudia KEMFERT and Richard S.J. TOL: <u>Strategic Action in the Liberalised German Electricity Market</u></i>
CLIM	4.2003	<i>Laura MARSILIANI and Thomas I. RENSTRÖM: <u>Environmental Policy and Capital Movements: The Role of Government Commitment</u></i>
KNOW	5.2003	<i>Reyer GERLAGH: <u>Induced Technological Change under Technological Competition</u></i>
ETA	6.2003	<i>Efrem CASTELNUOVO: <u>Squeezing the Interest Rate Smoothing Weight with a Hybrid Expectations Model</u></i>
SIEV	7.2003	<i>Anna ALBERINI, Alberto LONGO, Stefania TONIN, Francesco TROMBETTA and Margherita TURVANI: <u>The Role of Liability, Regulation and Economic Incentives in Brownfield Remediation and Redevelopment: Evidence from Surveys of Developers</u></i>
NRM	8.2003	<i>Elissaios PAPYRAKIS and Reyner GERLAGH: <u>Natural Resources: A Blessing or a Curse?</u></i>
CLIM	9.2003	<i>A. CAPARRÓS, J.-C. PEREAU and T. TAZDAÏT: <u>North-South Climate Change Negotiations: a Sequential Game with Asymmetric Information</u></i>
KNOW	10.2003	<i>Giorgio BRUNELLO and Daniele CHECCHI: <u>School Quality and Family Background in Italy</u></i>
CLIM	11.2003	<i>Efrem CASTELNUOVO and Marzio GALEOTTI: <u>Learning By Doing vs Learning By Researching in a Model of Climate Change Policy Analysis</u></i>
KNOW	12.2003	<i>Carole MAIGNAN, Gianmarco OTTAVIANO and Dino PINELLI (eds.): <u>Economic Growth, Innovation, Cultural Diversity: What are we all talking about? A critical survey of the state-of-the-art</u></i>
KNOW	13.2003	<i>Carole MAIGNAN, Gianmarco OTTAVIANO, Dino PINELLI and Francesco RULLANI (lix): <u>Bio-Ecological Diversity vs. Socio-Economic Diversity. A Comparison of Existing Measures</u></i>
KNOW	14.2003	<i>Maddy JANSSENS and Chris STEYAERT (lix): <u>Theories of Diversity within Organisation Studies: Debates and Future Trajectories</u></i>
KNOW	15.2003	<i>Tuzin BAYCAN LEVENT, Enno MASUREL and Peter NIJKAMP (lix): <u>Diversity in Entrepreneurship: Ethnic and Female Roles in Urban Economic Life</u></i>
KNOW	16.2003	<i>Alexandra BITUSIKOVA (lix): <u>Post-Communist City on its Way from Grey to Colourful: The Case Study from Slovakia</u></i>
KNOW	17.2003	<i>Billy E. VAUGHN and Katarina MLEKOV (lix): <u>A Stage Model of Developing an Inclusive Community</u></i>
KNOW	18.2003	<i>Selma van LONDEN and Arie de RUIJTER (lix): <u>Managing Diversity in a Globalizing World</u></i>
Coalition	19.2003	<i>Sergio CURRARINI: <u>On the Stability of Hierarchies in Games with Externalities</u></i>
Theory	20.2003	<i>Giacomo CALZOLARI and Alessandro PAVAN (lx): <u>Monopoly with Resale</u></i>
Network	21.2003	<i>Claudio MEZZETTI (lx): <u>Auction Design with Interdependent Valuations: The Generalized Revelation Principle, Efficiency, Full Surplus Extraction and Information Acquisition</u></i>
PRIV	22.2003	<i>Marco LiCalzi and Alessandro PAVAN (lx): <u>Tilting the Supply Schedule to Enhance Competition in Uniform-Price Auctions</u></i>
PRIV	23.2003	<i>David ETTINGER (lx): <u>Bidding among Friends and Enemies</u></i>
PRIV	24.2003	<i>Hannu VARTIAINEN (lx): <u>Auction Design without Commitment</u></i>
PRIV	25.2003	<i>Matti KELOHARJU, Kjell G. NYBORG and Kristian RYDQVIST (lx): <u>Strategic Behavior and Underpricing in Uniform Price Auctions: Evidence from Finnish Treasury Auctions</u></i>
PRIV	26.2003	<i>Christine A. PARLOUR and Uday RAJAN (lx): <u>Rationing in IPOs</u></i>
PRIV	27.2003	<i>Kjell G. NYBORG and Ilya A. STREBULAIEV (lx): <u>Multiple Unit Auctions and Short Squeezes</u></i>
PRIV	28.2003	<i>Anders LUNANDER and Jan-Eric NILSSON (lx): <u>Taking the Lab to the Field: Experimental Tests of Alternative Mechanisms to Procure Multiple Contracts</u></i>
PRIV	29.2003	<i>TangaMcDANIEL and Karsten NEUHOFF (lx): <u>Use of Long-term Auctions for Network Investment</u></i>
PRIV	30.2003	<i>Emiel MAASLAND and Sander ONDERSTAL (lx): <u>Auctions with Financial Externalities</u></i>
ETA	31.2003	<i>Michael FINUS and Bianca RUNDSHAGEN: <u>A Non-cooperative Foundation of Core-Stability in Positive Externality NTU-Coalition Games</u></i>
KNOW	32.2003	<i>Michele MORETTO: <u>Competition and Irreversible Investments under Uncertainty</u></i>
PRIV	33.2003	<i>Philippe QUIRION: <u>Relative Quotas: Correct Answer to Uncertainty or Case of Regulatory Capture?</u></i>
KNOW	34.2003	<i>Giuseppe MEDA, Claudio PIGA and Donald SIEGEL: <u>On the Relationship between R&D and Productivity: A Treatment Effect Analysis</u></i>
ETA	35.2003	<i>Alessandra DEL BOCA, Marzio GALEOTTI and Paola ROTA: <u>Non-convexities in the Adjustment of Different Capital Inputs: A Firm-level Investigation</u></i>

GG	36.2003	<i>Matthieu GLACHANT</i> : <u>Voluntary Agreements under Endogenous Legislative Threats</u>
PRIV	37.2003	<i>Narjess BOUBAKRI, Jean-Claude COSSET and Omrane GUEDHAMI</i> : <u>Postprivatization Corporate Governance: the Role of Ownership Structure and Investor Protection</u>
CLIM	38.2003	<i>Rolf GOLOMBEK and Michael HOEL</i> : <u>Climate Policy under Technology Spillovers</u>
KNOW	39.2003	<i>Slim BEN YOUSSEF</i> : <u>Transboundary Pollution, R&D Spillovers and International Trade</u>
CTN	40.2003	<i>Carlo CARRARO and Carmen MARCHIORI</i> : <u>Endogenous Strategic Issue Linkage in International Negotiations</u>
KNOW	41.2003	<i>Sonia OREFFICE</i> : <u>Abortion and Female Power in the Household: Evidence from Labor Supply</u>
KNOW	42.2003	<i>Timo GOESCHL and Timothy SWANSON</i> : <u>On Biology and Technology: The Economics of Managing Biotechnologies</u>
ETA	43.2003	<i>Giorgio Busetti and Matteo MANERA</i> : <u>STAR-GARCH Models for Stock Market Interactions in the Pacific Basin Region, Japan and US</u>
CLIM	44.2003	<i>Katrin MILLOCK and Céline NAUGES</i> : <u>The French Tax on Air Pollution: Some Preliminary Results on its Effectiveness</u>
PRIV	45.2003	<i>Bernardo BORTOLOTTI and Paolo PINOTTI</i> : <u>The Political Economy of Privatization</u>
SIEV	46.2003	<i>Elbert DIJKGRAAF and Herman R.J. VOLLEBERGH</i> : <u>Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods</u>
ETA	47.2003	<i>Jens HORBACH</i> : <u>Employment and Innovations in the Environmental Sector: Determinants and Econometrical Results for Germany</u>
CLIM	48.2003	<i>Lori SNYDER, Nolan MILLER and Robert STAVINS</i> : <u>The Effects of Environmental Regulation on Technology Diffusion: The Case of Chlorine Manufacturing</u>
CLIM	49.2003	<i>Lori SNYDER, Robert STAVINS and Alexander F. WAGNER</i> : <u>Private Options to Use Public Goods. Exploiting Revealed Preferences to Estimate Environmental Benefits</u>
CTN	50.2003	<i>László Á. KÓCZY and Luc LAUWERS (Ixi)</i> : <u>The Minimal Dominant Set is a Non-Empty Core-Extension</u>
CTN	51.2003	<i>Matthew O. JACKSON (Ixi)</i> : <u>Allocation Rules for Network Games</u>
CTN	52.2003	<i>Ana MAULEON and Vincent VANNETELBOSCH (Ixi)</i> : <u>Farsightedness and Cautiousness in Coalition Formation</u>
CTN	53.2003	<i>Fernando VEGA-REDONDO (Ixi)</i> : <u>Building Up Social Capital in a Changing World: a network approach</u>
CTN	54.2003	<i>Matthew HAAG and Roger LAGUNOFF (Ixi)</i> : <u>On the Size and Structure of Group Cooperation</u>
CTN	55.2003	<i>Taiji FURUSAWA and Hideo KONISHI (Ixi)</i> : <u>Free Trade Networks</u>
CTN	56.2003	<i>Halis Murat YILDIZ (Ixi)</i> : <u>National Versus International Mergers and Trade Liberalization</u>
CTN	57.2003	<i>Santiago RUBIO and Alistair ULPH (Ixi)</i> : <u>An Infinite-Horizon Model of Dynamic Membership of International Environmental Agreements</u>
KNOW	58.2003	<i>Carole Maignan, Dino PINELLI and Gianmarco I.P. OTTAVIANO</i> : <u>ICT, Clusters and Regional Cohesion: A Summary of Theoretical and Empirical Research</u>
KNOW	59.2003	<i>Giorgio BELLETTINI and Gianmarco I.P. OTTAVIANO</i> : <u>Special Interests and Technological Change</u>
ETA	60.2003	<i>Ronnie SCHÖB</i> : <u>The Double Dividend Hypothesis of Environmental Taxes: A Survey</u>
CLIM	61.2003	<i>Michael FINUS, Ekko van Ierland and Robert DELLINK</i> : <u>Stability of Climate Coalitions in a Cartel Formation Game</u>
GG	62.2003	<i>Michael FINUS and Bianca RUNDSHAGEN</i> : <u>How the Rules of Coalition Formation Affect Stability of International Environmental Agreements</u>
SIEV	63.2003	<i>Alberto PETRUCCI</i> : <u>Taxing Land Rent in an Open Economy</u>
CLIM	64.2003	<i>Joseph E. ALDY, Scott BARRETT and Robert N. STAVINS</i> : <u>Thirteen Plus One: A Comparison of Global Climate Policy Architectures</u>
SIEV	65.2003	<i>Edi DEFRANCESCO</i> : <u>The Beginning of Organic Fish Farming in Italy</u>
SIEV	66.2003	<i>Klaus CONRAD</i> : <u>Price Competition and Product Differentiation when Consumers Care for the Environment</u>
SIEV	67.2003	<i>Paulo A.L.D. NUNES, Luca ROSSETTO, Arianne DE BLAEIJ</i> : <u>Monetary Value Assessment of Clam Fishing Management Practices in the Venice Lagoon: Results from a Stated Choice Exercise</u>
CLIM	68.2003	<i>ZhongXiang ZHANG</i> : <u>Open Trade with the U.S. Without Compromising Canada's Ability to Comply with its Kyoto Target</u>
KNOW	69.2003	<i>David FRANTZ (Ixi)</i> : <u>Lorenzo Market between Diversity and Mutation</u>
KNOW	70.2003	<i>Ercole SORI (Ixi)</i> : <u>Mapping Diversity in Social History</u>
KNOW	71.2003	<i>Ljiljana DERU SIMIC (Ixi)</i> : <u>What is Specific about Art/Cultural Projects?</u>
KNOW	72.2003	<i>Natalya V. TARANOVA (Ixi)</i> : <u>The Role of the City in Fostering Intergroup Communication in a Multicultural Environment: Saint-Petersburg's Case</u>
KNOW	73.2003	<i>Kristine CRANE (Ixi)</i> : <u>The City as an Arena for the Expression of Multiple Identities in the Age of Globalisation and Migration</u>
KNOW	74.2003	<i>Kazuma MATOBA (Ixi)</i> : <u>Glocal Dialogue- Transformation through Transcultural Communication</u>
KNOW	75.2003	<i>Catarina REIS OLIVEIRA (Ixi)</i> : <u>Immigrants' Entrepreneurial Opportunities: The Case of the Chinese in Portugal</u>
KNOW	76.2003	<i>Sandra WALLMAN (Ixi)</i> : <u>The Diversity of Diversity - towards a typology of urban systems</u>
KNOW	77.2003	<i>Richard PEARCE (Ixi)</i> : <u>A Biologist's View of Individual Cultural Identity for the Study of Cities</u>
KNOW	78.2003	<i>Vincent MERK (Ixi)</i> : <u>Communication Across Cultures: from Cultural Awareness to Reconciliation of the Dilemmas</u>
KNOW	79.2003	<i>Giorgio BELLETTINI, Carlotta BERTI CERONI and Gianmarco I.P. OTTAVIANO</i> : <u>Child Labor and Resistance to Change</u>
ETA	80.2003	<i>Michele MORETTO, Paolo M. PANTEGHINI and Carlo SCARPA</i> : <u>Investment Size and Firm's Value under Profit Sharing Regulation</u>

IEM	81.2003	<i>Alessandro LANZA, Matteo MANERA and Massimo GIOVANNINI: <u>Oil and Product Dynamics in International Petroleum Markets</u></i>
CLIM	82.2003	<i>Y. Hossein FARZIN and Jinhua ZHAO: <u>Pollution Abatement Investment When Firms Lobby Against Environmental Regulation</u></i>
CLIM	83.2003	<i>Giuseppe DI VITA: <u>Is the Discount Rate Relevant in Explaining the Environmental Kuznets Curve?</u></i>
CLIM	84.2003	<i>Reyer GERLAGH and Wietze LISE: <u>Induced Technological Change Under Carbon Taxes</u></i>
NRM	85.2003	<i>Rinaldo BRAU, Alessandro LANZA and Francesco PIGLIARU: <u>How Fast are the Tourism Countries Growing? The cross-country evidence</u></i>
KNOW	86.2003	<i>Elena BELLINI, Gianmarco I.P. OTTAVIANO and Dino PINELLI: <u>The ICT Revolution: opportunities and risks for the Mezzogiorno</u></i>
SIEV	87.2003	<i>Lucas BRETSCGHER and Sjak SMULDERS: <u>Sustainability and Substitution of Exhaustible Natural Resources. How resource prices affect long-term R&D investments</u></i>
CLIM	88.2003	<i>Johan EYCKMANS and Michael FINUS: <u>New Roads to International Environmental Agreements: The Case of Global Warming</u></i>
CLIM	89.2003	<i>Marzio GALEOTTI: <u>Economic Development and Environmental Protection</u></i>
CLIM	90.2003	<i>Marzio GALEOTTI: <u>Environment and Economic Growth: Is Technical Change the Key to Decoupling?</u></i>
CLIM	91.2003	<i>Marzio GALEOTTI and Barbara BUCHNER: <u>Climate Policy and Economic Growth in Developing Countries</u></i>
IEM	92.2003	<i>A. MARKANDYA, A. GOLUB and E. STRUKOVA: <u>The Influence of Climate Change Considerations on Energy Policy: The Case of Russia</u></i>
ETA	93.2003	<i>Andrea BELTRATTI: <u>Socially Responsible Investment in General Equilibrium</u></i>
CTN	94.2003	<i>Parkash CHANDER: <u>The γ-Core and Coalition Formation</u></i>
IEM	95.2003	<i>Matteo MANERA and Angelo MARZULLO: <u>Modelling the Load Curve of Aggregate Electricity Consumption Using Principal Components</u></i>
IEM	96.2003	<i>Alessandro LANZA, Matteo MANERA, Margherita GRASSO and Massimo GIOVANNINI: <u>Long-run Models of Oil Stock Prices</u></i>
CTN	97.2003	<i>Steven J. BRAMS, Michael A. JONES, and D. Marc KILGOUR: <u>Forming Stable Coalitions: The Process Matters</u></i>
KNOW	98.2003	<i>John CROWLEY, Marie-Cecile NAVES (Ixxiii): <u>Anti-Racist Policies in France. From Ideological and Historical Schemes to Socio-Political Realities</u></i>
KNOW	99.2003	<i>Richard THOMPSON FORD (Ixxii): <u>Cultural Rights and Civic Virtue</u></i>
KNOW	100.2003	<i>Alaknanda PATEL (Ixxii): <u>Cultural Diversity and Conflict in Multicultural Cities</u></i>
KNOW	101.2003	<i>David MAY (Ixxiii): <u>The Struggle of Becoming Established in a Deprived Inner-City Neighbourhood</u></i>
KNOW	102.2003	<i>Sébastien ARCAND, Danielle JUTEAU, Sirma BILGE, and Francine LEMIRE (Ixxiii) : <u>Municipal Reform on the Island of Montreal: Tensions Between Two Majority Groups in a Multicultural City</u></i>
CLIM	103.2003	<i>Barbara BUCHNER and Carlo CARRARO: <u>China and the Evolution of the Present Climate Regime</u></i>
CLIM	104.2003	<i>Barbara BUCHNER and Carlo CARRARO: <u>Emissions Trading Regimes and Incentives to Participate in International Climate Agreements</u></i>
CLIM	105.2003	<i>Anil MARKANDYA and Dirk T.G. RÜBBELKE: <u>Ancillary Benefits of Climate Policy</u></i>
NRM	106.2003	<i>Anne Sophie CRÉPIN (Ixiv): <u>Management Challenges for Multiple-Species Boreal Forests</u></i>
NRM	107.2003	<i>Anne Sophie CRÉPIN (Ixiv): <u>Threshold Effects in Coral Reef Fisheries</u></i>
SIEV	108.2003	<i>Sara ANIYAR (Ixiv): <u>Estimating the Value of Oil Capital in a Small Open Economy: The Venezuela's Example</u></i>
SIEV	109.2003	<i>Kenneth ARROW, Partha DASGUPTA and Karl-Göran MÄLER(Ixiv): <u>Evaluating Projects and Assessing Sustainable Development in Imperfect Economies</u></i>
NRM	110.2003	<i>Anastasios XEPAPADEAS and Catarina ROSETA-PALMA(Ixiv): <u>Instabilities and Robust Control in Fisheries</u></i>
NRM	111.2003	<i>Charles PERRINGS and Brian WALKER (Ixiv): <u>Conservation and Optimal Use of Rangelands</u></i>
ETA	112.2003	<i>Jack GOODY (Ixiv): <u>Globalisation, Population and Ecology</u></i>
CTN	113.2003	<i>Carlo CARRARO, Carmen MARCHIORI and Sonia OREFFICE: <u>Endogenous Minimum Participation in International Environmental Treaties</u></i>
CTN	114.2003	<i>Guillaume HAERINGER and Myrna WOODERS: <u>Decentralized Job Matching</u></i>
CTN	115.2003	<i>Hideo KONISHI and M. Utku UNVER: <u>Credible Group Stability in Multi-Partner Matching Problems</u></i>
CTN	116.2003	<i>Somdeb LAHIRI: <u>Stable Matchings for the Room-Mates Problem</u></i>
CTN	117.2003	<i>Somdeb LAHIRI: <u>Stable Matchings for a Generalized Marriage Problem</u></i>
CTN	118.2003	<i>Marita LAUKKANEN: <u>Transboundary Fisheries Management under Implementation Uncertainty</u></i>
CTN	119.2003	<i>Edward CARTWRIGHT and Myrna WOODERS: <u>Social Conformity and Bounded Rationality in Arbitrary Games with Incomplete Information: Some First Results</u></i>
CTN	120.2003	<i>Gianluigi VERNASCA: <u>Dynamic Price Competition with Price Adjustment Costs and Product Differentiation</u></i>
CTN	121.2003	<i>Myrna WOODERS, Edward CARTWRIGHT and Reinhard SELTEN: <u>Social Conformity in Games with Many Players</u></i>
CTN	122.2003	<i>Edward CARTWRIGHT and Myrna WOODERS: <u>On Equilibrium in Pure Strategies in Games with Many Players</u></i>
CTN	123.2003	<i>Edward CARTWRIGHT and Myrna WOODERS: <u>Conformity and Bounded Rationality in Games with Many Players</u></i>
	1000	Carlo CARRARO, Alessandro LANZA and Valeria PAPPONETTI: <u>One Thousand Working Papers</u>

NOTE DI LAVORO PUBLISHED IN 2004

ITEM	1.2004	<i>Anil MARKANDYA, Suzette PEDROSO and Alexander GOLUB: <u>Empirical Analysis of National Income and So₂ Emissions in Selected European Countries</u></i>
ETA	2.2004	<i>Masahisa FUJITA and Shlomo WEBER: <u>Strategic Immigration Policies and Welfare in Heterogeneous Countries</u></i>
PRA	3.2004	<i>Adolfo DI CARLUCCIO, Giovanni FERRI, Cecilia FRALE and Ottavio RICCHI: <u>Do Privatizations Boost Household Shareholding? Evidence from Italy</u></i>
ETA	4.2004	<i>Victor GINSBURGH and Shlomo WEBER: <u>Languages Disenfranchisement in the European Union</u></i>
ETA	5.2004	<i>Romano PIRAS: <u>Growth, Congestion of Public Goods, and Second-Best Optimal Policy</u></i>
CCMP	6.2004	<i>Herman R.J. VOLLEBERGH: <u>Lessons from the Polder: Is Dutch CO₂-Taxation Optimal</u></i>
PRA	7.2004	<i>Sandro BRUSCO, Giuseppe LOPOMO and S. VISWANATHAN (lxv): <u>Merger Mechanisms</u></i>
PRA	8.2004	<i>Wolfgang AUSENNEGG, Pegaret PICHLER and Alex STOMPER (lxv): <u>IPO Pricing with Bookbuilding, and a When-Issued Market</u></i>
PRA	9.2004	<i>Pegaret PICHLER and Alex STOMPER (lxv): <u>Primary Market Design: Direct Mechanisms and Markets</u></i>
PRA	10.2004	<i>Florian ENGLMAIER, Pablo GUILLEN, Loreto LLORENTE, Sander ONDERSTAL and Rupert SAUSGRUBER (lxv): <u>The Chopstick Auction: A Study of the Exposure Problem in Multi-Unit Auctions</u></i>
PRA	11.2004	<i>Bjarne BRENDSTRUP and Harry J. PAARSCH (lxv): <u>Nonparametric Identification and Estimation of Multi-Unit, Sequential, Oral, Ascending-Price Auctions With Asymmetric Bidders</u></i>
PRA	12.2004	<i>Ohad KADAN (lxv): <u>Equilibrium in the Two Player, k-Double Auction with Affiliated Private Values</u></i>
PRA	13.2004	<i>Maarten C.W. JANSSEN (lxv): <u>Auctions as Coordination Devices</u></i>
PRA	14.2004	<i>Gadi FIBICH, Arie GAVIOUS and Aner SELA (lxv): <u>All-Pay Auctions with Weakly Risk-Averse Buyers</u></i>
PRA	15.2004	<i>Orly SADE, Charles SCHNITZLEIN and Jaime F. ZENDER (lxv): <u>Competition and Cooperation in Divisible Good Auctions: An Experimental Examination</u></i>
PRA	16.2004	<i>Marta STRYSZOWSKA (lxv): <u>Late and Multiple Bidding in Competing Second Price Internet Auctions</u></i>
CCMP	17.2004	<i>Slim Ben YOUSSEF: <u>R&D in Cleaner Technology and International Trade</u></i>
NRM	18.2004	<i>Angelo ANTOCI, Simone BORGHESI and Paolo RUSSU (lxvi): <u>Biodiversity and Economic Growth: Stabilization Versus Preservation of the Ecological Dynamics</u></i>
SIEV	19.2004	<i>Anna ALBERINI, Paolo ROSATO, Alberto LONGO and Valentina ZANATTA: <u>Information and Willingness to Pay in a Contingent Valuation Study: The Value of S. Erasmo in the Lagoon of Venice</u></i>
NRM	20.2004	<i>Guido CANDELA and Roberto CELLINI (lxvii): <u>Investment in Tourism Market: A Dynamic Model of Differentiated Oligopoly</u></i>
NRM	21.2004	<i>Jacqueline M. HAMILTON (lxvii): <u>Climate and the Destination Choice of German Tourists</u></i>
NRM	22.2004	<i>Javier Rey-MAQUIEIRA PALMER, Javier LOZANO IBÁÑEZ and Carlos Mario GÓMEZ GÓMEZ (lxvii): <u>Land, Environmental Externalities and Tourism Development</u></i>
NRM	23.2004	<i>Pius ODUNGA and Henk FOLMER (lxvii): <u>Profiling Tourists for Balanced Utilization of Tourism-Based Resources in Kenya</u></i>
NRM	24.2004	<i>Jean-Jacques NOWAK, Mondher SAHLI and Pasquale M. SGRO (lxvii): <u>Tourism, Trade and Domestic Welfare</u></i>
NRM	25.2004	<i>Riaz SHAREEF (lxvii): <u>Country Risk Ratings of Small Island Tourism Economies</u></i>
NRM	26.2004	<i>Juan Luis Eugenio-MARTÍN, Noelia MARTÍN MORALES and Riccardo SCARPA (lxvii): <u>Tourism and Economic Growth in Latin American Countries: A Panel Data Approach</u></i>
NRM	27.2004	<i>Raúl Hernández MARTÍN (lxvii): <u>Impact of Tourism Consumption on GDP. The Role of Imports</u></i>
CSRM	28.2004	<i>Nicoletta FERRO: <u>Cross-Country Ethical Dilemmas in Business, a Descriptive Framework</u></i>
NRM	29.2004	<i>Marian WEBER (lxvi): <u>Assessing the Effectiveness of Tradable Landuse Rights for Biodiversity Conservation: an Application to Canada's Boreal Mixedwood Forest</u></i>
NRM	30.2004	<i>Trond BJORN DAL, Phoebe KOUNDOURI and Sean PASCOE (lxvi): <u>Output Substitution in Multi-Species Trawl Fisheries: Implications for Quota Setting</u></i>

- (lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002
- (lx) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
- (lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
- (lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002
- (lxiii) This paper was presented at the ENGIME Workshop on “Social dynamics and conflicts in multicultural cities”, Milan, March 20-21, 2003
- (lxiv) This paper was presented at the International Conference on “Theoretical Topics in Ecological Economics”, organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003
- (lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
- (lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003
- (lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003

2003 SERIES

CLIM	<i>Climate Change Modelling and Policy</i> (Editor: Marzio Galeotti)
GG	<i>Global Governance</i> (Editor: Carlo Carraro)
SIEV	<i>Sustainability Indicators and Environmental Valuation</i> (Editor: Anna Alberini)
NRM	<i>Natural Resources Management</i> (Editor: Carlo Giupponi)
KNOW	<i>Knowledge, Technology, Human Capital</i> (Editor: Gianmarco Ottaviano)
IEM	<i>International Energy Markets</i> (Editor: Anil Markandya)
CSRM	<i>Corporate Social Responsibility and Management</i> (Editor: Sabina Ratti)
PRIV	<i>Privatisation, Regulation, Antitrust</i> (Editor: Bernardo Bortolotti)
ETA	<i>Economic Theory and Applications</i> (Editor: Carlo Carraro)
CTN	<i>Coalition Theory Network</i>

2004 SERIES

CCMP	<i>Climate Change Modelling and Policy</i> (Editor: Marzio Galeotti)
GG	<i>Global Governance</i> (Editor: Carlo Carraro)
SIEV	<i>Sustainability Indicators and Environmental Valuation</i> (Editor: Anna Alberini)
NRM	<i>Natural Resources Management</i> (Editor: Carlo Giupponi)
KTHC	<i>Knowledge, Technology, Human Capital</i> (Editor: Gianmarco Ottaviano)
IEM	<i>International Energy Markets</i> (Editor: Anil Markandya)
CSRM	<i>Corporate Social Responsibility and Management</i> (Editor: Sabina Ratti)
PRA	<i>Privatisation, Regulation, Antitrust</i> (Editor: Bernardo Bortolotti)
ETA	<i>Economic Theory and Applications</i> (Editor: Carlo Carraro)
CTN	<i>Coalition Theory Network</i>