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Multi-national Industry Capacity in the North Sea Flatfish Fishery

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Abstract *Fisheries managers often see the management of regional fisheries as a more pertinent approach than managing separate national fleet units that exploit numerous fish stocks. This article considers an industry approach, using data envelopment analysis (DEA), to shed light on the exploitation of the North Sea flatfish fishery by a multi-national fleet, identifying overcapacity and possible reductions of the current fleet. The analysis estimates that the same catch could be taken with a fleet at 77% of its current size, and suggests an optimal reallocation of fixed inputs of each national fleet. Further insight is also given to surplus and optimal vessels in terms of catches and vessel characteristics. Simulations of the impact of possible quota reductions and restrictions of equal capacity reduction across nations are also considered.*

Key words Data Envelopment Analysis, capacity output, industry allocation, multi-national fleet.

JEL Classification Codes C14, D24, Q22.

Introduction

Fishing capacity has become a management topic of great significance in recent years. Problems stemming from ill-defined property rights and race to fish behaviour include overcapitalisation of the fishing industry and consistent overexploitation of the resource base. Under the initiative of the Food and Agriculture Organisation of the United Nations (FAO) and the International Plan of Action for the Management of Fishing Capacity, the use of Data Envelopment Analysis (DEA) has been proposed as the preferred tool to enable the measurement of fishing capacity worldwide (FAO 2001). Such analysis gives fishery managers valuable information on the commensurate level of fleet capacity, given the availability of resources and the economic status of the fishing industry. Most capacity analyses have, however, concentrated on single fleets defined by nationality or gear type, whereas a multi-national fleet approach may be more desirable.[1]

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The article serves as an analytical extension of the work undertaken in EU project 99/005, Vestergaard, N., A. Hoff, J.L. Andersen, E. Lindebo, L. Grønbæk, S. Pascoe, D. Tingley, S. Mardle, O. Guyader, F. Daures, L. van Hoof, J.W. de Wilde, and J. Smit (2002) entitled, “Measuring Capacity in Fishing Industries using the Data Envelopment (DEA) Approach.” The access to data from the project participants is gratefully acknowledged. The author is also grateful to Ayoe Hoff, Niels Vestergaard, Jesper Andersen, Hans Frost, and two anonymous referees for helpful comments and suggestions on earlier drafts of this article. Any shortcomings, however, remain the responsibility of the author.

[1] Lassen (1996) applied a ‘biological’ multi-national fleet dimension to estimating fishing mortality reductions in EU fisheries.

What has become increasingly clear is the general wish of fisheries managers to know the level of capacity on a fishery, national or regional level, and not purely the capacity of a small number of independent operating units. This is none more evident than in the European Union (EU), where recently adopted reforms of the Common Fisheries Policy (CFP) aim to deal with multi-national regulation on a stock-by-stock basis. In such cases, an industry allocation model can be applied to address the status of capacity on a fishery level (*e.g.*, for particular fish stocks), and so include multi-national fleets that operate in the same fishery. Further, reallocation of capital, labour, and other productive resources in relation to capacity adjustment initiatives can similarly be estimated on a multi-national level.

The EU capacity problem has received specific attention during the last two decades through the implementation of capacity adjustment programmes. Under the Multiannual Guidance Programme (MAGP), an overall EU fleet reduction of 20% in terms of vessel tonnage and engine power has resulted over the last two decades, although to highly variable extents across fleet segments and member states. Following the reform of the CFP, capacity reduction will now be targeted in response to required cuts in fishing mortality of overexploited stocks. It can thus be anticipated, for example, that any desired reductions in flatfish mortality rates will require a reduction in capacity, equally applied to those nations that exploit the flatfish fishery in the North Sea due to the concept of relative stability.

The aim of this article is to apply DEA to analyse the multi-national capacity dimension of the North Sea flatfish fishery, based on aggregated input/output data for 1998. The multi-national aspect of this article is important, since no other analyses of this nature have been carried out for European fisheries. The article applies a methodology developed by Dervaux, Kerstens, and Leleu (2000), based on the Johansen (1972) short-run sector model, and combines capacity at the individual firm level and at the industry level. This helps to evaluate overall capacity reductions through reallocation of inputs at the industry level. Other papers that have analysed industry reallocation include Färe *et al.* (2000) and Kerstens, Vestergaard, and Squires (2004).

This article firstly introduces the North Sea fisheries, where fish stocks, fleet components, and management regulations are discussed. The DEA capacity analysis approach is reviewed and the two-phase analysis is outlined: the firm model phase and industry allocation phase. Model specifications and data are described, and results of the allocation analysis are presented and discussed. An impact analysis for various quota reduction scenarios is also undertaken, directly linked to current EU management policies, as well as imposing equal capacity reduction across all nations.[2]

Concluding remarks are finally drawn.

North Sea Fisheries

The North Sea (ICES Division IV) is a multi-species, multi-gear fishery of great commercial importance in many European countries (figure 1). Historically, more than half of all total allowable catches (TACs) of commercially targeted species in EU waters is from the North Sea, with most of the commercial activity undertaken by fishermen from the United Kingdom, Denmark, the Netherlands, France, Germany, Belgium, and Norway. Fish landed for human consumption include pelagic species such as herring, mackerel, and horse mackerel. Demersal species include cod, haddock, whiting and saithe, and benthic flatfish species such as sole and plaice. There are also several commercially important molluscs and crustaceans.

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[2] In line with the ‘relative stability’ principle of the EU that requires the current balance between member states be maintained, based on historical landings of member states.

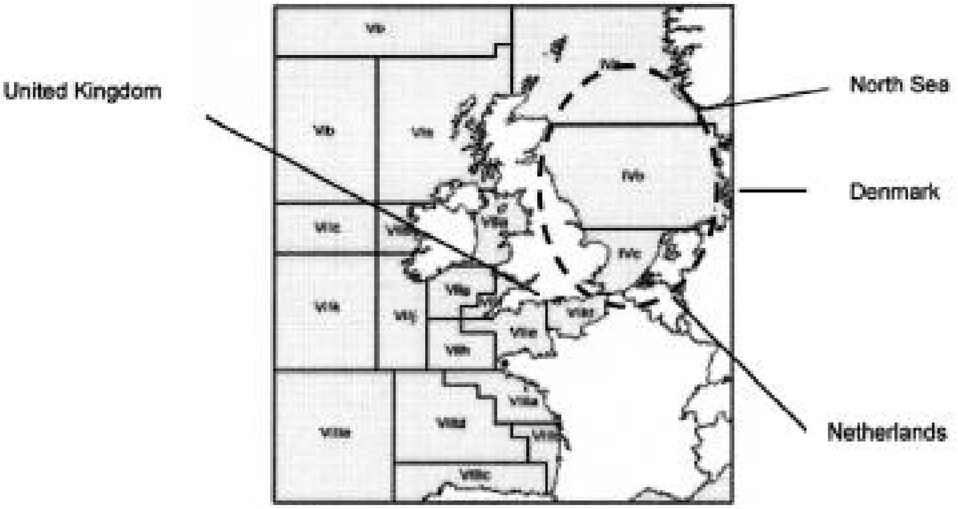

Figure 1. North Sea Fishing Areas, ICES Divisions IVabc
Source: Adapted from CEFAS (2002).

Landings from the industrial fishery mainly consist of sandeel, Norway pout, and sprat.

North Sea TACs for all species are assigned on the basis of recent historic catch data, and the fishery is managed according to the guidelines of the CFP, through *inter alia* vessel and gear restrictions, effort controls, area closures, and minimum landing sizes. The national management measures with regard to the implementation of the quota differ both between species and countries, however. The fleets exploiting the North Sea fishery have also been impacted by capacity and effort restrictions under the MAGP of the EU. Norway has, in this regard, cooperated with the EU by defining suitable management measures for their industry.

Flatfish Fishery

The flatfish fishery of the North Sea is of significant commercial importance. Sole and plaice dominate the fishery, and are usually targeted with a bycatch of demersal species. Other flatfish species targeted or landed as bycatch in the fishery include brill, dab, flounder, lemon sole, megrim, and turbot. The flatfish stocks have deteriorated over the last 10 years; the major reasons being continuously high exploitation, fluctuating recruitment, and extensive discarding (ICES 2002).

Sole *(Solea solea)* is mainly taken by beam trawlers in a mixed fishery with plaice using 80 mm mesh in the southern part of the North Sea. There is also a directed gill net sole fishery around the Danish coast, predominantly in the second quarter of the year (CEFAS 2002). According to the International Council for the Exploration of the Sea (ICES), the stock is currently being harvested outside safe biological limits. The spawning stock biomass reached a historic low in 1998[3] at 25,000 tonnes,

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[3] 1998 is also the year chosen for this analysis, given the availability of data. It is thus conceivable that the poor catches in 1998 may adversely impact the capacity utilisation scores of fleets.

but was followed by a slight recovery as the result of a strong year class in 1996. Fishing mortality has risen gradually since 1960, mainly due to the development of the beam trawl fishery. The reported nominal catches and estimated landings of North Sea sole during 1994–2001 can be viewed in table 1, below.

Plaice *(Pleuronectus platessa)* in the North Sea is mainly taken by beam trawls in a mixed fishery with sole using 80 mm mesh or as a directed fishery using nets above 100 mm. The remainder is taken in a directed fishery with seines and gill nets and a mixed otter trawl fishery. A protected nursery area in the coastal waters of the eastern North Sea, the Plaice Box, was established in 1989 in order to reduce the amount of discarding of undersized fish. Since 1995 the area has been closed for beam trawlers >300 HP. In 1999, the EU and Norway agreed to implement a long-term management plan for plaice (CEFAS 2002).

The stock is also considered by ICES to be outside safe biological limits. The spawning stock biomass declined from 1989 to 1997, when it reached its historical minimum of 180,000 tonnes, and similar to sole, was followed by a recovery as a result of a strong year class in 1996. Fishing mortality increased from the 1960s to the 1990s, again mainly through the expansion of the beam trawl fleets. The reported nominal landings of North Sea plaice during 1994–2001 can be viewed in table 2, below.

The TACs for sole and plaice in 2003 were 15,850 tonnes and 73,250 tonnes, respectively (DG Fisheries 2003). The flatfish quota allocations for 2003 in the North Sea are shown in figure 2, below.

Table 1

Reported Nominal Catches and Estimated Landings of North Sea Sole (tonnes)

Country	1994	1996	1998	2001
Denmark	1,804	1,018	520	773
Netherlands	22,874	15,344	15,198	11,547
United Kingdom	1,137	848	549	596
Other[1]	5.476	3,989	3,472	3,512
Unallocated landings[2]	1,711	1,532	1,129	3,421
Total landings estimate	33,002	22,651	20,868	19,849
TAC	32,000	23,000	19,100	19,000

Source: ICES (2002).

[1] Includes Belgium, Germany, France, and other countries.

[2] Landings cannot be specified for a specific country.

Table 2

Reported Nominal Landings of North Sea Plaice (tonnes) to ICES

Country	1994	1996	1998	2001
Denmark	17,056	11,776	10,087	13,797
Netherlands	50,289	35,419	30,541	33,290
United Kingdom	27,749	20,992	19,915	19,111
Other[1]	14,585	11,846	9,861	13,466
Unallocated landings[2]	713	1,640	1,130	2,183
Total landings estimate	110,392	81,673	71,534	81,847
TAC	165,000	81,000	87,000	78,000

Source: ICES (2002).

[1] Includes Belgium, Germany, France, Norway, and Sweden.

[2] Landings cannot be specified for a specific country.

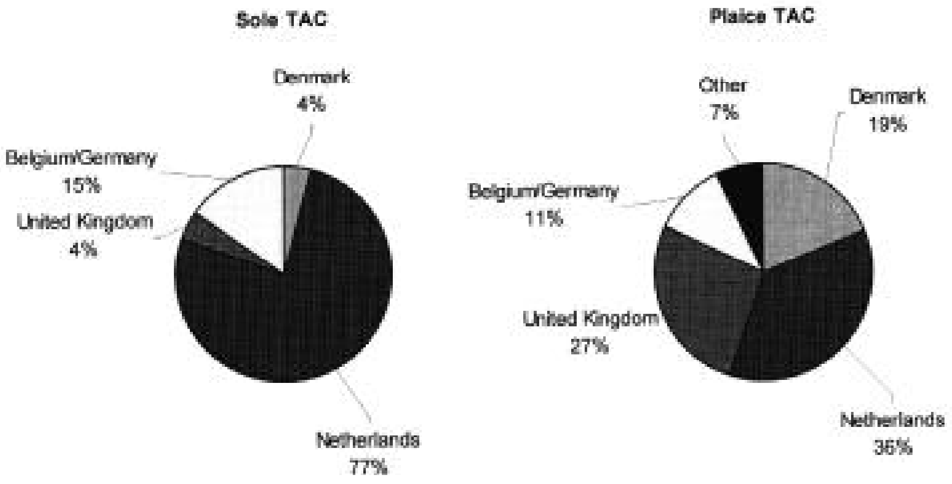

Figure 2. Allocation of North Sea Flatfish TACs in 2003
Source: DG Fisheries (2003).

Flatfish Fleet

Denmark, the Netherlands, and the United Kingdom are among the countries that dominate the North Sea flatfish fishery. These national fleets serve as the basis for the analysis presented in this article. Fleet components from Belgium, Germany, and Norway are also present and play an important role in the fishery, but are not included in the analysis due to the lack of available vessel-level data.

The major components of the Danish fleet are trawlers, gill netters, and Danish seiners. Gill netters and Danish seiners primarily target sole, plaice, other flatfish, and cod. Trawlers have a varied product mix that includes flatfish, codfish, herring, mackerel, crustaceans, and industrial species, with the species targeted largely being determined by vessel size and access to coastal and international fishing areas. The Danish fleet represented about 15% of total plaice landings in the North Sea in 1998 (table 2), the year chosen for the capacity analysis outlined in this article.

The cutter fleet of the Netherlands mainly targets flatfish, shrimp, cod, and whiting in the North Sea and coastal waters. The fleet is the biggest producer of flatfish in Europe, predominantly caught by beam trawlers, which cover nearly 90% of all kW-days spent in the fishery and account for more than 80% of revenues in the fishery (FOI 2001; Vestergaard *et al.* 2002). In addition to EU regulation, the Dutch beam trawl fishery is managed by Individual Transferable Quotas (ITQs), with vessels pooling their ITQs within producer organisation management groups. Beam trawlers also have small bycatch quotas for cod and whiting. The Dutch fleet was responsible for almost three-quarters of total North Sea sole landings in 1998, and over 40% of total plaice landings (tables 1 and 2). Participating United Kingdom vessels are mainly demersal beam trawlers, with the fleet being responsible for almost 30% of total North Sea plaice landings in 1998.

DEA Capacity Analysis

Based on the traditional Farrell (1957) approach to technical efficiency (TE) analysis, Charnes, Cooper, and Rhodes (1978) and Banker, Charnes, and Cooper (1984) were the first to apply DEA to multiple input, multiple output processes. Since then, DEA has been used to assess efficiency in many different areas, ranging from the fishing industry to the public sector. The DEA technique allows the assessment of efficiency of an existing technology relative to a 'best practice' frontier technology, formed as a non-parametric, piece-wise linear combination of observed 'best practice' activities (Coelli, Rao, and Battese 1999). The frontier envelops the observations that are not 'best practice'; *i.e.*, not operating at full technical efficiency, and allows for the calculation of technical efficiency scores for each observation based on their radial distance from the frontier. In the output-oriented approach, these scores indicate how close the actual output is to the maximal output that could be produced given the observed input levels (fixed as well as variable).

The TE approach can be extended to the analysis of fishing capacity utilisation. Fishing capacity is here defined as a short-run concept in line with Johansen (1968), where capacity is "the level of output of fish over a period of time that a given fishing fleet could expect to catch if variable inputs are utilised under normal operating conditions, for a given resource condition, state of technology and other constraints" (Walden, Kirkley, and Kitts 2003). Färe, Grosskopf, and Valdmanis (1989) show how DEA can be applied to estimate the Johansen concept of full capacity. The approach is, in essence, the same as the Farrell TE approach, but where variable inputs are allowed to vary freely.

The Johansen (1972) short-run sector model allows for the analysis of the industry structure, following from the Johansen (1968) capacity measure at the firm level. This helps to determine the optimal level of firm capacities and minimises the levels of fixed inputs whilst maintaining the current output. Dervaux, Kerstens, and Leleu (2000) later refined this approach by accommodating multiple outputs and adopting the DEA frontier-based method.

This article adopts a physical nonparametric approach to estimating capacity, as discussed above. It is nevertheless noted that economic approaches also exist, the dual approaches. In this regard, there are three basic ways of defining a cost-based notion of capacity; namely, (*i*) the minimum of the short-run variable cost function (Morrison 1985; Nelson 1989), (*ii*) the minimum of the long-run total cost function (Cassels 1937; Klein 1960), and (*iii*) a tangency definition based on the intersection point of short- and long-run expansion paths (Segerson and Squires 1990, among others). Capacity notions have also been defined based on the revenue function (Segerson and Squires 1995) and on the profit function (Squires 1987). Furthermore, Prior (2003) applies a cost-minimisation approach to DEA, where capacity utilisation is defined in terms of a ratio of minimum long-run total costs to minimum short-run total costs (*i.e.*, minimum variable costs plus fixed costs). The DEA used here is nonparametric in contrast to the parametric approach that requires estimation of cost functions by means of econometrics.

Although a dual economic approach to estimating capacity is intuitively appealing, it requires detailed vessel-level cost data for the vector inputs. Given the scope of this article, in which I attempt to contrast multi-national fleet technologies, such data are not available for all the national fleets concerned. Hence, this article opts for the physical approach of estimating capacity.

Firm Model

The estimation of capacity output at the firm level can be obtained by solving a linear programming model (Vestergaard *et al.* 2002; Vestergaard, Squires, and Kirkley 2003).[4]

The model designates the vector of outputs by y and the vector of inputs by x, with M outputs, F fixed inputs, V variable inputs, and J firms. Capacity output and the optimum input utilisation values require the solution of the following problem for each firm k.

$$\underset{\theta,z,\lambda}{Max}\ \theta_1^k \tag{1}$$

subject to:

$$\sum_{j=1}^{J} z_j y_{jm} \geq \theta_1^k y_{km},\ m = 1,\ldots,M \tag{2}$$

$$\sum_{j=1}^{J} z_j x_{jf} \leq x_{kf},\ f = 1,\ldots,F \tag{3}$$

$$\sum_{j=1}^{J} z_j x_{jv} = \lambda_{kv} x_{kv},\ v = 1,\ldots, V \tag{4}$$

$$\sum_{j=1}^{J} z_j = 1 \tag{5}$$

$$z_j, \lambda_{jv} \geq 0, \quad j, v, \tag{6}$$

where $\theta_1{}^k$ is the capacity score greater than or equal to 1; *i.e.*, the amount by which the output must be increased to reach full capacity utilisation; y_{km} is the amount of output, m, produced by firm k; x_{kf} is the quantity of fixed input used by firm k; x_{kv} is the quantity of variable input used by firm k; z_j is the activity vector for firm j; and λ_{kv} is the variable input utilisation rate. The variable input utilisation rate is the ratio of optimal use of the v'th variable input to observed use, ensuring full capacity for firm k. Equation (2) represents one constraint for each output, while equation (3) constrains the set of fixed inputs. Equation (4) allows the variable inputs to reach their optimal levels, and equation (5) imposes variable returns to scale. An exclusion of equation (5) would impose constant returns to scale. Equation (6) is the non-negativity condition on the z and λ variables.

The model is run once for each dataset, producing a capacity measure ($\theta_1{}^k$) for each vessel, k, in the dataset. This measure indicates the possible radial expansion of outputs given the inputs of each vessel. For example, a score of 1.20 indicates that a

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[4] The DEA models are written and executed using the General Algebraic Modelling System (GAMS) software (Brooke *et al.* 1998).

vessel should be able to increase each of its outputs by 20%. Capacity output for each firm *k* can then be determined by multiplying the capacity measure (θ_1^k) by observed output vector (y_{km}). It should be noted that the capacity output calculated here includes potential technical inefficiencies.[5]

The reason for running separate firm models for each country, rather than incorporating all the dataset observations in one model, is important. We acknowledge that although all the firms are fishing the same stocks and face similar resource conditions, the different countries face different technologies (*e.g.*, gear technologies) and regulation measures, and hence warrant separate analysis.

Industry Allocation Model

From the firm model described above, we can construct the individual frontiers of the fleets participating in a fishery. These individual frontiers (*e.g.*, frontier technologies 1, 2, and 3) can then be compared to each other in aggregate (figure 3) and used to assess the overcapacity of each fleet, and thus the corresponding fleet reductions. This is especially helpful if, as in the North Sea flatfish fishery, we have different country fleets that will have very different technologies in a standard firm model analysis.

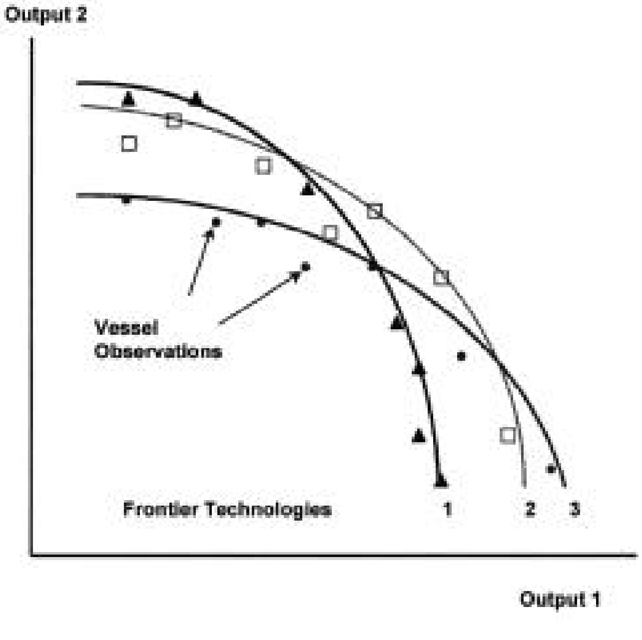

Figure 3. Stylised Representation of the Industry Approach

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[5] Färe *et al.* (1994) offer an 'unbiased' measure of capacity output by assuming that the currently observed output is produced in a technically efficient manner, helping to remove the technical inefficiency increment from the capacity output scores.

In order to test their technologies against each other, we first run the individual firm models described above for each fleet. From these models the optimal activity vector, z^{*k}, is provided for each firm k. This allows the computation of output at full capacity and the optimal use of fixed and variable inputs as follows:

$$\text{Outputs:}\quad y^*_{km} = \sum_{j=1}^{J} z_j^{*k} y_{jm} \tag{7}$$

$$\text{Inputs:}\quad x^*_{kf} = \sum_{j=1}^{J} z_j^{*k} x_{jf} \quad x^*_{kv} = \sum_{j=1}^{J} z_j^{*k} x_{jv}. \tag{8}$$

The outputs are increased, the fixed inputs decreased if they have excess slacks (but not by much according to the firm model), and the variable inputs either increase or decrease depending on which operation makes the vessel operate at full capacity, thus projecting each non-efficient vessel on the frontier as a linear combination of one or more of the originally efficient vessels. These optimal frontier figures are then used as parameters in a short-run industry model (Dervaux, Kerstens, and Leleu 2000; Vestergaard *et al.* 2002). Based on the methodology developed by Dervaux, Kerstens, and Leleu (2000), an industry model problem can be described as follows:[6]

$$\underset{\theta, z, X_v}{Min}\,\theta \tag{9}$$

subject to:

$$\sum_{j=1}^{P} z_j y^*_{jm} \geq Y_m,\, m = 1,\ldots,M \tag{10}$$

$$\sum_{j=1}^{P} z_j x^*_{jf} \leq \theta X_f,\, f = 1,..., F \tag{11}$$

$$-X_v + \sum_{j=1}^{P} z_j x^*_{jv} \leq 0,\, v = 1,..., V \tag{12}$$

$$0 \leq z_j \leq 1, \theta \geq 0, \quad j, \tag{13}$$

where Y_m is the m'th industry output level, X_v is the industry's use of variable inputs, X_f is the aggregate fixed inputs available to the industry, and P is the total number of observations in all countries. The activity vector, z_j, is constrained so current capacities of each vessel cannot be exceeded, equation (13).[7]

It is noted that the constraint imposed in equation (12) relating to the input use is trivial (since the final input use cannot exceed current input use given that z_j is

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[6] Other approaches to industry capacity include Färe *et al.* (1992) and Färe *et al.* (2000).

[7] In contrast to the firm model where z_j represents the activity vector of each firm.

less than or equal to 1), but is maintained for completeness. The solution gives the combination of firms that can produce the same or more total outputs with less or the same amount of fixed inputs in aggregate, and allows for the identification of surplus vessels in an optimal fleet structure.

Traditionally the TAC of the species fished should serve as a reference level, Y, to possible production in the North Sea flatfish fishery (equation 10). However, since not all vessels in the fishery are included in the analysis, the reference level applied here is the total observed catches of the vessels in the dataset.

The model is highly flexible and can incorporate restrictions on equal input reductions across fleets and nations, in line with current capacity policies in EU fisheries. Similarly, declines in stock biomass and quotas can be easily simulated by the model. Such impacts in industry reallocation are analysed in this article.

Data

Given the structure of the flatfish fishery in the North Sea and data availability, the fleet data applied to the analysis are comprised of annual 1998 catch data from North Sea vessels of Denmark, the Netherlands, and the United Kingdom.[8]

Vessels are only included in the dataset if (*i*) at least 30% of their total catch is composed of flatfish and (*ii*) they spent at least 50 days in the North Sea in 1998. The fixed inputs registered for each vessel are gross tonnage (GT) and engine power (kW), and variable inputs are days at sea (DAS). The outputs are registered in terms of aggregated catches of each vessel in the North Sea in 1998, classified as sole, plaice, other flatfish, and other fish, measured in unweighted kilograms.[9]

The vessel and catch characteristics of the fleets are depicted in tables 3 and 4, below.

As viewed in table 4, a fair coverage of the North Sea fishery is observed, with the model coverage ranging from 31% to 66% of total national catches in the sole and plaice fisheries. Average vessel characteristics and associated catches of the analysed fleets are portrayed in tables 5 and 6, below. It is clearly shown that Dutch vessels are generally bigger than their counterparts. Danish vessels, on the other hand, are markedly smaller and spend fewer fishing days in the North Sea. Catches of sole and other flatfish are dominated by the Netherlands, whereas the United Kingdom vessels catch mostly plaice.

Table 3

Fleet Characteristics, 1998

Country	Vessels	Total GT	Total kW	Total DAS	Gear Types
Denmark	110	6,313	18,263	13,632	28 TR, 45 DS, 37 GN*
Netherlands	62	18,661	88,358	11,981	Beam Trawl
United Kingdom	36	9,053	33,983	7,183	Beam Trawl

Note: *Trawl (TR), Danish Seine (DS), Gill Net (GN).

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[8] Available vessel-level data is for 1998 only.

[9] In contrast to revenue-weighted catches that are sometimes used to distinguish the relative importance of species in value terms.

Table 4

Catch (tonnes) per Fleet, 1998

Country	Sole	% NS Sole Landings*	Plaice	% NS Plaice Landings*	Other Flatfish	Other Fish	Total
Denmark	199	38%	6,648	66%	1,298	5,752	13,897
Netherlands	4,966	33%	9,601	31%	2,616	5,436	22,619
United Kingdom	251	46%	8,829	44%	553	2,243	11,876

Note: *Represents the % covered by the analysed vessels as a proportion of the observed national total sole and plaice catches in the North Sea in 1998.

Table 5

Vessel Characteristics, 1998

Country	Vessels	Average GT	Average kW	Average DAS
Denmark	110	57	166	124
Netherlands	62	301	1,425	193
United Kingdom	36	251	944	200

Table 6

Average Catch (kg) per Vessel, 1998

Country	Sole	Plaice	Other Flatfish	Other Fish	Total
Denmark	1,809	60,436	11,800	52,290	126,335
Netherlands	80,097	154,855	42,194	87,677	364,823
United Kingdom	6,972	245,250	15,361	62,306	329,889

Results

Capacity of National Fleets—Firm Level

The first stage of the analysis looks at the capacity output scores of the national fleets in isolation. The capacity output scores indicate the desired average expansion of the output vectors of vessels in each fleet to reach full capacity (figure 4 and table 7). For example, the average Dutch vessel should increase its output by 15% to operate at full capacity. The average UK and Danish vessels should increase their outputs by 68% and 72%, respectively.

Capacity of the North Sea Fleet—Industry Model

Following the projection of vessels [equations (7)-(8)] onto their respective national capacity frontiers and the industry minimisation problem [equations (9)-(13)], the resulting reduction θ of the fixed inputs is 0.768 or 23%. That is, only 77% of cur-

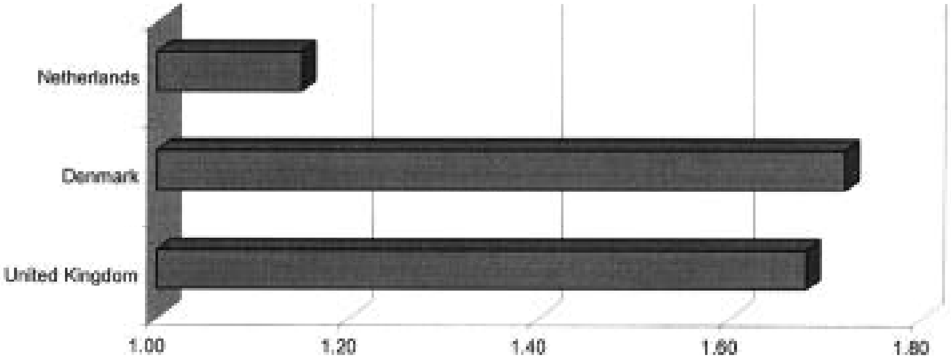

Figure 4. Average Vessel Capacity Output

Table 7
Average Vessel Capacity Output

Country	Vessels	Avg. Capacity Output	St. Dev.
Denmark	110	1.72	1.35
Netherlands	62	1.15	0.21
United Kingdom	36	1.68	1.53

rent fixed inputs of the total North Sea fleet are required to produce the current level of output. Table 8 and figure 5 help to illustrate the proportions by which fleet and industry inputs should be specifically reduced, allowing a reallocation of production. The results also help to identify the particular vessels that are deemed ‘surplus’ and should exit the fleet. Here, a surplus vessel is not necessarily an inefficient or unprofitable vessel, but is deemed surplus by the model (being assigned an activity vector z_j equal to 0), as the particular vessel is unnecessary to produce the outputs from the available mixes of industry inputs. The ‘optimal’ vessels are those that remain in the optimal full-capacity North Sea fleet following reallocation.

It is noted that the surplus vessels do not necessarily correspond to reductions in kW and GT. This is an explicit component of the industry model. Some vessels that remain may be assigned an activity contraction vector that is less than 1 but greater than 0, as a result of the minimisation problem in equations (9)-(13). Results show, however, that only four vessels remain in the fleet with activity contraction vectors, and hence the impact on the overall fixed input reductions is minor.

The results indicate that the United Kingdom fleet should reduce its fixed inputs by some 40%. The Danish fleet is less impacted, with a required reduction of 23%, with surplus vessels clearly being larger than their optimal counterparts (*i.e.*, the 8% reduction in surplus vessels is responsible for 23% of fixed GT and kW inputs). Further, an optimal (full capacity) North Sea fleet needs to see reductions of Dutch inputs on the order of 15–18%.

As gathered from the firm model described above, Dutch vessels are, on aver-

Table 8
Reduction of Fixed Industry Inputs

	Vessels				GT		kW	
Country	Original	Optimal	Surplus	% Red.	Reduction	%	Reduction	%
Denmark	110	101	9	8	1,424	23	4,296	23
Netherlands	62	54	8	13	2,858	15	15,531	18
United Kingdom	36	20	16	44	3,626	40	12,852	38
North Sea fleet	208	175*	33	16	7,908	23	32,679	23

Note: *Includes four vessels with activity vectors less than 1 but greater than 0 (three Dutch vessels, one UK vessel).

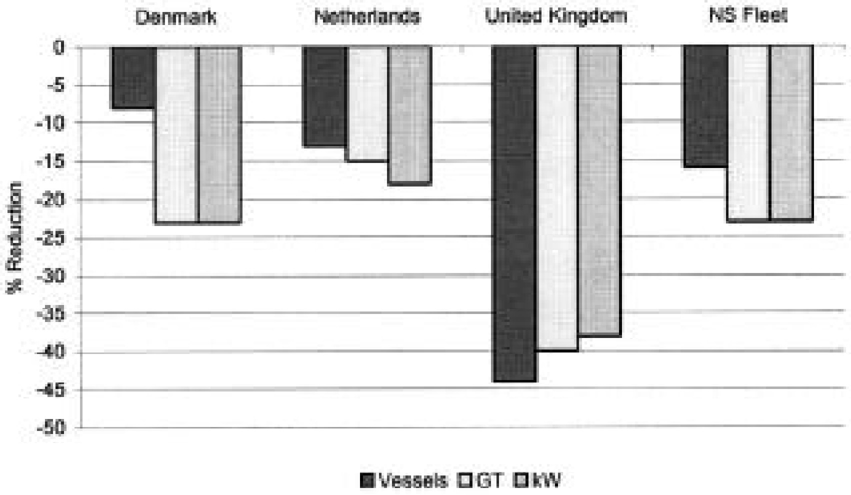

Figure 5. Reduction of Fixed Industry Inputs

age, closer to operating at full capacity (table 7 and figure 4). It is intuitively pleasing to see that these vessels require smaller cutbacks in the industry model, although it is noted that low capacity output scores at the firm stage do not automatically lead to low fleet reductions at the industry level, since all vessels are projected onto their respective capacity frontiers. One can nevertheless begin to consider plausible reasons for the Dutch fleet results at the industry stage. It is conceivable that the ITQ management system governing the Dutch beam trawlers has led to an improved, more ‘flatfish-oriented’ frontier technology.

Surplus and Optimal Vessels

In addition to identifying the extent of input reductions and the nationality of vessels most impacted, it is beneficial to examine the originally observed catch and input characteristics of the surplus and remaining optimal vessels.[10]

It is interesting to examine the specific differences in sole and plaice catch compositions of surplus and optimal vessels, based on their originally observed catches (figures 6 and 7). Results indicate that the optimal structure of the North Sea fleet would favour the removal of Danish and Dutch vessels that have relatively low sole catch rates. In the case of plaice, the surplus vessels of the United Kingdom, in particular, have much lower plaice catch rates than the optimal vessels.

In terms of average input and output characteristics, a further examination of original, surplus, and optimal vessels can be considered for the North Sea fleet (table 9 and figure 8).

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[10] The original input/output characteristics are those observed before vessels are projected onto their capacity frontiers.

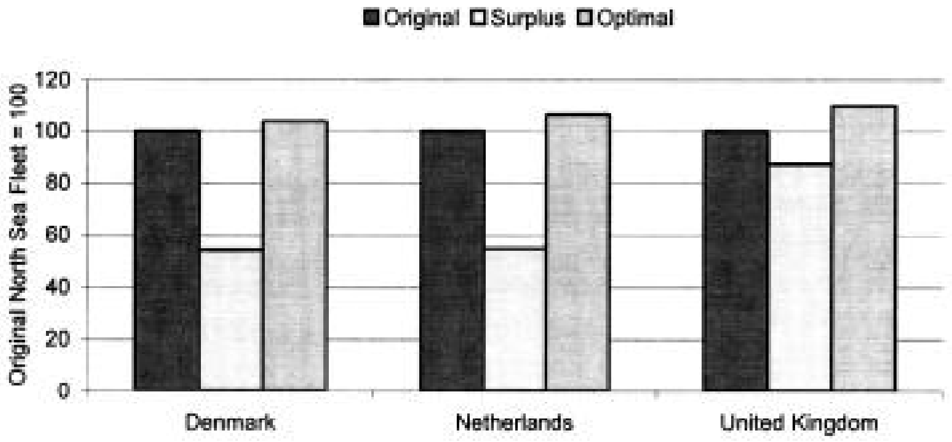

Figure 6. Average Sole Catches of National Vessels

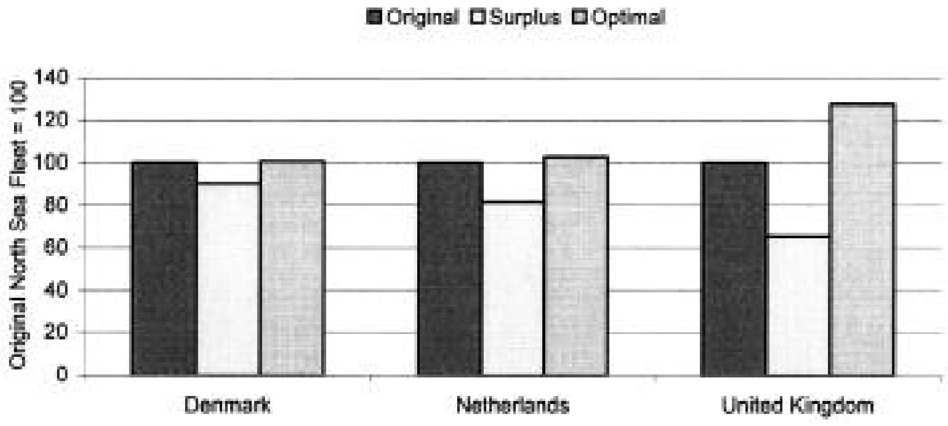

Figure 7. Average Plaice Catches of National Vessels

The benefits of industry reallocation are two-fold (figure 8). Firstly, the average size of vessels in terms of GT and kW is reduced in the optimal setup, resulting in increased catches per input usage. Secondly, following the removal of the surplus vessels from the original fleet setup, a reallocation of catches among the remaining optimal vessels will result.[11] The total catch of each species is the same, so the new, optimal fleet with a lower number of vessels will ultimately lead to higher catches per vessel. It can be shown that the average catch per vessel of each species increases by 19% as a result of catch reallocation among the vessels in the optimal North Sea fleet, as portrayed in figure 8.

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[11] Through, for example, vessel decommissioning or transferral to activities other than fishing.

Table 9
Average Vessel Indicators of Surplus Vessels

Country	Vessels	Catch (*t*)	GT	kW	DAS
Denmark	9	132	113	282	128
Netherlands	8	304	263	1,318	182
United Kingdom	16	219	207	699	168
North Sea fleet	33	216	195	735	160

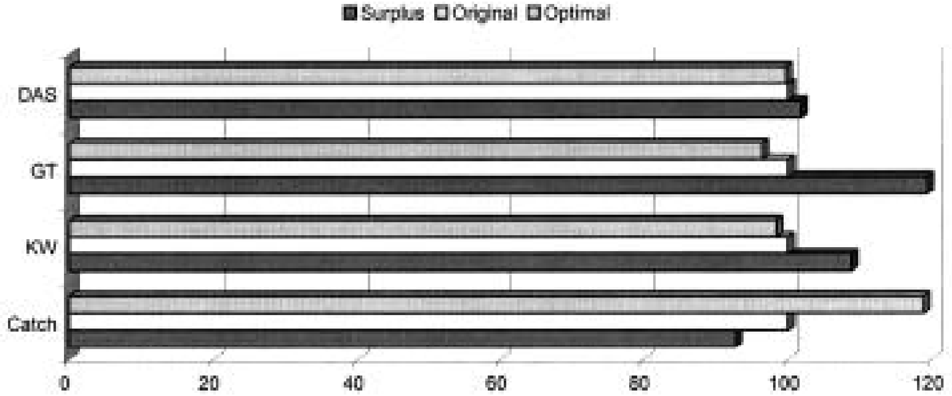

Figure 8. Average Vessel Indicators of the North Sea Fleet

Impact of TAC Reductions

The impact of reductions in TACs on the reallocation of fixed inputs can be easily incorporated into the industry model, helping to identify the vessels and nations most affected by plausible changes in quota restrictions.[12]

Based on recorded sole and plaice TACs for 2003, the impact of TAC reductions in the flatfish fishery can be examined. Here, TACs have decreased by 16% and 17%, for plaice and sole, respectively, since 1998. For illustrative purposes, reductions in other flatfish and other fish quotas can be similarly analysed (an arbitrary reduction of 15% of these species groups has been applied in the model). Various scenarios can be applied to the industry allocation model that restrict the total output of the various species groups. For example, a TAC reduction in sole of 17% can be simulated in the model by restricting overall catches of sole to 83% of the observed 1998 catches. Table 10, below, illustrates the impact on the North Sea fleet configuration under six short-term scenarios.

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[12] An increase in quota can also be simulated, although it is not attempted in this article.

A constraint of this analysis is, however, that one can expect a drop in days at sea in the short run following a reduction in quotas, which is not incorporated into the model. This decline is not expected to be linear, given variable port proximity, species behaviour, *etc.*, and hence complicates the impact a quota reduction may have. Despite this, for reasons of simplicity it is assumed that all vessels in the North Sea will be equally impacted by quota reductions and will reduce their days at sea in a similar linear fashion. In the long run, reductions in TACs will imply reductions in both variable and fixed inputs.

Table 10 depicts the reduction in vessel number under the various scenarios.[13] When compared to the base case, it is fairly visible that the Dutch fleet is substantially impacted by reductions in the sole TAC and total TAC. Danish vessels tend to improve their status in the overall North Sea fleet following reductions in sole and plaice TACs, whereas reductions in other flatfish TACs negatively impact the Danish fleet. The United Kingdom fleet sees further reductions in the fleet following a cut in the plaice TAC as well as the total TAC.

Since these reductions in quota are not only plausible, but also very much a management reality, it can be expected that this kind of impact analysis will provide fisheries managers with important information on possible effects of TAC reductions on different fleets. Conversely, and perhaps more relevant in the current management setting, this type of analysis can supply managers with information on required fleet reductions if stock conditions improve.[14]

It needs noting, however, that the undertaken analysis refers to a rather static, short-term situation, where technologies cannot be altered, and may only provide a 'worst-case' snapshot scenario. It is likely that if quotas change considerably, then a fleet will eventually react to the new status of stocks and economics and adapt their technologies accordingly.

Table 10
Vessel Reductions (%) under TAC Scenarios

	Reduction	Denmark	Netherlands	United Kingdom
Base case	None	8	13	44
Scenario 1	Sole: 17%	2	26	39
Scenario 2	Plaice: 16%	3	10	75
Scenario 3	Scenarios 1+2	2	16	67
Scenario 4	Other flatfish: 15%	16	13	42
Scenario 5	Other fish: 15%	8	13	44
Scenario 6	Total: 15%	10	24	58

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[13] As previously, the magnitude of GT and kW reductions will differ from those of vessel reductions. Nevertheless, the table depicts the general change in input reductions of the various fleets under the various scenarios.

[14] Current EU fisheries policy initiatives are dominated by recovery plans of certain fish stocks (*e.g.,* North Sea cod).

Impact of Equal Fixed Input Reduction

In the industry problem given in equations (9)-(13), an overall reduction of the total capacity of the North Sea fleet; *i.e.*, of the capacity summed over all countries, is evaluated. As shown previously, the individual capacity reductions of the three country fleets will be different when using this method. The industry problem can, however, be reformulated to claim equal capacity reductions for each country's fleet. Such a restriction may possibly result in lower overall reductions in fixed inputs and should be seen as a cost of implementing such restrictions, which is intrinsically based on the relative stability (status quo) principle that underpins EU fisheries policy and capacity management.[15]

Equal capacity reductions for each country's fleet are imposed in the industry problem (9)-(13) by reformulating to:

$$\underset{\theta, z, X_v}{Min}\ \theta \tag{9a}$$

subject to:

$$\sum_{c=1}^{C} \sum_{j=1}^{J_c} z_{cj} y^{*}_{cjm} \geq Y_m,\ m = 1,..,M \tag{10a}$$

$$\sum_{c=1}^{C} \sum_{j=1}^{J_c} z_{cj} x^{*}_{cjf} \leq \theta X_{cf},\ c = 1,.., C,\ f = 1,..,F \tag{11a}$$

$$-X_v + \sum_{c=1}^{C} \sum_{j=1}^{J_c} z_{cj} x^{*}_{cjv} \leq 0,\ v = 1,..,V \tag{12a}$$

$$0 \leq z_{cj} \leq 1, \theta \geq 0, \quad j, \tag{13a}$$

where C is the number of countries, and J_c is the number of firms in country c. This problem results in an equal capacity reduction of $\theta = 0.806$ for each country, compared to 0.768 for the total fleet in the base case (a difference of 3.8%). This entails that an even reduction of fixed inputs of at least 19% is needed for each individual fleet. It can thus be argued that on the basis of these analytical results, imposing equal fixed input reduction does impact the overall reduction; *i.e.*, the overall cost is noticeable. The reallocation of fixed input reductions among nations, however, is impacted, and the breakdown can be viewed in table 11 and figure 9.

As observed above, equal reductions of 19–20% in terms of GT and kW are now required for all fleets. Compared to the base case, the Dutch fleet is required to make more cutbacks than before. This allows many more United Kingdom vessels (fixed inputs) to remain in the fishery.

Although EU policy supports relative stability of fishing nations, based on historical landings of member states, capacity reduction programmes have not attempted equal capacity reduction for all nations. Since the main objective of capacity reduction has been to reduce fishing pressure on certain overexploited fish stocks, equal overall reductions for all fleets have not been sought. The results show that imposing equal fixed input reductions will lead to a smaller overall reduction of the North Sea fleet and the overall composition of national fleets may be rather different.

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[15] A review of the EU fisheries policy and fleet capacity reduction programme can be found in Lindebo, Frost, and Løkkegaard (2002).

Table 11
Impact of Equal Fixed Input Reduction

	Vessels				GT		KW	
Country	Original	Optimal	Reduction	%	Reduction	%	Reduction	%
Denmark	110	100	10	9	1,227	19	3,716	20
Netherlands	62	51	11	18	3,626	19	18,260	20
United Kingdom	36	32	4	11	1,759	19	6,603	20
North Sea fleet	208	183	25	12	6,612	19	28,579	20

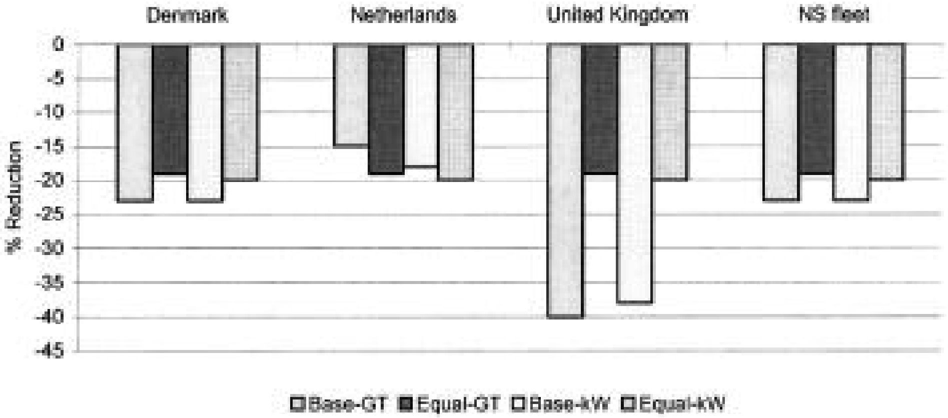

Figure 9. Impact of Equal Fixed Input Reduction

Concluding Remarks

The main motivation of this article was to analyse industrial capacity in a multi-national European fishery, which has not been attempted in fisheries economics research to date. The analysis serves as a good example of how industry reallocation theory can be directly incorporated into capacity analysis of a shared fishery. It is shown how the results can be translated into useful fisheries management insight, in terms of short-term industry capacity reduction for various scenarios. However, the results stated herein should be considered with caution, given the aged, incomplete data (*i.e.*, not all vessels and national fleets are featured in the analysis), the dynamic changes in fish stocks, lack of economic considerations, and the inclusion of technical inefficiencies. Furthermore, if this analysis is to provide authorities with a complete planning model for the North Sea flatfish fishery, we also need to include the other major players, such as Norway, Germany, and Belgium.

The article shows that the North Sea fleet, composed of Danish, Dutch, and United Kingdom vessels, requires 23% reductions in fixed inputs to reach full capacity. The United Kingdom fleet requires the largest cutbacks of between 38–40%, whereas the Danish and Dutch fleets need reductions of around 23% and 15–18%, respectively. The analysis has further shed light on the catch and input characteristics of surplus vessels following industry reallocation and shows variable outcomes for the different fleets when catch rates of various species groups are examined. Following catch reallocation, after the removal of surplus vessels, overall catches per remaining optimal vessels can expect to increase by 19%, on average. It would nevertheless be interesting to apply economic capacity concepts to this analysis (*i.e.*, incorporating costs and revenues), as this will likely capture different estimations of fixed input reductions for the various national fleets and the overall North Sea fleet.

For further management insight, an impact analysis of quota (TAC) reductions was undertaken. This can provide useful information for managers wishing to improve stock conditions and help to identify the extent of fixed input reductions that is required to obtain such improvements by means of quota reductions. Since future quota reductions are highly plausible, this kind of impact analysis is of significant importance. In line with the relative stability principle, a restriction on fixed input reductions was simulated, resulting in 3.8% fewer fixed inputs being removed from the fleet. A further impact is the reallocation of fixed input reductions among the three countries, as expected, leading to more Dutch vessels being affected than in the base case. These results are further evidence of the strength and flexibility of the industry model as an analytical tool for management initiatives. Policy decisions can readily be incorporated as constraints on inputs and outputs and can be extended to proposals for banning specific gear types in certain fisheries or decisions to enforce stricter mesh size restrictions to lower fishing mortality rates of overexploited fish stocks.

Of final note are the possible ramifications for fisheries management. Although this article has helped to illustrate industry reallocation scenarios in the North Sea flatfish fishery, what meaning will this have for future management initiatives? It may be argued that even if all possible dynamic dimensions are accounted for in this form of analysis, to allow for a more long-term approach, actually imposing the favoured reallocation of industry inputs is still confronted with the limitations dictated by relative stability. It is expected that any management advice based on analytical results of this nature may face considerable difficulties of unilateral acceptance, regardless of what fisheries managers may decide is the most optimal and efficient fleet configuration.

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