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Output Substitution in a Regulated Fishery[1]

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Abstract

Production condition and behavioural reactions have traditionally been modelled in unregulated industries. The paper examines the impact that output regulation will have in an industry of multiple outputs where production of regulated and unregulated outputs are combined. The industry's respond to output regulation is critical depending on whether the regulated and unregulated outputs are produced as complements or substitutes in the production process. The elasticity between restricted and unrestricted outputs measure the output transformation in the regulated industry. Applied on a regulated fishery that consists of revenue maximising firms the paper examines how a tightening of the output regulation will affect the exploitation of the unregulated fish resources.

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1. Introduction

Output regulation is one of the key instruments to prevent overexploitation of fish resources in the Western world. Also in the European Union where regulation by TAC has a prominent position in the Conservation policy. Enactment of the output regulation has the impact that it changes the cost and revenue of the industry participants. The behaviour of the firms in industry in response to the regulation is of importance to the regulators who are interested in the impacts on the industry structure as well as the economic performance of the firms.

The methodology used relies on the principle of duality and flexible forms with competitive behaviour and regular technology; the theory of duality ensures consistency between the revenue and the production functions. The unregulated multispecies fisheries has been widely addressed in the literature by Squires (1987a, b), Kirkley and Strand (1988), and Bjørndal and Gordon (1993). The outline in the present paper is to estimate the technological conditions within an output-regulated fishery. This is accomplished by explicit to incorporate the impacts that the output regulation will have on the transformation between outputs in the industry. In the analysis to follow is emphasised the impact that a tightening/loosening of the output regulation will have on the unrestricted outputs. In this sense the paper offers information that is valuable to the regulators in order to predict the economic spillovers effects following output regulation in an industry of multiple outputs.

A quadratic revenue function is applied to describe the transformation between outputs in the pelagic fishery in the North Sea/Skagerrak. The empirical result reveals that the pelagic fishery is a joint fishery and that both the output prices and the imposed regulation have had significant influence on the vessels' production pattern. The study shows that the imposed regulation on herring will have spillover effects on the reduction fishery, whereas the output regulation of the mackerel is not found to any impact on the production of the unrestricted output in the present application.

The study of pelagic fishery is organised as follows. In the section to follow is emphasised that conventional elasticities between unrestricted outputs is not appropriate to evaluate the economic impact of an output regulated industry. Section 1.3. describes the output regulation implemented to manage the pelagic fishery of the Danish trawlers. In section 1.4. is accomplished a discussion on different ways to model output regulation of the industry. The representation of the empirical model follows in section 1.5. The empirical results and estimated the own- and cross-price elasticities of the regulated industry are presented in sections 1.6.-1.7. The paper is finalised by discussing specific elements in the output regulation of the pelagic fishery.

2. The elasticity between restricted and unrestricted outputs in a regulated fishery

Fisheries regulation, where the purpose is to avoid overexploitation is often accomplished by the use of output management. As emphasised in the studies of Squires (1987), Kirkley and Strand (1988), Alam, Omar and Squires (1996) the outcome of output management is critical depending on whether the industry can be characterised as a production of a single species or multiple species. Given that the fishery is characterised by a multispecies production it means that the industry can transform its production between multiple outputs. This could imply that output regulation of a single species would result in that the industry substitutes to other unregulated species.

In the conventional studies of the unregulated multispecies industry, the firm is assumed to vary its output freely. In a model where all inputs are fixed in the short run, the firm chooses the mix of outputs that maximises its revenue. The quantity of variable and unrestricted outputs are denoted by $Q = (Q_1, Q_2, \ldots, Q_n)$, the exogenous given output prices are denoted by $P = (P_1, P_2, \ldots, P_n)$, the fixed inputs are denoted by Z. In the fishery of no output regulation the firm maximise the revenue function:

(1) $R(P_1, P_2, \ldots P_n) = \max_Q \{P_Q Q; (Q, Z)\},$

where P_Q and Q represents the vectors of respectively the output prices (market prices) and output quantities. By applying Hotelling's lemma, the revenue function can be transformed into output supply functions for the unrestricted outputs. In the studies of the fisheries without output regulation, the output supply functions have been applied to estimate own- and cross price elasticities for the unrestricted outputs. This is based on the assumption that the supplied outputs are depending on the exogenous market prices for outputs. The transformation between the unrestricted outputs that is to state whether the outputs are substitutes or complements, can be accomplish by estimating the cross price elasticity:

$$(2)\quad E_{im} = \frac{\partial Q_i(P_i, P_m, Z)}{\partial P_m}\frac{P_m}{Q_i}, i \neq m,$$

which describes how an incremental change in the price of output m, P_m, affects the quantity supplied of output i, Q_i. Given that no output regulation is imposed on the fishery, the elasticity in (2) would be feasible to describe the optimal behaviour of the fishermen.

In practise the majority of fisheries in the western world are restricted by output regulation. This imply that the fishermen do not have the possibility to transform between the restricted outputs based on market prices. In this sense the revenue function expressed in (1) should be revised to:

$$(3)\quad R(P_1, P_2, \ldots P_n) = \max_Q \{P_Q Q; (Q, Y, Z)\},$$

where Y represents the restricted outputs of the firm. The firm is still maximising its revenue but only in the sub-space of the unrestricted outputs. In this sense the elasticities employed in (2) are only describing the transformation between the unrestricted outputs and thereby ignores the impact of the output regulation. However, as outlined by Dupont (1991) the elasticity between the restricted and unrestricted variables, denoted by the elasticity of intensity, provides information that is valuable to describe the technological condition within

a regulated industry. In the present context the elasticity of intensity is used to describe the spillover effect that the output regulation will have on the unregulated species. The elasticity between the restricted and the unrestricted outputs follows as,

$$(4)\quad E_{ih} = \frac{\partial Q_i(P_i, P_m, Y_h)}{\partial Y_h}\frac{Y_h}{Q_i}.$$

The elasticity measures the impact that an incremental change of regulated output, Y_h, will have on the supply of the unregulated output, Q_i, given that the exogenous market prices P_i, P_m are held constant. A negative elasticity of intensity indicates that a tightening of the output regulation would be compensated by an increase in the supply of the unrestricted output, whereas a positive elasticity indicates a complementary relationship between the regulated and the unregulated outputs. The latter situation will have the implication that a tightening of the output regulation will also reduce the industry's supply of the unrestricted outputs. In this sense the elasticity of intensity embody information that can be used to predict the output transformation that will occur under output regulation of a multiproduct industry.

3. The Pelagic Fishery in Denmark

The management of herring and mackerel in the Danish North Sea fisheries is traditionally based on individual quotas (catch permission), which are defined on a monthly (mackerel) or 120 days basis (herring) and give each vessel the right to catch a certain quantity within the defined period. In 1994 management of the herring and mackerel fisheries changed from quotas on a short-termed seasonal level to quotas defined on a common yearly basis[2] for herring and

2 The management of the individual quota system between 1994 and 1996 is stated in proclamation number 244, 7th April 1994 and proclamation number 981, 7th December 1994; proclamation number 920, 5th December 1995.

mackerel.[3] The individual quota system put into force in the herring fisheries in 1994 cover the areas, Skagerrak, the North Sea, and the English Channel. The individual quota system in force for the mackerel fisheries cover the North Sea, Skagerrak, Kattegat, and the Danish quota in the Norwegian zone north of 62°N, and the Danish quota in the zone of the Faroe Islands.

The individual quotas are distributed among the vessels applying to participate in either herring fisheries or both herring and mackerel fisheries. The Ministry of Fisheries supplies the quotas without charge or fee; transferability of the quotas between vessels is not permitted, which means that there is no market where quotas are traded. The individual quota give the right to catch a certain quantity within the current year. The quota is distributed to each vessel depending on its size and its share in previous years' total Danish landings of herring and mackerel from the relevant fishing zones. In general, the quotas are defined for herring and mackerel. However, the individual vessel can be given permission to have a minor by-catch of reduction fish in the herring fisheries if the reduction catch is separated from the herring catch. This dispensation in the individual quota system is of significant importance to the trawlers, which have a minor catch of reduction species in their catch. Given that a vessel has caught 70% of its individual initial quota, it can apply for a bonus quota, which constitutes a maximum of 10% of the vessel's initial quota. The Ministry of Fisheries has the obligation to reduce a vessel's individual quota if the opportunity to utilise the quota is neglected by the vessel. The vessel's quota can be reduced by up 30% of the uncaught quota, which will have an impact on the vessel's quota in the year to come. Although the vessels have individual quotas in herring and mackerel fisheries, the vessels are still entitled to catch other species in accordance with the general regulation of these species.

3 For completeness it is noted that a minor part of the herring and mackerel catch in the North Sea region are regulated by catch per fishing trip. Only 15% of the catches of herring and mackerel in 1994-1996 were regulated as catch per fishing trip. It is emphasised that the firms analysed in the present paper are regulated by annual quota licenses and no effort management has been imposed on the firms.

Only the large trawlers that have individual quotas in the herring and mackerel fisheries in the North Sea /Skagerrak are covered in the study[4]. The trawlers contain two groups firms. The first group covers the firms that have only applied for annual licenses in herring fishery, these firms have not applied for a license in the mackerel but they are still allowed to a minor catch of mackerel on a monthly basis. The second group of trawlers contain the firms that have both applied for annual licenses in the herring and in mackerel fishery. Finally it should be emphasised that the trawlers are seen as very flexible; i.e. the trawlers are not entirely dependent on the catches of herring and mackerel. The trawlers are able to change fishing strategy depending e.g. on the relative prices of the species, because they have the potential to switch between catch of herring, mackerel, reduction species, and to some degree to other consumption fish. The trawlers normally have a large share of their earnings in the reduction fisheries. In general the trawlers are not restricted in their catch of either reduction fish or in their catch of other consumption species.

4. Discussion of the Theoretical Model

The use of flexible forms of the profit or the revenue function has shown to successful in describing output transformations in production characterised by multiple outputs. That is, based on the assumption of either profit or revenue maximisation the conditional output supply can be derived by applying Hotelling's lemma. The flexible dual approach has found many applications in fisheries that is based on the assumptions of exogenous prices and absence of output regulation to describe the substitution possibilities between inputs and outputs (Squires (1987), Kirkley and Strand (1988) and others).

The presence of output regulation in the applied industry has the implication that the output mix can not be determined by the exogenous prices because binding output restrictions means that the firm is no allowed to increase its supply to respond an increase in the exogenous price. The quota restriction has the

4 The study concerns the large trawlers that are located in the ports of Esbjerg, Hirtshals, Skagen, and Thyborøn. The purse seiners, which participate in pelagic fishery are not included in the present study.

impact that the firm is limited in its revenue maximisation because the output of the firm tend to be predetermined. In this sense the firm is instead facing a cost-minimising problem for given levels of outputs. The application of the cost minimisation devise to describe the technological conditions in the output regulated fishery has been employed by Lipton and Strand (1992) and Bjørndal and Gordon (1998). A potential problem in using the cost minimisation approach to describe output regulation is that it is not certain that all participating firms in the industry are restricted by the output regulation. This could imply that the unrestricted firms should be modelled by a revenue maximisation approach, whereas the restricted firms should be modelled by a cost minimising approach. Related to studies in the fishing literature this also leaves the problem in the modelling of the TAC regulation because there is needed to be an explicit distinguishing between the restricted and the unrestricted firms.

In the present paper the industry is characterised by a combination of restricted and unrestricted outputs. This has the implication that the firm is free to choose its mix of outputs with respect to the unrestricted outputs, whereas the restricted outputs most be treated as fixed. The firm can maximise its revenue with respect to the unrestricted outputs, whereas the restricted outputs most be treated as fixed outputs in the revenue maximisation. Moreover it is emphasised that given that the restricted and unrestricted outputs are produced in a joint fishery, this implies that the output regulation would impact the firms supply of the unrestricted outputs as well. The fishery that combines the supply of restricted and unrestricted outputs describes the situation of the pelagic fishery in the North Sea by the Danish trawlers. A fishery that is regulated by individual quota licenses on an annual basis. The presence of the vessels specific quotas has the advantages in the present context that it is facilitates to identify the firms that are restricted by the output regulation.

5. The Empirical model

The present application on the dual approach describes the production conditions of the Danish trawler fleet based on information in the revenue function for each of firm that have an individual annual license (quotas) in the herring or

mackerel fishery. In general, the advantage of using the dual approach lies in the flexibility, which is obtained when formulating the functional form of e.g. the revenue function. Also, the approach allows the derivation of a consistent system of output supply and input demand equations based on simple differentiation, facilitating the use of flexible functional forms. The duality theory makes it possible to choose a representation of the technology, which has desirable properties for estimation, such as exogenity of the regressors. The use of the dual representation of production structure is appropriate given that the behavioural assumption of the revenue maximisation is valid in the industry. Further, the applied representation of e.g. the revenue function has to meet the regularity conditions. The estimation of the dual approach can be based on the use of a single equation without any inconsistency, where the regressors are treated as exogenous. However, the efficiency of the estimators can be improved by using the consistent system, which arises when using the output supply functions derived e.g. from the revenue function. The possible efficiency gains occur as a result of the cross equation error correlation but also as a result of the equation restrictions imposed by the regularity conditions.

When applying the dual theory to the pelagic fishery, it is assumed that the firm base its mix of unrestricted output on the output prices that are determined exogenously in the market. The supply of the regulated outputs are treated as exogenously given for the firm in the sense that the quantity of the individual quota is predetermined by the regulators. It is assumed that the firm chooses its quantity of restricted and unrestricted outputs in order to maximise its revenue, whereby the fishing effort is treated quasi-fixed in the short run. In the long run, the firm has the possibility to maximise its profit by simultaneously optimising its mix of outputs and inputs, the latter implies changes in vessel design, gear, equipment and other inputs. However due to the absence of costs data for the pelagic trawlers, the present modelling of the production conditions is restricted to the short-run, where the inputs are treated as fixed. This implies that the vessel maximise revenue given their characteristics. Moreover, the trip length and the fact that trips are planned based on perceived quotas and market prices results in input mixes that can be viewed as fixed costs. For this study, a vessel composite input was constructed (the product of number of trips times the ves-

sel size in GRT) based on the assumption that the vessels, or capital, are relatively fixed and thus determine the level of variable input use. To specify the revenue function has been chosen the quadratic form which has shown to be flexible in modelling of restricted and unrestricted variables (Dupont, 1991). The revenue maximising behaviour, based on exogenous prices on unrestricted output and quantities of imposed vessel quotas, is modelled by use of the quadratic revenue function[5]:

$$
\begin{aligned}
R = {} & \alpha + \sum_{i=1}^{2} \alpha_i P_i + \sum_{j=1}^{2} \beta_j Z_j + \sum_{h=1}^{2} \varepsilon_h Y_h \\
& + \sum_{i=1}^{2}\sum_{h=1}^{2} \chi_{ih} P_i Y_h + \sum_{j=1}^{2}\sum_{h=1}^{2} \mu_{jh} Z_j Y_h + \tfrac{1}{2}\sum_{i=1}^{2}\sum_{m=1}^{2} \alpha_{im} P_i P_m \\
& + \tfrac{1}{2}\sum_{j=1}^{2}\sum_{n=1}^{2} \beta_{jn} Z_j Z_n + \tfrac{1}{2}\sum_{h=1}^{2}\sum_{l=1}^{2} \varepsilon_{hl} Y_h Y_l + \sum_{i=1}^{2}\sum_{j=1}^{2} \gamma_{ij} P_i Z_j
\end{aligned}
\qquad (5)
$$

Symmetry is imposed by the restrictions $\alpha_{im}=\alpha_{mi}$ and $\beta_{jn} = \beta_{nj}$, and
R is the revenue;
P_i is the prices of the unrestricted outputs (P_R - species for reduction, P_C - other species for consumption)
Z_j is the composite input fishing effort[6] (GRT*TRIPS)
Y_h is the restricted outputs (Y_H - herring, Y_M - mackerel)
α's , β's ε's μ's and γ's are the parameters.

By applying Hotelling's lemma the output supply for the each unrestricted species is derived as,

$$
\frac{\partial R}{\partial P_i} = Q_i = \alpha_i + \sum_{h=1}^{2} \chi_{ih} Y_h + \sum_{m=1}^{2} \alpha_{im} P_m + \gamma_{ij} Z_j \qquad 6)
$$

5 The application of the revenue function accomplishes a first stage (short-run) optimisation, the profit function is addressed in the second stage (long-run) optimisation, which accomplishes optimisation of the inputs.

6 By employing the composite quasi-fixed input is it assumed separability in the input. Admitting that this is a inadequate measure of the composite input. However, the present definition is consistent with the traditional fishing effort used in other studies for example Kirkley and Strand (1988).

where Q_i is the supply of reduction species and other consumption species, denoted by Q_R and Q_O. The supply of the licensed species herring and mackerel is measured by Y_h. The exogenous prices of species for reduction purposes and other consumption species than herring and mackerel is denoted by P_m. Finally Z denotes the quantity of the quasi-fixed composite input.

The system of the output supply functions forms a theoretical consistent way to estimate on the one hand the elasticity between the unrestricted outputs, and on the other the spillover effect that the license regulation license would has on the unrestricted outputs.

An extension of the present study could be accomplished by estimating the profit function and the supply function simultaneously and thereby estimating the shadow value of the restricting herring and mackerel licenses. In these sense revealing the market price the vessels would be willing to pay for additional license of herring and mackerel, and thereby the consequence of transforming the regulation from a system where licenses was granted gratis to a markets based system. Unfortunately due to the circumstance that no cost data is available in the present study the opportunity to employ the profit function to estimate the shadows value is impossible. Instead the focus in the current analysis is narrowed to employ the system of output supply function to estimate the elasticities described above.

6. Data and Estimation

The Danish Directorate of Fisheries supplies data used in estimation. The model has been built on yearly observations given that the regulation applied in the pelagic herring and mackerel fisheries is imposed by individual yearly quotas. The observations are initially divided between two groups of trawlers. The first group contains the trawlers that have obtained yearly licenses in the herring fishery, the second group cover the trawlers that both have licenses in the herring and the mackerel fishery. The estimations are applied on yearly observations, this involves the risk of insufficient price variability. However, given that

the regulation is implemented on a yearly basis, this justifies that a significant impact of the regulation should be expected within this frequency. The observations include recorded details of dockside landing quantities and prices as well as the number of fishing trips and GRT-capacity of each vessel. The yearly data include herring, mackerel, reduction species and other species of consumption. It is noted that the reduction catches represent catches of the following fish categories: sand eel, Norway pout, sprat, horse mackerel, blue whiting and miscellaneous catches. The category of other consumption species includes: shrimp, lobster, whiting, haddock, hake, plaice, cod, sole, saithe and mackerel, but the latter species is only included for the trawlers in the first group, as these firms have not applied for licenses in the mackerel fishery. The data include the vessels' specific landings distributed on the single species categories. To avoid missing observation as a consequence of zero of one of the dependent variables, the zero catches of any of the four species were assigned by the arbitrary small value of 0.00001 kilo according to Kirkley and Squires (1988). The Gross Registered Tonnage measures the capital stock and is multiplied by the number of fishing trips per year in order to measure the effort intensity of the single vessel per year. Summaries of the data used in the study are given in Table 1.

In total data consists of 92 observations of trawlers with an individual herring quota in the North Sea/Skagerrak and the vessels operate from the ports of Esbjerg, Thyborøn, Hirtshals and Skagen. Some of the trawlers have a quota in the mackerel fisheries. The trawlers included operated in the fisheries between 1994 and 1996.

Table 1. Summary Statistics, All 92 Trawlers , Price, Quantities, Year

Description	Mean	Standard Error	Minimum	Maximum
Quantity (kg) landed of:		**1994**[3)]		
Herring	2138494	751534	861085	38885248
Mackerel	50536	635688	0	1880866
Reduction	528263	1563561	1231643	8347375
Other	24692	74696	0	416015
Price (DKK/kg):[1)]				
Herring	1.60	0.17	1.00	1.84
Mackerel	1.10	0.71	0.00	1.78
Reduction	0.53	0.01	0.47	0.56
Other	1.36	2.02	0.00	6.56
GRT- Gross Register Tonnage	328	142	149	611
Number of trips	41	17	24	78
Herring quota	1950848	71870	800000	3353000
Mackerel quota[2)]	859058	5694449	210000	1506000

Continued…

Description	Mean	Standard Error	Minimum	Maximum
Quantity (kg) landed of:		**1995**		
Herring	1953007	936201	619128	4193249
Mackerel	380558	467316	0	1655510
Reduction	6731337	2428056	3352514	14309306
Other	4151	16996	0	94749
Price (DKK/kg):				
Herring	1.41	0.14	1.04	1.69
Mackerel	1.57	1.19	0.00	3.17
Reduction	0.54	0.03	0.48	0.59
Other	1.86	3.07	0.00	11.18
GRT- Gross Register Tonnage	334	149	149	654
Number of trips	38	12	24	61
Herring quota	577722	331760	135000	1056000
Mackerel quota[2)]	1946967	753582	925000	3525000

Continued…

Description	Mean	Standard Error	Minimum	Maximum
Quantity (kg) landed of:		**1996**		
Herring	1133345	467148	413764	2213382
Mackerel	353447	340267	0	1143743
Reduction	5891243	2158473	1055181	9038340
Other	41270	72979	0	219602
Price (DKK/kg):				
Herring	1.91	0.19	1.53	2.32
Mackerel	4.32	1.82	0.00	5.69
Reduction	0.62	0.01	0.58	0.65
Other	2.69	3.06	0.00	12.13
GRT – Gross Register Tonnage	361	137	149	654
Number of trips	36	15	18	63
Herring quota	1343464	498447	316000	2014000
Mackerel quota[2)]	488428	200540	112000	742000

1) All estimations are conducted using current prices
2) Include only the vessels that have a mackerel license.
3) The yearly individual quota system was introduced 1st May 1994.

In Table 1 there is indicated to be large variation on prices for mackerel and the category of other species for consumption purpose. The variation in the mackerel price could indicate that the impact of the mackerel regulation would differ between the years. In the sense that the relative low mackerel price in 1994 would tend to give a modest supply of mackerel in this year compared to the years 1995 and 1996 where the mackerel price is higher and thereby also the supply of mackerel. The yearly price variability on mackerel could therefore indicate that a higher proportion of the firms are unrestricted in the mackerel fishery in 1994 compared to 1995 and 1996. Moreover price variation of other consumption species could indicate the existence of aggregation problems due to changes in the distribution of species in this category on a yearly basis. An obvious way to deal with these annual fluctuations could be accomplished be

conducting estimations on annual basis as in Bjørndal and Gordon (1993). Unfortunately the yearly estimations would be applied at the cost of reducing the degree of freedom, and given the relative low number of observation this is not recommendable in the present application. The estimation has therefore been accomplished for entire period 1994-1996 for the two separate trawler groups.

Another important theme in the estimation of the supply functions in the regulated industry is to consider whether the firm is restricted in its transformation between outputs due to the license regulation. If this is the case the firm's output of herring and mackerel should be modelled as restricted outputs. On the other hand, if regulation not restricts the output supply of the firm it is appropriate to model the output transformations by the elasticities between the unrestricted output, as in the unregulated industry e.g. outlined in Kirkley and Strand (1988). In the latter case, there should be defined output supply functions for herring and mackerel as well rather than restricting their quantities as in (6). However, given that the output supply of herring and mackerel is not restricted, the supply functions in (6) could still be employed but the quantities of herring and mackerel should be treated as endogenous in the system. In this sense employing the supply functions in (6) involve discrepancy between the situation where the regulation of herring and mackerel is binding versus not binding, because it means that the quantities of herring and mackerel should be treated respectively as an exogenous versus an endogenous variable. An obvious way to deal with the discrepancy would be to estimate the restricted and unrestricted vessels separately[7]. However, based on the relatively low of number of observations in the data set, the estimations has been accomplished by incorporate the restricted and unrestricted vessels in the same estimation. For the vessels that are not restricted in the herring and mackerel fishery the correlation between quantities of herring and mackerel and the error is avoided by conducting IV-estimations. To spot the firms that are considered not to be restricted in the herring and mackerel there has been defined an ad hoc rule stating that a firm that has landed less than 80% of its allowed annual quota is assumed to be not restricted in the herring and mackerel fishery. For the unre-

7 I would like to thank Douglas Larson for this highly relevant suggestion.

stricted firms are employed IV-estimation on the supply of herring and mackerel, which is based on OLS of the following relations,

7a) $$\frac{\partial R}{\partial P_H} = Q_H = \alpha_i + \sum_{m=1}^{4} \alpha_{im} P_m + \gamma_{ij} Z_j$$

7b) $$\frac{\partial R}{\partial P_M} = Q_M = \alpha_i + \sum_{m=1}^{4} \alpha_{im} P_m + \gamma_{ij} Z_j$$

which are similar to the output supply functions in (6) that are derived from the quadratic revenue function expressed in (5). The only difference between (7a,b) and (6) is that the catches of all four species (herring, mackerel, species for reduction and other consumption) are treated as unrestricted[8] in (7a,b).

The estimation of (7a) is undertaken for vessel that have applied for a license in herring fisheries[9], whereas (7b) is estimated only for the vessels that have mackerel license. The IV-estimation is only conducted for the unrestricted vessels, the procedure is conducted by using the predicted quantities of herring and mackerel from (7a) and (7b) as input in the supply functions in (6). Based on the ad hoc rule it is indicated that 31 firms out of a total of 43 firms are restricted in the herring fishery for the first group. Moreover it is indicated that out of the 49 firms in the second group, there are 36 firms that are restricted in the herring fishery, whereas 37 vessels are restricted in the mackerel fishery. A closer inspection of the restricted vessels in Table 2 show the impact that the annual regulation has had on the development of the restricted vessels on the yearly basis. There is seen an annual trend towards a tightening of the mackerel regulation between 1994 and 1996, which is indicated by the increased share of

8 Naturally there is only conducted IV estimations for herring for vessels that have only applied for a herring license. For these vessels catches of mackerel is included in the category of other consumption species.

9 These vessels are allowed minor catches of mackerel (for example as by-catches). The catches of mackerel for the vessels are included in the catches of other consumption species. The vessels that have only applied for herring licenses in unrestricted in the mackerel fishery, otherwise they would have applied for a mackerel license.

restricted firms in 1996. This development is consistent with the price statistics in Table 1 indicating that the increased price of mackerel in 1996 has created incentive to increase the output supply of mackerel, whereby a larger share of the firms are restricted in 1996. In the herring fishery, there is seen an annual trend between 1994 and 1996 towards a more loose regulation for both groups of trawlers. It is interesting to note that only 50% of the trawlers in the first group are restricted by the herring licenses in 1996, in this sense it is difficult to assign whether the fishery should be modelled as restricted or unrestricted in this year.

Table 2. The Percentage of Trawlers Restricted by the Annual Quota Regulation

	94	95	96
Trawlers restricted in the herring fishery[1)]	94%	69%	50%
Trawlers restricted in the herring fishery[2)]	88%	72%	64%
Trawlers restricted in the mackerel fishery[2)]	65%	72%	86%

1) The first group of trawlers that have applied for a license in the herring fishery but not in the mackerel fishery.
2) The second group of trawlers that have applied for licenses in the herring and mackerel fisheries.

The data is analysed for heteroscedasticity by applying Glejser tests. The tests indicate heteroscedasticity of the form assumed by Parks (1970) in which the error variance is proportional to the squared level of input, Z. As a consequence the output supply function in (6) is divided by Z according to Squires and Kirkley (1991) (see also Campbell and Nicholl, 1995, 47). The tests also indicate the existence of heteroscedasticity due to Y_h for the vessels in the first group and P_o for the vessels in the second group. The heteroscedasticity could be corrected by deflating the estimations by respectively Y_h and P_o. Deflating the data by Y_h and P_o changed the signs of estimated parameters compared to the OLS estimation, this indicates problems of multicollinearity when deflation by Y_h and Po. The consequence of the heteroscedasticity by using OLS estimator is that the

estimators are unbiased but inefficient. As a consequence the input-scaled output supply functions in (6) were estimated by maximum likelihood estimation.

7. Results

The maximum likelihood estimations of the input-scaled output supply functions are presented in Table 3. The estimations indicate different impacts of the price components and the regulation components for the two groups of trawlers. In the first group, there is lack of significant parameter estimates both with respect to price and the herring regulation. For the second group, there is indicate a significant impact from the herring regulation on the supply of species reduction purpose and a significant price component in the supply of other consumption species.

The insignificant price effect with respect to reduction species for both groups could be due to insufficient price variation in the data applied on an annual basis. In most other applications that describe transformations between output in the fishing industry, the price variations are defined per fishing trip or per trip on a monthly basis. However, in the present context the price variation is based on the annual fluctuation due the fact that the purpose is to draw inference on the output regulation that is imposed on an annual basis. Moreover it should be emphasised that conducting estimations based on a monthly basis would create problems to identify whether the seasonal production process is restricted by annual license or not. In the present context the set-up that has been designed to describe the impact of the annual output license, the estimation has therefore been conducted on an annual basis.

Table 3. Parameter Estimates Output Supply Functions[1)] for the groups of trawlers that have output license in the pelagic fishery

Prices and other exogenous variables	Quantity supply of			
	Trawlers having only a herring license		Trawlers having both a herring and a mackerel license	
	Reduction	Other consumption species	Reduction	Other consumption species
Intercept	3923602 (5161184)	-70526 (855099)	14100878** (4415686)	463.461 (695.288)
Price on species for reduction purposes	2154150 (8389962)	-150815 (124964)	-11348655(*) (7159247)	-1079.73 (1128.25)
Price on other consumption species	-150815 (124964)	7195.07(*) (4381.17)	-1079.73 (1128.25)	304.204** (21.216)
Herring license	-1.2413(*) (0.8505)	-0.0146 (0.0212)	-1.943** (0.514)	$3.75*10^{-5}$ $(8.11*10^{-5})$
Mackerel license			0.1142 (0.816)	$6.68*10^{-5}$ $(1.29*10^{-4})$
Fishing effort	185.973 (184.332)	22.262** (5.714)	240.565** (78.600)	0.0016 (0.013)

Standard errors in parentheses

(*) Denotes significant at the 15% level

* Denotes significant at the 10% level

** Denotes significant at the 5% level

Note: Quadratic functional form. Apparent heteroscedasticity required estimation of supply per unit of effort.

1) Asymmetric separability is assumed so that inputs are separable from the output, but converse separability is not imposed. Separability is assumed with respect to reduction species and other consumption species.

The tests on nonjointness in inputs for each trawler group that are presented in Table 4 are accomplished as likelihood ratio tests. The null hypothesis of nonjointness with respect to species for reduction and other consumption species is rejected for the trawlers in the second group. This implies that the fishery can be characterised as a multispecies fishery in the sense that there are spillover effects among the different species. This has the implication that regulators should based their management as existed there a fishery of multiple outputs, management of a single species would have spillover effects on the other species in the joint production (see Hall, 1973). For the first group of trawlers the hypothesis of nonjointness in inputs can not be rejected. This implies that species for reduction and other consumption are characterised as separate fisheries that are characterised by individual production functions. In this sense neither of the fisheries are impacted by the regulation of the herring or exogenous price impacts of other fisheries. It is therefore legitimated empirically to estimate a single production function for each of the unrestricted output independent of the herring fishery for the trawlers in the first group (see Shumway, 1983). It most be emphasised that the result that nonjointness in inputs can not be rejected is an amazing result, because the vessels are characterised to be rather flexible, therefore it would be expected to be some degree of substitution between the species in the pelagic fishery. However, it should be stressed that there are some conditions that could bias the test towards not rejecting the hypothesis. Firstly, the modelling on an annual basis could create problems with insufficient price variability in the data set and thereby bias the test toward not rejecting the nonjointness. Merely it is indicated that the large share of unrestricted vessels in the first group segment during 1996 could indicate that the fishery is not restricted in this year, which would also bias the test for nonjointness. The latter condition could be adjusted for by modelling the sub-group of unrestricted firms following the lines in the unregulated fishery.

Moreover Table 4 presents likelihood ratio tests of input-output separability in all outputs for each of the trawler groups. The hypothesis has the implication that the marginal transformation between outputs is independent of the inputs (see Chambers, 1994). In this sense the null hypothesis states that effort management will not change the firms' relative quantities of outputs. The null of

input-output separability is rejected (γ_{ij}=0) for both groups of trawlers, this imply that imposed management of the composite input would change the relative catch composition of the vessel. This has the implication in a management setting that imposed effort restriction would have different impact on the firms depending on the employed fishing effort. The parameter estimates on fishing effort in Table 3 indicate that restriction on effort will especially reduce the product species output of other consumption species in the first group of trawlers and the product specific output of species for reduction purpose in the second group.

Finally there is employed likelihood ratio tests to test whether the imposed output regulation have spillover effects on the supply of the unrestricted outputs. The test is in line with the previous results that tested the nonjointness in inputs. This implies for the first group of trawlers that the production of the unrestricted species are not impacted by the fishery of the other species nor is the supply of the unrestricted species impacted by the imposed regulation on the restricted species. For the second trawler category, the null hypothesis that the annual quota regulation does not have any impact on the output supply of the unrestricted species is rejected by the data. In this sense the regulator should be aware that the imposed output regulation will have consequences for the output supply of the unrestricted species as well. The specific consequence of the output regulation on the supply of the unrestricted outputs is analysed in detail by estimating the elasticity of intensity.

Table 4. LR-Tests of Hypothesis about the Production Technology

Null Hypothesis	**Test Statistic**	**Critical Value (a £ 0.05)**	**Degrees of freedom**	**Conclusions**
Trawler having only a herring license				
Non-jointness in inputs[1)]	3.557005	7.81473	3	accept null
Separability in outputs[1)]	17.57948	5.99147	2	reject null
Regulation zero[1)]	3.036595	5.99147	2	accept null
Trawler having both a herring and a mackerel license				
Non-jointness in inputs[2)]	16.65644	11.0705	5	reject null
Separability in outputs[2)]	8.574682	5.99147	2	reject null
Regulation zero[2)]	13.80173	9.48773	4	reject null

1) The individual quotas for herring.
2) The individual quotas for herring and mackerel.

The estimated parameters in Table 3 are used to calculate the elasticity of intensity and thereby the impact that the output regulation of herring and mackerel have of the fishing pattern of the trawlers. The estimated elasticity of intensity in Table 5a indicates that the supply of herring and reduction species are found to be substitutes for the first group of trawlers, the relationship is significant at α=15%. In this sense a tightening of the herring licenses would be compensated by an increase the supply of species for reduction purposes by the trawler in the first group. The fishery for reduction is a ”buffer” fishery that the trawlers increases in the case of tightening herring regulation. The fishery of other consumption species is on the other hand not a “buffer” fishery for the trawlers. The reason being that there is not seen any significant impact from the output regulation of herring towards the supply of the other consumption species. The trawlers are merely traced to the other consumption species due to a exogenous price effect, which is indicated by the significant own-price elasticity (significant at α=15%).

The conventional elasticities of the unrestricted outputs covering the own-price elasticity of species for reduction purposes and the cross price elasticity between species for consumption and reduction purposes are all insignificant. In this sense the period 1994 to 1996 do not indicate any transformation between the unrestricted output of the average vessel in the first group.

Table 5a. Elasticities for regulated and unregulated species in the North Sea trawler fishery, 1994-1996

Impact on endogenous output supply for:	**Elasticity of changing the exogenous variables**		
	Herring license	Price of reduction species	Price Other species
Reduction species	-0.32234(*) (0.220863)	0.248031 (0.966029)	-0.06485 (0.053738)
Other consumption species	-0.39221 (0.570989)	-1.79433 (1.486765)	0.319712* (0.194676)

(*) Denotes statistical significance at the 0.15 level
* Denotes statistical significance at the 0.10 level
** Denotes statistical significance at the 0.05 level

Table 5b. Elasticities for regulated and unregulated species in the North Sea trawler fishery, 1994-1996

Impact on endogenous output supply for:	**Elasticity of changing the exogenous variables**			
	Herring license	Mackerel license	Price of reduction species	Price Other species
Reduction	-0.62446**	0.012544	-0.93212(*)	-0.00028
	(0.165383)	(0.089738)	(0.588028)	(0.00029)
Other consumption species	0.146573	152.4279	-1.07762	0.951517**
	(0.316769)	(1090.427)	(1.126043)	(0.066363)

(*) Denotes statistical significance at the 0.15 level
* Denotes statistical significance at the 0.10 level
** Denotes statistical significance at the 0.05 level

The elasticities for the second group of trawlers containing the firms that have granted licenses in both the herring and mackerel fisheries, are outlined in Table 5b. The elasticity of intensity indicates substitution between the regulated supply of herring and the species for reduction purposes. The similar relationship was found for trawlers in the first group but it is emphasised that the magnitude and significance of the estimated elasticity is stronger for the trawlers in the second group. The elasticity of intensity for the second group of trawlers indicates that a 1% decrease in the licenses for herring would be compensate by a 0.62% increase catch of species for reduction purpose. In terms of gross income the 1% tightening of the herring output would be followed by a decrease in the gross income of 11602 DKK. This is calculated by relating the 21889 kilos of herring to a price on 1.61 DKK/kilo to (minus) the catches for reduction purposes of 42246 kilos of a price of 0.56 DKK/kilo. It is noted that the impact in terms of gross income ignores the impact the change in catch composition would have on the profit of the firm due to due the lack of cost data. For the first group of trawlers, the 1% decrease in the herring license would lead to a decrease in the gross income of 12365 DKK of the average vessel (calculated as 12927 kilos of herring at a price of 1.66 DKK/kilo minus 15930 kilos of catches

for reduction purposes at a price of 0.57 DKK/kilo). In this sense there is found similar impact in terms of direct decrease in gross income for the two trawler groups. It is noted that the calculation on the consequence of gross earnings build on the assumption that the trawlers do not have the possibility to use the catches of other consumption as a "buffer" to compensation a tightening of the herring license. The latter is verified by the insignificant elasticity between herring license and supply of residual species for consumption both trawler groups. Another way that the trawlers in the second group could compensate restrictions of the herring licenses could exist if the vessels had not fully utilised their mackerel license. However the majority of vessels are also found to be restricted by regulation of the mackerel.

The elasticity of intensity with respect to the mackerel, Table 5b does not indicate any substitution or complementary relationship between a tightening of the mackerel license and the supplied outputs of species for reduction or consumption purposes. Given that the vessels are not compensating a decrease in the mackerel license by increasing landings landing of the unrestricted species for reduction or consumption purposes, the fall in gross earnings due a 1% decrease would be 21855 DKK (calculated as 7484 kilos of mackerel at a average price of 2.92 DKK/kilo). In this sense the vessels would be worse off by a 1% tightening of the mackerel than by a 1% tightening of the herring license in terms of gross earnings.

The conventional cross-price elasticities between the unrestricted species for reduction and consumption purpose do not show any indication of substitution or complementary relationship between the unrestricted outputs for the trawlers in the second group. The own price elasticity of other consumption species indicates a significant impact in the sense that a 1% increase in price would be follow by 0.95% increase in output supply. In addition it is should be remarked that the own-price elasticity of reduction show a negative own-price elasticity. This is not consistent with the revenue maximising behaviour assumed in model. The inappropriate elasticity can presumable be explained by aggregation problems in the category that includes the landing of sand eel, Norway pout, sprat, horse mackerel, blue whiting and miscellaneous catches. Particular the

miscellaneous catches is expected to create problems due to large variation that is discovered in the category that probably both contain species for reduction and consumption purposes. A reasonable solution would be either to include the miscellaneous catches in the category of other consumption or alternative to undertake the estimation on yearly basis which would implies the homogeneity in the species categories would be increased. Estimating the miscellaneous catches has been accomplished but just moved the problem to the category of other consumption species. The estimations on a yearly basis has not been accomplished due to a relative low number of observations in the analysis[10].

8. Conclusion

Quantitative regulation of fishing output is one of the most used instruments to prevent overfishery in the European Union. The paper examines the impact that output regulation of selected species would have on the unrestricted species in a multispecies fisheries. A complementary relationship between the regulated and unregulated species would mean that the output regulation would not only restrict the income of the regulated species but would also lead to decline the catches of the unregulated species as well. On the other hand a relationship of substitution between the regulated an unregulated species would allow the fishermen to compensate a tightening of the output regulation by an increase of the unrestricted outputs. In the sense the analysis of the multispecies production relations embody information that is essential for regulators to predict how different segments of the fishing fleet would be impacted economically by imposed output regulation.

By examination of the elasticities between the restricted and unrestricted outputs in the pelagic fishery of the North Sea, it is concluded that the output regulation of herring would lead to increased catches of species for reduction purposes in the trawler fleet. Moreover it is found that the output regulation of the mackerel fishery have no spillover effects on the unrestricted outputs, in this sense a tightening of the license regulation of mackerel would not be compen-

10 I would like to thank Trond Bjørndal for the proposition.

sated by increased catches of the unrestricted species. Trawlers that are tied by mackerel regulation at the end of the year would given that it is a nonjoint fishery reduce their fishing effort in order to meet the imposed regulation.

The employed annual vessels license has the advantages that it gives the firms a high degree of flexibility to plan their harvesting strategies without seasonal restrictions. On the other hand, the implemented management system based on gratis licenses might have the potential problem that it attracts the firms to apply for higher quotas than they plan to use. The reason being that the holding an extra unit of quota can be compared to a financial option in the assets market. The difference between the financial option and the holding of the license is that the former offers a potential to a gain at a certain cost, whereas the latter in the implemented regulation system offers a potential gain but free of costs[11]. The gain of holding an extra quota of herring for the firms could be exercised if the firm for one reason or another is restricted[12] in its traditional fishery. This means that there is a tendency to overcrowding for the gratis herring licenses. However, if some firms are overcompensated with quotas, this would have external consequences for the firms that are restricted by their licenses, because they could have obtained larger license, if the overcompensation has been avoided. The implemented management system has dealt with the described problem by defining that individual quota for the vessel is depending on its catches during three previous years. Moreover it is stated in the legislation that firms that did not use the license in the present year could be denied a license in the year to come, and thereby to punish the firms that do not use their quotas. Finally, the management system allows bonus licenses given that the total allowed catches have not been utilised at the end of the year. In this sense the management system seeks to take account of the external effects by allowing fishermen that are restricted by the quotas a bonus quota.

An alternative way to deal with the overcompensation of certain license holders could be accomplished by introducing license payment (ITQ), which would

11 What is meant is that there is no fee to get access to catch an extra kilo of the regulated species.

12 A significant decline in the abundance of unrestricted species.

prevent license holders to apply for a large quotas than they need. In this sense the quota payment could be seen as an effective way to redistribute licenses during the year given that some vessel realised that they for one reason of another will not use their license. Finally the payment system would also have the implication that the economic most efficient vessels would be employed in the fishery, given this a goal for the politicians.

However, given that the political consensus to agree on individual transferable quota system can not be found, the task to distribute the quotas among the fishermen is accomplished within the terms of the imposed management system. Based on the approach in the present paper the regulators can apply the elasticity between the regulated and unregulated output to describe the impact of imposed regulation. In this sense the approach is not only applicable to the fishing industry but could also be applied to other industries that consists of regulated and unregulated outputs for example the milk quotas applied in agricultural industry in the European Community.

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