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Individual Vessel Quotas and Unregulated Species: The Norwegian Blue Whiting Fishery

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Abstract

This survey of the Norwegian purse seine fleet licensed to fish blue whiting focuses on the relationship between restricted fisheries, such as spring-spawning herring, North Sea herring, mackerel, and capelin, and unrestricted fisheries, of which blue whiting is the most important. To model the behaviour of the fishermen a restricted profit function is used, where species quotas are treated as fixed factors while blue whiting along with other non-quota species are variable factors. We find no relationship between blue whiting and herring, and mackerel. Blue whiting and capelin are substitutes. So are other non-quota species and spring-spawning herring. Other non-quota species are complements to mackerel and North Sea herring.

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1 Introduction

Most fishing vessels target several stocks and species. In biological fisheries management, however, multi-species characteristics are largely ignored, managing the different stocks and species separately. Moreover, only the most important stocks are regulated by individual vessel quotas (IVQs), and for the other stocks there is either a total quota, which allows the fishermen to catch as much as they can until the quota is fished, or there is no quota restriction at all.

When some fisheries are strictly regulated, and some are not, the unregulated ones will attract more of the fishing effort than if none of the fisheries were quota regulated. The reasons for this are the fishermen's incentive to obtain as high a share as possible of the total quota before it is considered fished and the fishery is closed, and the opportunity to increase their income beyond what they are able to earn catching their IVQs. The size of this extra income depends on the characteristics of the unregulated fishery and, more importantly for this work, on the opportunity cost of foregoing a unit of quota fish for one unit of unregulated fish. If the vessels have limited fishing capacity, *i.e.,* the catching of unregulated fish is restricted by the quota fisheries, the unregulated fishery is restricted indirectly by the quotas on other species.

An important unregulated fishery in the North East Atlantic is the blue whiting fishery. Fishing for blue whiting appears to be a very attractive strategy for economic expansion for actors who otherwise operate within a system that is both closed and has strict quota regulations (Standal 2006). Because blue whiting is a straddling stock, migrating through the exclusive economic zones (EEZs) of several nations as well as on the high seas, there existed no international agreement on the joint management of the stock. Only recently (in 2005) have the largest exploiting nations reached an agreement on a total allowable catch (TAC) for the blue whiting stock. Prior to this agreement the nations competed in catching blue whiting in an effort to establish rights in the fishery and the best possible bargaining position for a future TAC (Ekerhovd 2003).

Asche, Gordon, and Jensen (forthcoming), in an empirical analysis of Norwegian purse seiners, investigated to what extent fishermen target unregulated species when

IVQs are used to manage the regulated species. Their results indicate that restricted and unrestricted outputs are substitutes, and accordingly a reduction in the quotas induces firms to increase production of unregulated species. Moreover, Asche, Gordon, and Jensen (forthcoming) found the supply elasticity for the unregulated species to be close to zero and statistically insignificant. Hence, it is not the price of the unregulated species that determines catches and fishing effort for these species. This supports the notion that IVQs give strong incentives to increase fishing effort for unregulated species, particularly when the quotas are reduced.

What separates this work from that of Asche, Gordon, and Jensen (forthcoming) is that while they analyse the behaviour of purse seiners without a blue whiting fishing licence, here we analyse a subfleet of the purse seiners licensed to fish blue whiting in addition to the species targeted by all Norwegian purse seiners. Instead of combining all unregulated outputs into one index for variable output, we specify two unregulated outputs: blue whiting and other non-quota species. This allows us to analyse the effects of the quota on restricted fisheries on the landings of blue whiting. Furthermore, we can compare the quota species' effects on other non-quota species with the results of Asche, Gordon, and Jensen (forthcoming).

Each year the purse seine vessels are given IVQs for the stocks of spring-spawning herring, North Sea herring, mackerel, and capelin. The quotas have to be fished within that year, otherwise they are lost to the vessels. Transferring quotas, or some of them, given in any one year to the next year is not allowed. The purse seiners have the opportunity to fish some non-quota species in addition to the quotas. The blue whiting fishery is one non-quota option for those purse seine vessels holding a blue whiting fishing licence. The quota species and non-quota species are targeted species-by-species, and stock-by-stock, so by-catch is not an issue in these fisheries.

The fact that the species/stocks are targeted one at a time suggests that the fisheries are not joint in production by technical interdependence. However, there is another potential source of jointness in production: allocatable fixed factors (Shumway, Pope, and Nash 1984), when "there is a fixed input which is not fully utilized in producing a single product at optimal scale", Leathers (1991) (p. 1086).

The Norwegian purse seine vessels face several fixed factors in production: in the short run, the IVQs allocated to each vessel each year and, in the long run, the vessel size, in particular their capacity to catch fish. Then there is the choice of how much time to spend fishing for the non-quota species, assuming that IVQs are binding, *i.e.,* that the allocated individual vessel quotas will be fished by the end of the year. If all the fixed factors, IVQs, fishing capacity, and time, are binding, the production of the quota-restricted species and the non-quota species will be joint. Consequently, there will be a substitute relationship between the non-quota species landings and the quotas of spring-spawning herring, mackerel and North Sea herring, and capelin. A substitute relationship means that an increase in the quota of one species, holding the quotas of the other species fixed, will decrease the landings of the non-quota species. However, if one or more of the fixed factors are not binding, either the relationships are statistically insignificant or the non-quota species and the quota species are complements. This means that an increased quota will lead to an increase in landings of non-quota species as well.

While the results indicate that blue whiting and capelin are substitutes, the elasticity of intensity associated with blue whiting is close to zero and statistically insignificant with respect to spring-spawning herring, and mackerel and North Sea herring, the most important quota-regulated fisheries. Moreover, the supply elasticity for blue whiting is positive with respect to other non-quota species and negative with respect to fuel, and statistically significant, while the own-price elasticity is close to zero and statistically insignificant. Hence, it is neither the price of blue whiting nor the quotas on herring and mackerel that determines the landings and fishing effort for blue whiting, but rather the capelin quotas, the price for other non-quota species, and the operation costs, *i.e.,* the price of fuel.

For other non-quota species we see that the landings and fishing effort directed towards these fisheries is to some degree dependent on their own price and the price of fuel, but not on the price of blue whiting. Other non-quota species appear to have a substitute relationship with spring-spawning herring but are complementary to mackerel and North Sea herring.

This paper is organized in the following way. The theory is reviewed in Section II. Section III describes the industry and the data used in the estimation. Section IV presents the empirical model and Section V the estimation strategies. Section VI reports the results and Section VII concludes.

2 Theory

Profit maximization can be a good approximation of the behaviour of the skippers/vessel owners in the relatively unrestricted blue whiting fishery that is free of individual vessel quotas (Squires 1987, Squires 1988, Squires and Kirkley 1991) as opposed to the strictly regulated purse seine fisheries for spring-spawning herring, mackerel and North Sea herring, and capelin, where cost minimization is often considered the proper representation of fishermen's behaviour (Weninger 1998, Bjørndal and Gordon 2000, Nøstbakken 2006).

Both Moschini (1988) and Fulginiti and Perrin (1993) provide a framework for supply management in agriculture. This framework is easily extended to a fishery were some, but not all, outputs are quota regulated.

Consider a production process where a vector y of I outputs is produced during a given period using a vector x of J variable inputs and a vector z of K fixed inputs.

If the maximum allowable output for some components of the vector y is constrained, as in fisheries with individual vessel quotas, total variable profit is maximized when the profit from the unconstrained outputs is maximized. Thus, if the output vector y is partitioned into a subvector y^0 of I^0 for which the constraint is binding and a subvector y^1 of I^1 unconstrained products, and if the output price vector is similarly partitioned into p^0 and p^1, the restricted profit function is defined as:

$$\pi^R(p^1, w, y^0, z) = \max_{y^1}\{p^{1\prime}y^1 - C(y^1, y^0, w, z)\}. \tag{1}$$

Given the properties of the cost function, the restricted profit function $\pi^R(p^1, w, y^0, z)$ is non-decreasing in p^1 and z, non-increasing in w and y^0, convex in (p^1, w), and continuous and twice differentiable. Here, $\pi^R(p^1, w, y^0, z)$ can be viewed as a form of McFadden's (McFadden 1978) restricted profit function and of Diewert's (Diewert 1982) variable profit function, with the explicit extension of the constraints to the output side, which implies that the restricted profit function $\pi^R(p^1, w, y^0, z)$ does not satisfy the property of non-negativity (Moschini 1988).

The restricted profit function satisfies the derivative property (Hotelling's lemma):

$$y^1(p^1, w, y^0, z) = \nabla_{p^1}\pi^R(p^1, w, y^0, z), \tag{2}$$

$$x(p^1, w, y^0, z) = -\nabla_w\pi^R(p^1, w, y^0, z), \tag{3}$$

where ∇ indicates a vector of partial derivatives, and $y^1(p^1, w, y^0, z)$ and $x(p^1, w, y^0, z)$ are the vectors of the unrestricted output supply and variable input demand that maximize profits. From a restricted profit function $\pi^R(p^1, w, y^0, z)$, Hotelling's lemma allows the derivation of an estimable system of output supplies and input demands consistent with the constraint of the underlying technology and with profit maximization under supply constraints. This makes it explicit that the supply of products not subject to supply management and the demand of variable inputs in general depend on the level of restricted commodities, and this dependency can be quantified and tested in empirical applications.

The shadow value of quota holdings is measured as the value to the vessel of a unit increase in quota holdings. The shadow value of the n^{th} vessel, for the quota species, y^0, is written as:

$$SV_n^{y^0} = p_n^0 + \frac{\partial \pi_n^R}{\partial y^0}. \tag{4}$$

The term, p_n^0, is the price paid to vessel n per unit of quota landed of output y^0, where $n = 1, ..., N$. The second term on the right-hand side of (4) represents the change in restricted profit of non-quota landings associated with a one unit change in the quota species in question.

A change in quota landings results in two separate effects on restricted profit: *i*) A one-unit increase in quota landings will increase marginal costs through an increase in the variable input factor necessary to land the additional quota. This will have an unambiguously negative effect on restricted profit that is not related to quota. *ii*) The change in restricted profit from non-quota landings depends on whether there is a substitute or a complementary relationship between non-quota and quota landings. If non-quota and quota landings are substitutes, then marginal restricted profit from non-quota landings will decline as quota landings increase. A complementary relationship will increase marginal restricted profit as landings of quota species increase. The change in restricted profit from non-quota landings for each individual vessel is conditioned on vessel characteristics and other quota holdings.

Following Dupont and Gordon (2006), the two separate effects on marginal restricted profit are separated out by calculating the marginal shadow value (MSV), which focuses only on the decline in restricted profits resulting from the increase in the marginal cost of landing an additional unit of quota.

$$MSV_n^{y^0} = SV_n^{y^0} - \sum_{I^1} \frac{\partial y^1}{\partial y^0} p^1. \tag{5}$$

The elasticity of intensity of unrestricted non-quota outputs with respect to quota output and the shadow value of each of the output- regulated species are two fundamental characteristics of the production structure. The elasticity of intensity is a measure of the change in non-quota landings caused by a one-percentage change in quota landings for a specific species (Diewert 1974). The elasticity of intensity of non-quota landings associated with quota-restricted factors is defined as:

$$\eta_{y^1,y^0} = \frac{\partial y^1}{\partial y^0} \frac{y^0}{y^1}. \tag{6}$$

A negative elasticity of intensity implies that an increase of one per cent in a quota causes a decline in the harvest of the unrestricted landings indicating a substitute relationship between the output- regulated species and unrestricted landings, whereas a positive elasticity of intensity implies that an increase of one per cent in a quota causes an increase in the harvest of non-quota species. In addition, standard price elasticities can be calculated and are conditional on fixed output and fixed input factors.

3 The Industry and Data

The blue whiting (*Micromesistius poutassou*), a small gadoid, characterized as an oceanic semi-pelagic species living in the North East Atlantic (see figure (1)), is one of the most abundant fish species in the Norwegian Sea. The blue whiting stock is a straddling stock. Straddling stocks migrate through waters under different jurisdictions, both national exclusive economic zones (EEZs) and international waters. This behaviour complicates the management of these stocks compared to stocks attached only to one or two EEZs. The international management of blue whiting has many similarities with the management of the spring-spawning herring (Bjørndal, Gordon, Kaitala, and Lindroos 2004).

During the period 1970–1997 the blue whiting fishery was dominated by Russia (former Soviet Union) and Norway, which developed it. Since the late 1990s there has been an increased interest in the blue whiting fishery, and the total landings increased from about 650 thousand tons in 1997 to 2.3 million tons in 2003 (ICES 2004). Iceland, which previously had for a large part ignored the blue whiting fishery, began to substantially increase its blue whiting landings in 1998 (Ekerhovd 2003).

Since 1999, there have been several attempts among the coastal states of the European Union (EU), Norway, Iceland, and Denmark (on behalf of the Faroe Islands and Greenland), and Russia to reach an agreement and set a common maximum total allowable catch (TAC). The negotiations have failed because each nation wants a higher share of the quota than the others are willing to accept (Standal 2006).

Table (1) shows the distributions proposed by each of the nations and what they

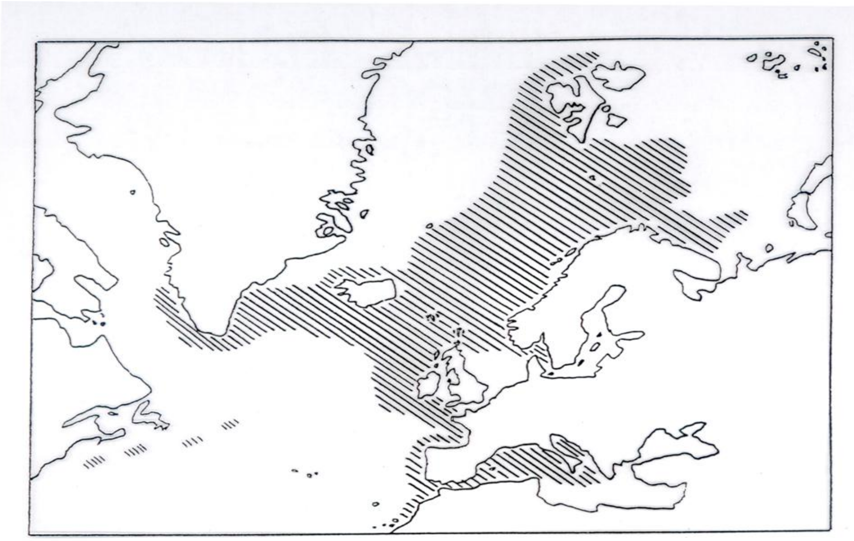

Figure 1: The blue whiting distribution in the North East Atlantic

consider their rightful share of a TAC[1]. The dispute has led the nations to increase their quotas unilaterally during the fishing season in an effort to keep their catches at a certain level according to their claims and, also, in response to increased quotas of other nations.

However, in December 2005 the coastal states of the EU, Faroe Islands, Iceland, and Norway signed an agreement. The agreement, starting in 2006, includes a long run management strategy that implies annual reductions in the landings until the management goals are reached[2].

[1]Notice that the diagonal of the matrix (in bold face) sums to well above 100.

[2]Source: Stortingsmelding nr. 22, 2005–2006, "Om dei fiskeriavtalane Noreg har ingått med andre land for 2006 og fisket etter avtalane i 2004 og 2005", Det Kongelege Fiskeri- og Kystdepartementet (The Norwegian Ministry of Fisheries and Coastal Affairs).

Table 1: Proposal for the distribution of blue whiting quotas (%)†

	EU	Norway	Iceland	Faroe Islands	Russia
EU	**62.51**	30.31	22.41	41.00	?
Norway	12.58	**37.75**	24.94	17.00	?
Iceland	0.43	5.75	**22.00**	5.00	?
Faroe Islands	16.08	17.69	18.43	**31.00**	?
Greenland	0.00	0.63	0.38	0.00	?
Russia	8.40	7.88	9.53	6.00	**20.00**
Total	100.0	100.0	100.0	100.0	20.00

Source: The Norwegian Directorate of Fisheries, 2003; in Ekerhovd (2003).

† Claims proposed in negotiations in 2000.

3.1 The Norwegian Fishery Management System

According to Årland and Bjørndal (2002), two main characteristics of the Norwegian fisheries management system are restricted access through licensing schemes and restricted harvesting levels through quotas. Capacity is restricted through licensing in the purse seine fleet. To be allowed to fish blue whiting a special licence is needed[3].

Although, in reality, the licences are transferable, this system is rigid compared to individual transferable quotas and does not lead to a reduction in overcapacity. To facilitate this the so- called unit quota system was implemented, which allows for the concentration of more quotas per vessel (Årland and Bjørndal 2002). However, the unit quota system has not been as effective as some had hoped for. The fact that these quota rights only last for 13 or 18 years has made the purchase of additional quotas through the unit quota system less attractive than it would have been had the property

[3]A licence is issued to a particular owner and a particular vessel. If the vessel is sold or replaced by a new one, a transfer of the fishing licence must be approved by the fishing authorities. Hence, implicit in the price paid for a purse seiner, with the licence transferred to the new owner, is the value of the purse seining licence in general and the blue whiting licence in particular.

right to the quota been permanent. Transfer of fishing rights has to be approved by the fisheries authorities. Facilitation of approval requires the assistance of lawyers and brokers. Thus, high transaction costs are linked to investment in quotas from other vessels (Standal 2006).

The purse seiners are allocated individual vessel quotas (IVQs)[4] for all targeted species, except for blue whiting and other non-specified species. The blue whiting quotas, set unilaterally by Norway or acquired through exchanging quotas with other nations, are not divided into IVQs, but the vessels are allowed to catch as much as they can until the total quota is fished (Årland and Bjørndal 2002). Not dividing the total quota into IVQs gives incentives to compete for the fish as the fishery may be closed once the quota has been fished.

3.2 The Norwegian Blue Whiting Fishing Fleet

The sample used in the estimation consists of an unbalanced panel data series of the combined Norwegian purse seining and pelagic trawler fleets from 1990 to 2003 collected by the Norwegian Directory for Fisheries (1991–2004). The data include vessel length, fuel expenditure, and information on the quantity and value of the landings of fish. The landings are divided into spring-spawning herring, North Sea herring[5], mackerel[6], blue whiting, capelin[7] and other unspecified fish species[8]. These vessels target pelagic species, with herring and mackerel as the most important ones, using a purse seine net to catch schools of fish and a pelagic trawl to catch blue whiting[9]. Table (2) shows the species targeted by the purse seiners/pelagic trawlers

[4] The IVQs are "non-transferable" in the sense that they cannot be rented out on a yearly basis, but can be bought and sold as described above.

[5] (Norwegian) Spring-spawning herring and North Sea herring are subspecies of the Atlantic herring, *Clupea harengus harengus.*

[6] *Scomber scombrus*

[7] *Mallotus villosus*

[8] Atlantic horse mackerel (*Trachurus trachurus*) and sprat (*Sprattus sprattus*) make up the largest components of the non-quota species and are harvested in the North Sea and adjacent waters.

[9] After locating a school of fish, the vessel sails around it and encircles the fish with a net. By closing the bottom of the seine, a purse is formed. When the seine is pulled, the top of the purse is drawn closed and the fish are trapped in the net purse. Blue whiting, on the other hand, are caught using a pelagic trawl. A trawl is a cone-shaped net pulled through deep water, scooping the fish into the trawl.

by area, gear type, and the time of the year they fished the respective species[10]; each fishing season has at least one time-overlap with other fishing seasons.

The main fishing of the blue whiting stock takes place from January through April in the North East Atlantic, in waters west of Ireland. This coincides with the capelin fishery of the coast off Finnmark (adjacent to the Barents Sea), and the spring-spawning herring fishery. The spring-spawning herring fishing season lasts from October to April the following year. This means that herring forgone in the winter season, if the vessels choose to fish blue whiting instead, can be caught later. Blue whiting is to some extent fished in summer and early autumn in the Norwegian Sea, but as table (2) shows this is probably the busiest time of the year for these vessels, with North Sea herring, mackerel, and capelin to catch in addition to blue whiting[11]. This illustrates that the vessels are more or less fully occupied throughout the year, catching both quota-regulated fish, *i.e.,* spring-spawning herring, North Sea herring, mackerel, and capelin, and non-quota fish, such as blue whiting and other non-quota species, and that a change in the quotas can affect the blue whiting quantity and vice versa.

In the analysis we only use data on purse seiners fishing for blue whiting. Table 3 reports some summary statistics of the sample of the Norwegian purse seiners/blue whiting trawlers.

[10] "Kart over norske fangster 2001 og 2004". Fiskeridirektoratet (Directorate of fisheries), Bergen, www.fiskeridir.no

[11] Note that individual vessel quotas are given on a yearly basis, from January 1st to December 31st, during which the quotas have to be taken or forfeited

Table 2: Fishing season for the Norwegian purse seiner fleet, by species, area, gear, and month †

		Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Species	Area	Gear												
Capelin	Barents Sea	PS‡	X	X	X	X								
Capelin	Iceland	PS						X	X	X	X			
BW††	Norwegian Sea	PT‡‡					X	X	X	X	X			
BW††	Atlantic	PT	X	X	X	X								
Mackerel	Norway	PS								X	X	X		
Mackerel	North Sea	PS					X	X	X	X	X	X	X	
NSH†††	North Sea	PS					X	X	X	X	X	X	X	X
SSH††††	Norway	PS	X	X	X							X	X	X

"X" indicates in what months and areas each species is fished.
† Source: Fiskeridirektoratet (Directorate of fisheries), Bergen, www.fiskeridir.no
†† BW = Blue whiting
††† NSH = North Sea herring
†††† SSH = Spring-spawning herring
‡ PS = Purse seine
‡‡ PT = Pelagic trawl

Table 3: Summary statistics of the sample vessels

Statistics	Mean	Min	Max	St. Dev.
Variables				
Observations	234	0	0	0
Vessel length†	65.38	49.35	77.4	5.92
Fuel expenditure††	3.825	1.039	7.564	1.043
Qty.††† blue whiting	11,333	61.238	26,670	5,899
Qty. other non-quota	948	0	6,010	1,050
Qty. SSH‡	3,160	118	7,632	1,579
Qty. North Sea herring	1,069	129	2,804	428
Qty. mackerel	1,522	998	2,648	329
Qty. capelin	3,738	0	12,560	2,294
Value†† blue whiting	9.648	0.018	32.085	5.653
Value other non-quota	1.828	0	8.157	1.761
Value SSH	9.239	0.445	19.179	4.398
Value North Sea herring	2.754	0.389	6.449	0.977
Value mackerel	10.503	5.454	19.103	2.627
Value capelin	3.788	0	15.093	2.570

† metres

†† million Norwegian Kroner (2001)

††† tons

‡ SSH = spring-spawning herring

Initial econometric work revealed a singularity problem in the regressor matrix.

Correlation coefficients[12] indicated that the singularity is caused by a high correlation between mackerel and North Sea herring. These species are harvested within the same geographic area under similar environmental conditions and quotas are determined based on similar regulatory principles. It was therefore decided to combine mackerel and North Sea herring into a single restricted output, using a Fisher quantity index for aggregation (Asche, Gordon, and Jensen forthcoming).

The purse seiners that trawl for blue whiting, in addition to the species caught by purse seine, are a unique fleet segment separable from the other purse seiners. The blue whiting is fished with a trawl while the other targeted species are caught using a purse seine. The purse seiners that participate in the blue whiting fishery must be rigged for both trawling and purse seining. Vessels fishing in the North Atlantic during wintertime need to be well built and the size of the pelagic trawl used in the blue whiting fishery requires vessels that are equipped with big engines. The need for power and strength, as well as an ability to handle large catches, separates the blue whiting fleet from the conventional purse seiners. Another feature of the blue whiting fishery distinguishing it from purse seining is the management regime; in most other fisheries targeted by purse seiners the TAC is divided among the individual vessels, while for the blue whiting there were no IVQs prior to 2006. This has lead to an expansion in the blue whiting fishery in order to increase the revenue of the vessels (Standal 2006).

The purse seiners engaged in blue whiting fishing are usually the larger vessels in

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	BW	Other	SSH†	NSH††	Mackerel	North Sea†††	Capelin
BW	1.000						
Other	-0.248	1.000					
SSH	0.398	-0.286	1.000				
NSH	-0.120	0.529	-0.419	1.000			
Mackerel	-0.246	0.381	-0.364	0.565	1.000		
North Sea	-0.247	0.483	-0.435	0.768	0.968	1.000	
Capelin	-0.226	-0.047	-0.414	0.058	-0.441	0.366	1.000

† Spring-spawning herring
†† North Sea herring
††† North Sea is a Fisher quantity index over the quantities of mackerel and North Sea herring.

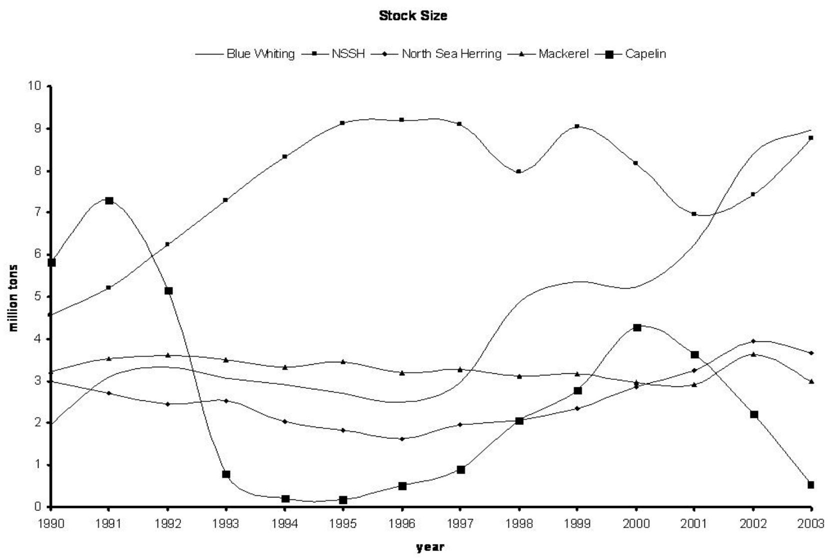

Figure 2: Stock size of blue whiting, spring-spawning herring, North Sea herring, mackerel, and Barents Sea capelin

the fleet with an average length of about 65 metres and displacement over a thousand tonnes. Because of the size of the pelagic trawls, the vessels require huge engine power in order to be able to operate the gear. Moreover, the fish are stored in the hold in refrigerated seawater. Refrigerating and circulating the seawater, operating the gear, and sailing between the port and fishing grounds burns a large amount of fuel. Fuel expenditure therefore constitutes the vessels main variable cost.

Blue whiting is a very important fishery for these vessels; with respect to quantity, blue whiting makes up about 52% of the total landings compared to 14.5% for spring-spawning herring and only 7% for mackerel. In value terms[13] blue whiting is still important but to a lesser extent; mackerel is the most valuable fish, making up about 28% of revenue followed by blue whiting (26%) and spring-spawning herring (24%).

Capelin and other non-quota species are not fished by all vessels every year. The capelin fishery in the Barents Sea was banned in the years 1987–1990, 1994–1998, and again from 2004. The fishery was re-opened in the winter season 1991 and again in the winter season 1999, following recovered stocks, see figure (2) (ICES 2004). Then there

[13]Monetary values referred to in table (3) are in real 2001 terms.

is the Norwegian quota in the Iceland capelin fishery, which is small compared to the quota in the Barents Sea fishery. In some years vessels skip the Iceland capelin. The other non-quota species are reported unspecified and represent unrestricted landings, *i.e.,* no IVQs are allocated for these species.

4 Empirical Model

The choice of functional form to be used in estimating a restricted profit function is important because profits can be positive or negative in such a constrained setting. Fulginiti and Perrin (1993) avoid this problem by constraining inputs as well as outputs in order to ensure that variable profits are positive. In this way, they can use a standard translog functional form. However, negative variable profits require alternative functional forms and Moschini (1988) uses a normalized quadratic equation, normalizing using one input factor. Diewert and Wales (1987) and Kohli (1993) show that the estimated results for this functional form depend on the normalization. These authors suggest a symmetric normalized quadratic functional form to avoid this problem and we use this empirical equation here.

A normalized quadratic functional form is well suited to modelling multiple-output technologies and it is easy to impose curvature properties on the model (Diewert and Wales 1987, Kohli 1993). Moreover, the restricted profit function, characterized by Lau (1976), can also illustrate the economic value of the restrictions (Moschini 1988). Obtaining the shadow prices per unit of a non-quota species conditioned on the vessel's own quota holdings allows us to obtain shadow values indirectly through observed choices (Dupont and Gordon 2006).

We start by defining a normalized quadratic restricted profit function (Lau 1976, Diewert and Ostensoe 1988, Moschini 1988, Dupont and Gordon 2006) for the Norwegian purse seine vessels licensed to fish blue whiting over the prices of three variable factors: The price of fuel[14] (F), as a variable input factor, and prices of blue

[14]The price of fuel is not included in the costs and earnings survey—only fuel expenditure; instead, an index for the wholesale prices for solid, liquid, and gaseous fuels and related products was used as a proxy for the fuel prices. Source: Statistics Norway, www.ssb.no

whiting (BW) and other unspecified non-quota fish species (O) as variable outputs. The variable quantities are conditioned on four fixed factors: Vessel length, L, as a proxy for capital, and fish landings under supply management: Spring-spawning herring (H), mackerel and North Sea herring (M)[15], and capelin (C). The normalized restricted profit function, assuming constant returns to scale[16], can be written in the following way:

$$\begin{aligned}\pi^R(p;\bar{q}) \equiv & \frac{1}{2}\left(\alpha'\bar{q}\sum_{i=1}^{3}\sum_{k=1}^{3}a_{i,k}p_ip_k\right)/p_f \\ & +\frac{1}{2}\left(\beta'p\sum_{j=1}^{4}\sum_{h=1}^{4}b_{j,h}\bar{q}_j\bar{q}_h\right)/\bar{q}_L \\ & +\sum_{i=1}^{3}\sum_{j=1}^{4}c_{i,j}p_i\bar{q}_j,\end{aligned} \tag{7}$$

where the prices of the variable quantities are indexed i and k, while the fixed factor quantities are indexed j and h. The function is normalized and thus p_F and $\bar{q}_L$ are chosen as *numèraires*[17].

We define matrix A with elements $a_{i,k}$. Because of the linear relationship between rows and columns in matrix A caused by linear homogeneity, the first row and column of A, are vectors of zeroes, $a_{F,k}$ through $a_{k,F}$ for the price of blue whiting, other non-quota species and fuel, respectively. Similarly, we define the matrix B with elements $b_{j,h}$. Because of linear homogeneity, the first row and column in matrix B are vectors of zeroes, and $b_{L,h}$ through $b_{h,L}$ are for vessel length and spring-spawning herring, mackerel and North Sea herring, and capelin landings.

Following Dupont and Gordon (2006), $\alpha'\bar{q}$ is defined as a Fisher quantity index over the fixed factors, $\bar{q}_j$, $j = L, H, M, C$[18], and $\beta'p$ is defined as a Fisher price index

[15]The quantity, q_M, is a Fisher quantity index over the quantities of mackerel and North Sea herring.

[16]The constant returns to scale assumption rests upon the fact that the vessels in the sample are fairly large and the assumption that an increase in size leads to only a proportional increase in capacity

[17]Given that we want to know something about the relationship between the variable and the fixed outputs, using the variable and fixed inputs as *numèraires* seems to be the natural choice

[18]The effective interest rate, Norwegian InterBank Offered Rate (NIBOR), is used as a proxy for the price of capital. Source: Norges Bank, The Norwegian Central Bank, Oslo.

over the variable input and output prices p_i, $i = O, BW, F$.

The normalized quadratic profit function described in equation (7) must satisfy the conditions required for it to represent the underlying production technology. The function is linear homogeneous, convex in prices and concave in fixed factors, separately. Symmetry in the cross-price and cross-quantity terms is obtained by defining the matrices A and B to be symmetric. The restricted profit function is convex in prices and concave in fixed factors globally, as well as locally, whenever the A matrix is positive semi-definite and the B matrix is negative semi-definite (Diewert and Wales 1987).

Instead of estimating the restricted profit function in (7), it is more convenient to estimate the system of the three variable quantity equations given in (8), (9), and (10). These equations, two for the supply of variable landings and one for the demand for fuel, are obtained by using Hotelling's lemma. These equations are formulated in actual quantities, not input or revenue shares; therefore, all three equations must be estimated to obtain the parameters in equation (7).

$$\begin{aligned}\frac{\partial \pi^R}{\partial p_O} &= q_O(p_O, p_{BW}, p_F; \bar{q}_L, \bar{q}_H, \bar{q}_M, \bar{q}_C) \\ &= \alpha' \bar{q}\Big(a_{O,O}p_O + a_{O,BW}p_{BW}\Big)/p_F \\ &+ \frac{1}{2}\Big(\beta_O \sum_{j=2}^{4}\sum_{h=2}^{4} b_{j,h}\bar{q}_j\bar{q}_h\Big)/\bar{q}_L \\ &+ \sum_{j=1}^{4} c_{O,j}\bar{q}_j,\end{aligned} \tag{8}$$

$$
\begin{aligned}
\frac{\partial \pi^R}{\partial p_{BW}} &= q_{BW}(p_O, p_{BW}, p_F; \bar{q}_L, \bar{q}_H, \bar{q}_M, \bar{q}_C) \\
&= \alpha' \bar{q}\Big(a_{O,BW} p_O + a_{BW,BW} p_{BW} \Big) / p_F \\
&+ \frac{1}{2}\Big(\beta_{BW} \sum_{j=2}^{4} \sum_{h=2}^{4} b_{j,h} \bar{q}_j \bar{q}_h \Big) / \bar{q}_L \\
&+ \sum_{j=1}^{4} c_{BW,j} \bar{q}_j,
\end{aligned} \tag{9}
$$

$$
\begin{aligned}
\frac{\partial \pi^R}{\partial p_F} &= -q_F(p_O, p_{BW}, p_F; \bar{q}_L, \bar{q}_H, \bar{q}_M, \bar{q}_C) \\
&= -\frac{1}{2}\Big(\alpha' \bar{q} \sum_{i=1}^{2} \sum_{k=1}^{2} a_{i,k} p_i p_k \Big) / p_F^2 \\
&+ \frac{1}{2}\Big(\beta_f \sum_{j=2}^{4} \sum_{h=2}^{4} b_{j,h} \bar{q}_j \bar{q}_h \Big) / \bar{q}_L \\
&+ \sum_{j=1}^{4} c_{F,j} \bar{q}_j,
\end{aligned} \tag{10}
$$

for $i, k = O, BW, F$ and $j, h = L, H, M, C$.

Cross-equation and symmetry restrictions, $a_{i,k} = a_{k,i}$ for i, k and $b_{j,h} = b_{h,j}$ for j, h in both equations, have already been imposed in (8), (9), and (10). The linear homogeneity restrictions, $a_{i,F} = 0$ for $i = O, BW, F$, and $b_{j,L} = 0$ for $j = L, H, M, C$, are imposed by dropping them from the estimating equations. β_i, $i = O, BW, F$, may be chosen arbitrarily[19] (Diewert and Wales 1987).

5 Estimation Strategy

Prior to estimation, additive disturbance terms are appended to each of the three quantity equations (8), (9), and (10). The estimation begins with the linear system

[19] Here, the βs are set such that they sum to one. Although several possible combinations of β_i were tested, the combination that appears to be best suited, $\beta_{BW} = 0.5$ and $\beta_O = \beta_F = 0.25$, is used in the estimations.

of equations (8), (9), and (10). Zellner's iterative technique for seemingly unrelated regressions is used. The sample consists of an unbalanced panel of 53 vessels, covering the years from 1990 to 2003.

If the unobserved variables are correlated with the other explanatory variables, estimation will yield biased results, *i.e.,* the omitted variable problem.

Over the time period 1990–2003 there were significant changes in technology and restructuring of the fleet (Standal 2006, Årland and Bjørndal 2002), in the competition between the blue whiting fishing nations (Ekerhovd 2003), and in the size of the fish stocks (ICES 2004). Taking account of these changes, the model is estimated with a binary variable for each year[20] with 2001 as the base year.

In addition to the prices of the variable inputs and outputs conditioned on the restricted input and output factors, the restricted profit in non-quota fisheries is expected to depend on the biomass of the stocks of non-quota species as well as the skills of the owner/skipper/crew and the physical characteristics of each vessel[21]. Although the blue whiting stock biomass is given in ICES (2004)[22], the lack of knowledge about what species are included in the other non-quota species component makes it difficult to come up with a good measure for stocks. Despite this, the stock effect is one of several effects controlled for by the dummy variables for each year. That leaves us with the unobserved skills of the owner/skipper/crew, a factor that needs special treatment.

The fixed effects method is a way of neutralizing the unobserved effect of skills. This technique is equivalent to assigning dummies for the vessels, an approach used in this paper. Of the 53 vessels in the sample, 52 vessels were assigned dummy variables[23].

[20]A binary variable takes the value one for a specific year, and zero for all others.

[21]The physical characteristics of the vessel are correlated with vessel length, which is already in the model.

[22]The annual assessment of the stock is uncertain, but its accuracy improves over time (Sandberg 2006). The inclusion the blue whiting biomass in the supply equation for blue whiting (9) resulted in a negative coefficient so the variable was dropped.

[23]Originally, the data were drawn from the Norwegian purse seiner fleet providing data on pure purse seining vessels as well as purse seiners holding blue whiting licences. Because the focus of this study is on blue whiting, all the pure purse seiners were excluded from the sample. Introduction of the fixed effects method led to further exclusions; it was not possible to estimate the model using fixed effect dummies on vessels that appeared in the data for less than three years. The vessel used as the base vessel was the vessel with the highest observed profit, which was in 2001. Therefore, the fixed effect dummies should be interpreted relative to this vessel in 2001.

If convexity and concavity are rejected by the data[24], which turns out to be the case, they can be imposed by reparameterization of the A and B matrices using the technique described by Wiley, Schmidt, and Bramble (1973) (Dupont 1991). This reparameterization uses the product of a matrix Δ and its transpose to replace the A matrix, i.e., $A = \Delta\Delta'$. The equivalent for the B matrix is $B = -DD'$. The Δ and D matrices are lower triangular matrices with zeros in the first columns.

$$\begin{bmatrix} a_{F,F} & a_{F,O} & a_{F,BW} \\ a_{O,F} & a_{O,O} & a_{O,BW} \\ a_{BW,F} & a_{BW,O} & a_{BW,BW} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \delta_1 & 0 & 0 \\ \delta_2 & \delta_3 & 0 \end{bmatrix} * \begin{bmatrix} 0 & \delta_1 & \delta_2 \\ 0 & 0 & \delta_3 \\ 0 & 0 & 0 \end{bmatrix} \tag{11}$$

$$\begin{aligned} &\begin{bmatrix} b_{L,L} & b_{L,H} & b_{L,M} & b_{L,C} \\ b_{H,L} & b_{H,H} & b_{H,M} & b_{H,C} \\ b_{M,L} & b_{M,H} & b_{M,M} & b_{M,C} \\ b_{C,L} & b_{C,H} & b_{C,M} & b_{C,C} \end{bmatrix} \\ &= -\begin{bmatrix} 0 & 0 & 0 & 0 \\ d_1 & 0 & 0 & 0 \\ d_2 & d_3 & 0 & 0 \\ d_4 & d_5 & d_6 & 0 \end{bmatrix} * \begin{bmatrix} 0 & d_1 & d_2 & d_4 \\ 0 & 0 & d_3 & d_5 \\ 0 & 0 & 0 & d_6 \\ 0 & 0 & 0 & 0 \end{bmatrix} \end{aligned} \tag{12}$$

While it is still possible to obtain separate elasticity estimates for each pair of inputs and outputs, the reparameterization requires a non-linear estimation technique. A new set of equations must be estimated using a non-linear maximum likelihood procedure because the $a_{i,k}$, $i, k = O, BW$, and $b_{j,h}$, $j, h = H, M, C$, parameters, respectively, are replaced by the appropriate combinations of the δ and d parameters from the Δ and D matrices, respectively equations (11) and (12). The correspondences between the $a_{i,k}$ and δ parameters are as follows: $a_{O,O} = \delta_1^2$, $a_{O,BW} = \delta_1 * \delta_2$, and $a_{BW,BW} = \delta_2^2 + \delta_3^2$.

[24]Failing to obtain convexity or concavity does not necessarily mean that the assumption of profit maximization is violated. Other reasons may exist, such as insufficient price variation in the data, multicollinearity, and aggregation of input or output quantities to obtain indexes (Squires 1987, Dupont 1991).

Whereas, the correspondences between the $b_{j,h}$ and the d parameters are $b_{H,H} = -d_1^2$, $b_{H,M} = -d_1 * d_2$, $b_{H,C} = -d_1 * d_4$, $b_{M,M} = -(d_2^2 + d_3^2)$, $b_{M,C} = -(d_2 * d_4 + d_3 * d_5)$, and $b_{C,C} = -(d_4^2 + d_5^2 + d_6^2)$.

6 Results

Table (4) reports the estimated parameters and standard errors for the estimation of equations (8), (9), and (10). The results for the fixed effect and the year dummies are not reported. Tests for correlation of the data from the vessels with the highest number of observations in the sample (eight and nine years) suggests that the problem of serial correlation is not an issue. Furthermore, because the vessels were all fairly large and of a homogeneous type, the possibility of heteroscedasticity in the variance is considered small.

Columns 1 and 2 in Table (4) represent the elements of Δ and D matrices, which will be used in the reparameterization of the A and B matrices. The other columns of Table (4) illustrate the effect the constrained factors have on the unrestricted factors, parameters $c_{i,j}$ in equation (7), where $i = O, BW, F$ and $j = L, H, M, C$. The results should be interpreted as if keeping all other things constant (*ceteris paribus*).

Table (5) shows the price elasticities for the variable factors. The landings of blue whiting are insensitive to changes in its own price, while they appear to be sensitive with regard to the price of other non-quota species and the price of fuel[25]. The landings of blue whiting appear to increase with the price of other non-quota species, which is surprising, but, as expected, decreasing as the price of fuel increases.

[25] Nøstbakken (2006), and Bjørndal and Gordon (2000) also reported the input factor demand for the purse seiners to be inelastic.

Table 4: The restricted profit function

Variable name	Δ and D matrices	Dependent variable	Blue whiting	Other non-quota species	Fuel
δ_1	-0.2140***	Independent variable			
	(0.0471)†	Vessel length	188157***	1106	-16487***
δ_2	0.5039***		(23734)	(4595)	(5283)
	(0.1987)	Herring quantity	0.0871	-0.2378***	0.1065E-3
δ_3	0.2033E-9		(0.1158)	(0.0379)	(0.0022)
	(0.5799)	North Sea quantity	-0.0625	0.1112***	-0.7197E-3
d_1	0.2806E-3*		(0.0412)	(0.0127)	(0.6999E-3)
	(0.1647E-3)	Capelin quantity	-0.3529***	-0.0528*	-0.0021***
d_2	0.8372E-4		(0.0991)	(0.0285)	(0.8958E-3)
	(0.5078E-4)				
d_3	0.1558E-3***				
	(0.6531E-4)				
d_4	-0.2915E-10				
	(0.3471E-3)				
d_5	0.1606E-10				
	(0.1780E-3)				
d_6	0.3820E-14				
	(0.1671E-3)				

N = 234
Log-likelihood function = -9426.873.
† Standard errors are in parentheses.
*** statistically significant at the 1% level.
** statistically significant at the 5% level.
* statistically significant at the 10% level.

Table 5: Price elasticity estimates†

Variable prices	Blue whiting	Other Non-Quota Species	Fuel
Variable quantities			
Blue Whiting	0.0068	0.0169***	-0.0139*
	(0.0053)††	(0.0029)	(0.0079)
Other Non-Quota Species	0.0146	0.0364**	-0.0707***
	(0.0136)	(0.0160)	(0.0239)
Fuel	0.0350*	0.0372***	-0.0721***
	(0.0198)	(0.0126)	(0.0281)

† Estimates use means of the data.

†† Standard errors are in parentheses. Asymptotic standard errors use the formula for the variance of a random variable that is a non-linear function of several random variables (Davidson and MacKinnon 2004).

*** statistically significant at the 1% level.

** statistically significant at the 5% level.

* statistically significant at the 10% level.

The landings of other non-quota species are insensitive to changes in the price of blue whiting, but appear to increase with their own price and decrease with the price of fuel. The amount of fuel increases with the price of blue whiting and the price of other non-quota species, and declines as its own price increases. Hence, the combined purse seiners and blue whiting trawlers seem not only responsive to input price changes but also to changes in the price of the unrestricted outputs, especially the price of other non-quota species. Thus, it is not only available excess capacity and fishing season considerations that decide the combined purse seiners' and blue whiting trawlers' production of unrestricted output. This is in contrast to what Asche, Gordon, and Jensen (forthcoming) found: that the purse seiners seem not to be responsive to changes in the price of the unrestricted outputs. Let it be stressed here that this work is not a replication of Asche, Gordon, and Jensen's that analyses the behaviour of purse seiners without blue whiting fishing licences, but an application of a similar framework to a segment of the Norwegian purse seiner fleet that fishes blue whiting in addition to herring, mackerel, and capelin. Moreover, our data series runs from 1990 to 2003, while their data series runs from 1992 to 1999. Blue whiting is an important species for the participating vessels, taking up a significant part of their available days at sea, leaving less time to target other non-quota species. The size of the blue whiting vessels, and the engine power required, can explain the importance of the price of fuel on production of unregulated outputs. Thus, the other non-quota species' contribution to the restricted profit can affect to what degree these vessels produce unrestricted outputs.

Table (6) presents the elasticities of intensity for the quota-regulated outputs: spring-spawning herring, mackerel and North Sea herring, and capelin. Looking first at the elasticities associated with blue whiting, for both spring-spawning herring and mackerel and North Sea herring these are not statistically significant, while statistically significant and negative for capelin. This indicates a substitute relationship between blue whiting and capelin.

According to Table (2) that shows the different fishing seasons, there is an overlap between the main season for fishing blue whiting on its spawning grounds in the North East Atlantic and fishing for capelin on the coast of Northern Norway, both taking place in winter and early spring. The capelin quotas have changed substantially over the years and the substitute relationship implies that an increase in the capelin quota causes a decrease in the landings of blue whiting. This is reasonable because of the overlap in fishing seasons, because the respective fisheries take place in waters far apart, and both capelin and blue whiting are low-valued species. Specifically, a 1% increase in the capelin quota causes a 0.12% decline in the harvest of blue whiting. This low, but statistically significant, elasticity probably reflects that the expanded fishing capacity makes it possible for the vessels to accommodate substantial increases in the capelin quotas without a similar reduction in the blue whiting harvest[26].

[26]Standal (2006) and Nøstbakken (2006) have documented substantial increases in capacity as well as economies of scale in Norway's pelagic fishing fleet.

Table 6: Elasticity of intensity†

Restricted outputs	Spring-spawning herring	Mackerel and North Sea herring	Capelin
Variable quantities			
Blue whiting	0.0257	-0.0870	-0.1164***
	(0.0322)††	(0.0591)	(0.0327)
Other non-quota species	-0.7844***	2.0989***	-0.2084
	(0.1263)	(0.2180)	(0.5047)
Fuel	-0.1029	0.4516	0.2691***
	(0.2224)	(0.3461)	(0.0475)

† Estimates use means of the data.

†† Standard errors are in parentheses. Asymptotic standard errors use the formula for the variance of a random variable that is a non-linear function of several random variables (Davidson and MacKinnon 2004).

*** statistically significant at the 1% level.

The elasticity associated with other non-quota species with respect to spring-spawning herring is negative and statistically significant. A 1% increase in the quota for spring-spawning herring causes a reduction of 0.78 % in the harvest of other non-quota species, implying a substitute relationship between these two fisheries. Looking at the quota effect of mackerel and North Sea herring on other non-quota species, on the other hand, revealed a strong complementary relationship, where a 1% increase in the quotas for mackerel and North Sea herring causes an increase of 2.1% in the harvest of other non-quota species. Because by-catch is not an issue in these fisheries this result needs further explanation. Although other non-quota species are low- value species relative to mackerel and North Sea herring, they are fished in the same waters, *i.e.,* mainly the North Sea and adjacent waters, using the same technology, *i.e.,* purse seine, under the same environmental conditions, and an increase in the quotas for mackerel and North Sea herring increases the time spent in these waters allowing the vessels to catch more of the other non-quota species whenever an opportunity to do so presents itself. Hence, the strong complementarity between mackerel and North Sea herring and other non-quota species. Between other non-quota species and capelin there appears to be no statistically significant relationship.

Asche, Gordon, and Jensen (forthcoming) found the unregulated species to be substitutes for spring-spawning herring, and mackerel and North Sea herring, with almost a one-to-one relationship between mackerel and North Sea herring, and unregulated species. In this work, however, we find that other non-quota species have close to a one-to-one substitute relationship with spring-spawning herring, and are in a strong complementary relationship with mackerel and North Sea herring.

The demand for fuel does not seem to be statistically significant, as affected by changes in the spring-spawning herring, mackerel and North Sea herring quotas. Changes in the capelin quota, on the other hand, have a strong positive, statistically significant effect on the demand for fuel. Specifically, a 1% increase in the capelin quota will be accompanied by 0.27% increase in the purse seiners demand for fuel. The capelin is not only a low-price species but a high-cost fishery too.

Once again according to Table (2), it is not just blue whiting and capelin that have an important fishing season in the first months of the year; simultaneously, a substantial part of the quota for spring-spawning herring is caught during the first months of the year. However, spring-spawning herring is also fished in the late autumn, enabling the vessels to fish all, or a part, of their quota either early or late in the year. Thus, it is possible that in years when the winter capelin fishery is open, the vessels concentrate on catching their capelin quota and then switch to blue whiting for the rest of the season, postponing the spring-spawning fishery until autumn. By doing so they are more focused on catching their quotas of mackerel and North Sea herring before fishing for the spring-spawning herring, leaving less time to fish other non-quota species.

Table (7) reports the average real prices of spring-spawning herring, mackerel and North Sea herring, and capelin along with their respective shadow values and marginal shadow values. Comparing the prices and the shadow values with the marginal shadow values tells us something of the overall relationship between the non-quota species (*i.e.,* blue whiting and other non-quota species) and the various restricted outputs, as well as the marginal cost of producing the restricted outputs. The shadow values of both spring-spawning herring and capelin, both statistically significant, are higher than their respective marginal shadow values, only statistically significant for spring-spawning herring, but less than the respective prices, suggesting a substitute relationship between the non-quota species and spring-spawning herring and capelin. For mackerel and North Sea herring, on the other hand, the shadow value is higher than the price and higher than the marginal shadow value; these results are statistically significant, indicating a complementary relationship between the unrestricted outputs and mackerel and North Sea herring.

Table 7: Prices and shadow values†

Restricted outputs	Spring-spawning herring	Mackerel and North Sea herring††	Capelin
Prices and values			
Real price	3.2490***	0.8414***	1.0806
	(1.1919)†††	(0.2138)	(0.9260)
Shadow value	2.8824***	0.9602***	0.4904***
	(0.2229)††††	(0.0749)	(0.1270)
Marginal shadow value	3.2407***	0.7806***	0.8392
	(0.1885)	(0.0599)	(7036231)

† Estimates use means of the data.

†† The price of mackerel and North Sea herring is a Fisher price index over the price of the two species.

††† Standard errors are in parentheses.

†††† Asymptotic standard errors use the formula for the variance of a random variable that is a non-linear function of several random variables (Davidson and MacKinnon 2004).

*** statistically significant at the 1% level.

The differences between the prices and marginal shadow values are the marginal costs of catching more of the quota species, holding the landings of the non-quota species constant. For capelin the marginal cost is about 22.3% of the price, but, because the price and the marginal shadow value are not statistically significant, the marginal costs are probably much higher for the majority of observations, and may in fact be higher than the price for some. The low and variable profitability of the capelin fishery is probably caused by the large volatility in the stock, with highly variable quota levels and prices, and remote fishing location north of Norway and Iceland.

Catching one extra unit of mackerel and North Sea herring comes at an expense of 7.2% of the price. The cost of catching one extra unit of spring-spawning herring, however, is only 0.26% of the price and statistically significant. The relatively low quota levels on mackerel, North Sea herring, and spring-spawning herring and the expanded fishing capacity of the vessels explain the low marginal costs. By exploiting the spare capacity, marginal increases in the quota levels can be accommodated without increasing the number of trips[27].

7 Concluding Remarks

Asche, Gordon, and Jensen (forthcoming) found the catch of unrestricted fish to be a substitute for the IVQ-regulated fisheries on spring-spawning herring, mackerel, and North Sea herring, with an almost one-to-one relationship with mackerel and North Sea herring. Moreover, they found only the own price elasticity of operation costs to be different from zero and statistically significant, and, thus, it is not the price of the unregulated species that determines landings and fishing effort for these species. Finally, they claim that IVQs give strong incentives to increase fishing effort, particular

[27]These marginal costs may seem unreasonably small and a few comments may be required. Firstly, the marginal shadow value focuses only on the change in restricted profits from a change in the quota, holding the unrestricted harvest constant. Thus, the potential gains and losses from changes in the unrestricted outputs that occur when quotas change are not part of the marginal shadow value. Secondly, operation costs can include costs of fuel, wages, insurance, bait and other variable costs. However, in this paper operating costs are identical to fuel expenditure. Because some of the other costs are not reported for all observations, including them in an operating costs index would mean a loss of observations. Because they are only reported as expenditures, it was decided to use fuel expenditure as a proxy for operating costs. Had other variable costs been included, marginal costs would of course have been higher too. Finally, changes in the TACs for the restricted outputs will usually be announced in advance of, or very early in, the fishing season, thus enabling the fishermen to take this into account in their planning and land more fish per trip without having to increase the number of trips.

when the quotas are reduced.

What Asche, Gordon, and Jensen (forthcoming) called unrestricted catch is comparable to what is called the other non-quota species in this paper, where the purse seiners are licensed to catch blue whiting in addition to other non-quota species, spring-spawning herring, mackerel, North Sea herring, and capelin. Our results for other non-quota species and fuel expenditure differ from Asche, Gordon, and Jensen's results regarding unrestricted catch and operation costs. We found the catch of other non-quota species to have a close to one-to-one substitute relationship with the quota on spring-spawning herring, and a strong complementary relationship with mackerel and North Sea herring, such that a reduction in the quota for spring-spawning herring would lead to more fishing effort directed towards the other non-quota fisheries, while a reduction in the quotas for mackerel and North Sea herring would be followed by a strong decrease in the catch of other non-quota species. The fishing effort and landings of other non-quota species are responsive to their own price and the price of fuel. Furthermore, the price of other non-quota species seems to have some positive effects on the supply of blue whiting and the demand for fuel.

The catch of blue whiting showed no statistically significant relationships with the quota-regulated species, except for being a substitute for capelin but with far from even a one-to-one relationship. Thus, the quota levels of spring-spawning herring, mackerel, North Sea herring, and capelin seem to have little effect on fishing effort and the catch of blue whiting. What seem to influence blue whiting fishery, however, are the price of other non-quota species and the price of fuel.

Although blue whiting and other non-quota species are all unregulated fisheries, there are clearly differences in the fishermen's behaviour towards the respective species. The blue whiting fishery is not influenced by its own price, and only to some degree affected by the capelin quotas and other factors of production. The other non-quota species, on the other hand, are strongly linked to the spring-spawning herring, mackerel, and North Sea herring fisheries as well as being responsive to their own price and the price of fuel.

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