SNF REPORT NO. 28/05

Modelling Fishermen Behaviour under New Management Regimes: Final report

Frank Asche
Trond Bjørndal
Håkan Eggert
Hans Frost
Daniel V. Gordon
Eyjolfur Gudmundsson
Ayoe Hoff
Carsten Lynge Jensen
Sean Pascoe
Elin H. Sissener
and
Ragnar Tveterås

This report is a part of the EU-funded project

Modelling Fishermen Behavior under New Regulatory Regimes

Contract no. QLRS-2001-01535

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, NOVEMBER 2005

ISBN 82-491-0385-8 trykt versjon
ISBN 82-491-0386-6 elektronisk versjon
ISSN 0803-4036

Affiliations

Frank Asche, Centre for Fisheries Economics, Institute for Research in Economics and Business Administration, email: Frank.Asche@snf.no

Trond Bjørndal, Centre for Fisheries Economics, Institute for Research in Economics and Business Administration, email: Trond.Bjorndal@snf.no

Daniel V. Gordon, Centre for Fisheries Economics, Institute for Research in Economics and Business Administration, email: dgordon@ucalgary.ca

Håkan Eggert, Gothenburg University, email: Hakan.Eggert@economics.gu.se

Hans Frost, SJFI, hf@SJFI.DK

Eyjolfur Gudmundsson, University of Akureyri, email: Eyjolfur@unak.is

Ayoe Hoff, SJFI, ah@foi.dk

Carsten Lynge Jensen, Centre for Fisheries Economics, Institute for Research in Economics and Business Administration, email: Carsten.Jensen@snf.no

Sean Pascoe, CEMARE, University of Portsmouth, Sean.Pascoe@port.ac.uk

Elin H. Sissener, Centre for Fisheries Economics, Institute for Research in Economics and Business Administration, email: Elinhelene.sissener@snf.no

Ragnar Tveterås, Depatment of Industrial Economics, Stavanger University College, email: Ragnar.tveteras@tn.his.no

Executive summary
Modelling Fishermen Behaviour under New Management Regimes:
Final report

The public management of marine fisheries is often seen as the only possible means of preventing overexploitation of our fish resources. The seminal paper of Gordon (1954) shows that because fish stocks in an unregulated state is a common pool resource, the tragedy of the commons will unfold. One main insight about fishermen behaviour comes out of this analysis. Under good management a fish stock gives rise to a resource rent, that is, the return on capital invested in a fishing vessel provides a return that exceeds what one would obtain in alternative use of the capital in a traditional industry. The resource rent act as pure profits for the fishermen, the fishery will attract excess capacity (including employment) until this resource rent is fully dissipated due to the competition between the fishermen. In addition, in an unregulated or open access fishery the fish stocks will be at a lower level than what is both biologically and economically optimal.

During the last half of the 20th century most fisheries have been regulated, making open access an imprecise description of the fishery. Indeed, with a correctly set TAC, one can prevent the stock from being biologically overfished. However, a TAC did nothing to solve the economic problem so the overcapacity will prevail. In fact, a TAC and most other regulations that have been used to limit fishing effort, does not change the economic incentives for the fishermen at all. As long as the resource is sufficiently valuable, as it seems to be in all commercial fisheries, the incentive for fishermen is to maximise their *share* of the catch as this gives the highest short-run profit.

During the 1990s, individual vessel quota (IVQ) schemes, where the quota may or may not be transferable, have become an important management tool. For these schemes, each participant in the fishery is entitled to a *quantity or quota* share of the TAC. This eliminates the race to fish as fishermen are ensured their quota share. Moreover, it changes the fishermens' incentives to maximise the profit for their quota. As the output quantity in this setting is given by the quota, this is equivalent to minimise the cost of harvesting the quota. Hence, the race to fish is eliminated, which also make rent generation possible. In this project we develop methods to measure potential rents and overcapacity in a fishery where the fishermen are regulated by individual quotas

Rent generation when the race to fish is eliminated has at least two causes. The most obvious is that harvesting costs are reduced as the race to fish is stopped. The second is that revenues are increased since fishers with better control of their harvests can target different markets. However, while individual quotas hold the potential to generate rent, it is not a sure outcome. To ensure rent generation due to lower costs, capacity in the fishery cannot be too high. This is a problem as there tends to be substantial overcapacity in fisheries when individual vessel quotas are introduced. There are a few examples of species where the introduction of individual quotas has generated a substantial revenue potential to be harvested, with the Pacific halibut fishery as the best known example. However, it is not obvious that all fisheries have this potential. Halibut is a high valued species with a substantial fresh market that was not really serviced when the halibut fishery was a derby fishery. Moreover, the derby was extreme as the season was down to 48 hours of fishing. Less valuable species like e.g. herring with little potential in the fresh market and a relatively long harvesting season even when there is competition for the quota may not hold the same potential.

Transferability of individual quota provides incentives for efficient harvesters to acquire quota from less efficient harvesters, which then leave the fishery, reducing harvesting capacity. This will improve overall harvesting efficiency in the fishery and generate rent. An interesting question is whether it is the changed incentives due to individual quota or the capacity reduction due to transferability of quota that is most important in generating rent in individual vessel quota schemes. This question has great practical implications as several countries, have chosen IVQ schemes that do not allow or have put in place strict limits on transferability of quota. Such countries risk the possibility of substantial rent dissipation through over-capacity in harvesting. In the European Economic Area there are several examples of different hybrids of individual quota schemes, including fisheries in the countries of all partners in this project. This ranges from full ITQ systems in Iceland, to systems with limited or no transferability in Denmark, Norway, Sweden and the United Kingdom. We investigate these issues for cod fisheries in these countries, where the fleets in Iceland and Norway consist of relatively large trawlers, while the other fleets consist of smaller vessels.

There are a number of striking results coming out of these case studies. First, it is only in Iceland, where the quotas are transferable, that there seems to be generated any rents. Not even the limited transferability in the Norwegian and UK systems seems to make any difference. This implies two main conclusions with respect to the present state for the regulatory systems in the four countries:

1. There was substantial overcapacity when the individual quotas were introduced, and the cost associated with the race to fish were primarily related to this overcapacity, so that it has not been possible to reduce harvesting cost to such an extent that rents are generated.
2. There are no alternative markets where value could be added to the landings because of better control with the harvest.

The first conclusion is the most surprising and its cause is probably related to the fact that although all the incentives to build capacity are present in European fisheries, the derby was never as strong as it was in many North American fisheries. There are few examples of European fisheries where the fishing season are down to a few days or weeks, and that are certainly not the case for any of the fisheries in question. Hence, the race to fish is not literally a derby like many of the cases one has observed in North America. The costs are therefore primarily related to the capacity, and are not variable costs associated with the derby that disappears when the derby is taken away. There are accordingly no easy cost savings associated with the regulatory structure one has in the cases studied. It seems to be only capacity reduction that allows rents to be generated, and as the capacity reduction has to be substantial. Even the Norwegian and UK cases where some transferability are allowed, do not allow rents to be generated. In the Icelandic case there are resource rents generated, but this is associated with a substantial capacity reduction. Furthermore, the capacity reduction did not start in earnest until the changes that was introduced to the system in 1990 with a high degree of transferability.

The lack of rent generation associated with revenue increasing measures is less surprising. Since the harvesting season for whitefish in Europe spans more or less the full year, there is a fresh market that has been supplied for decades. Although the estimates are imprecise there are little doubt that more than 100 000 tonnes of fresh cod in Europe are consumed, and the quantity of other fresh whitefish species like haddock, saithe, redfish and hake is also a six digit number of tonnes. Hence, there really are no high paying markets that the regulatory system has prevented the fishermen from serving. Certainly, the Icelandic exports of fresh cod have increased after the regulatory system allowed better control with the harvest, but the price increase at the ex. vessel level is orders of magnitude less than what was experienced in the Pacific halibut fishery.

The next conclusions are related to the rent potential in these fisheries given the present TACs and the capacity reduction required to reach this. The numbers are substantial, as potential rents is between 30 and 60% of total landing value (with Denmark as an exception with about 15%), and the fleets have to be reduced to between a half and a third of the current fleets sizes if the rents are to be realised. Also, even at Iceland where one has seen a substantial reduction in capacity, there is still a long way to go if all the rents are to be realised. There is a tendency for buy back programs and similar capacity reducing measures to target fairly limited fleet reductions. As it is the least efficient vessels that is removed first, these numbers from the case studies suggest that it is not surprising that such structural programs has little effect and that such programs do not have any effect on the rents realised. For capacity reduction to have a real effect, it seems like a substantial part, between a half and two thirds of the fleet needs to be removed.

In most fisheries there is little variation in the crew size on a given vessel over time. There is then a close relationship between the number of vessels removed from a fishery and the reduction in the number of fishers. It then follows that the more efficient one makes a fishery, the more the employment in the fishery is reduced. For policies that are concerned with living societies along remote coastlines, a more efficient regulatory system then will have the effect that employment is substantially reduced. There is accordingly a real trade-off between employment in a fishery and efficiency. And the magnitudes suggest that it is an important trade-off since a regulatory system that makes the fisheries as efficient as possible will have the side effect that several fishery dependent communities will disappear.

These results also clearly illustrates the fact that the resource rent are allowed to be used to build overcapacity is a real subsidy to coastal communities. Moreover, since the labour and capital used to create the over-capacity do not contribute anything to the value added in society, the size of the subsidy is not only the resource rent that is not generated, but also the loss of value added that this effort would have created if it were put to use in other sectors of society. This cost will only disappear if there are no other sectors that these factors can be used in, that is the fishermen becomes unemployed and the capital is sunk.

Contents

1. Introduction

The public management of marine fisheries is often seen as the only possible means of preventing overexploitation of our fish resources. The seminal paper of Gordon (1954) shows that because fish stocks in an unregulated state is a common pool resource, the tragedy of the commons will unfold. One main insight about fishermen behaviour comes out of this analysis. Under good management a fish stock gives rise to a resource rent, that is, the return on capital invested in a fishing vessel provides a return that exceeds what one would obtain in alternative use of the capital in a traditional industry. The resource rent act as pure profits for the fishermen, and the fishery will therefore attract excess capacity until this resource rent is fully dissipated due to the competition between the fishermen. In addition, in an unregulated or open access fishery the fish stocks will be at a lower level than what is both biologically and economically optimal.

During the last half of the 20th century most fisheries have been regulated, making open access an imprecise description of the fishery. Indeed, with a correctly set TAC, one can prevent the stock from being biologically overfished. However, economists soon realised that a TAC did nothing to solve the economic problem (Wilen, 2000). In fact, a TAC and most other regulations that have been used to limit fishing effort, does not change the economic incentives for the fishermen at all. As long as the resource is sufficiently valuable, as it seems to be in all commercial fisheries, the incentive for fishermen is to maximise their *share* of the catch. This incentive will lead to a race among fishermen to capture the largest share possible of the TAC and to over-capacity in harvesting as fishermen substitute away from those inputs restricted by regulation (Munro and Scott, 1985). These regulations can, in many cases, make the overcapacity problem even more severe than in unregulated fisheries because of the race to fish (Homans and Wilen, 1997). What is more, since the common property nature of the resource is essentially unaltered by these regulations, the resource rent is still in most cases fully dissipated.[1]

[1] See e.g. Dupont (1990) or Homans and Wilen (1997). However, if the fishermen are not able to fully substitute away from input factor restrictions, some resource rent can be realized (Flaaten, Heen and Salvanes, 1995).

During the 1990s, individual vessel quota (IVQ) schemes, where the quota may or may not be transferable, have become an important management tool. For these schemes, each participant in the fishery is entitled to a *quantity or quota* share of the TAC. This eliminates the race to fish as fishermen are ensured their quota share. Moreover, it changes the fishermen's incentives to maximise the profit for their quota. As the output quantity in this setting is given by the quota, this is equivalent to minimise the cost of harvesting the quota. That the race to fish is eliminated also make rent generation possible.

Rent generation when the race to fish is eliminated has at least two causes. The most obvious is that harvesting costs are reduced as the race to fish is stopped. The second is that revenues are increased since fishers with better control of their harvests can target different markets. However, while individual quotas hold the potential to generate rent, it is not a sure outcome. To ensure rent generation due to lower costs, capacity in the fishery cannot be too high. This is a problem as there tends to be substantial overcapacity in fisheries when individual vessel quotas are introduced. In most cases, the practice has been to initially allocate quota shares to fishermen *gratis*, usually based on historical catch records. Hence, the overcapacity is still present and most of the costs associated with the race to fish may still be present. There has been a few examples of species where individual quotas has allowed a substantial revenue potential to be harvested, with the Pacific halibut fishery as the best known example.[2] However, it is not obvious that all fisheries have this potential. Halibut is a high valued species with a substantial fresh market that was not really serviced when the halibut fishery was a derby fishery. Moreover, the derby was extreme as the season was down to 48 hours of fishing. Less valuable species like e.g. herring with little potential in the fresh market and a relatively long harvesting season even when there is competition for the quota may not hold the same potential.

Transferability of individual quota provides incentives for efficient harvesters to acquire quota from less efficient harvesters, which then leave the fishery, reducing harvesting capacity. This will improve overall harvesting efficiency in the fishery and generate rent. In principle, a well designed individual transferable quota (ITQ) system will allow all resource rents to be generated and reflected in the value of the quota (Arnason, 1990). An interesting

[2] Casey et al (1995) provide a review of the Pacific halibut fishery.

question is whether it is the changed incentives due to individual quota or the capacity reduction due to transferability of quota that is most important in generating rent in individual vessel quota schemes. This question has great practical implications as several countries, have chosen IVQ schemes that do not allow or have put in place strict limits on transferability of quota. Such countries risk the possibility of substantial rent dissipation through over-capacity in harvesting. In the European Economic Area there are several examples of different hybrids of individual quota schemes, including fisheries in the countries of all partners in this project. This ranges from full ITQ systems in Iceland, to systems with limited or no transferability in Denmark, Norway, Sweden and the United Kingdom.

Virtually all studies of fisherman behaviour show that fishermen respond strongly to their incentives.[3] Furthermore, as noted above, these incentives changes strongly when one goes from traditional regulatory measures to the new regulatory schemes based on individual quotas. Studies of behaviour have focused on a range of issues, including effort allocation (Pascoe and Robinson, 1998; Holland and Sutinen, 2000; Sampson, 2002), effort production and capacity utilisation (e.g. Campbell and Lindner, 1990; Vestergaard, 2002), response to risk (Eggert and Tveterås, 2004; Herrero and Pascoe, 2003), and discarding behaviour (Anderson, 1994; Arnason, 1994).

The main objective in this report is to investigate how these different individual quota systems work with focus on the main issues that Gordon (1954) raised about fisherman behaviour, that is; to what extent do they allow resource rent to be collected and what is the overcapacity in the fishery if some of the resource rent is dissipated. The measure of overcapacity will also indicate how much activity in the fishery communities will have to be reduced to obtain an efficient fishery and thereby give magnitudes to the tradeoff between employment and efficiency. These issues are well understood in theory (Munro and Scott, 1985; Arnason, 1993; Wilen, 2000). However, few studies actually measure their magnitude, and it is accordingly difficult to assess their real importance. With the conflict that often arise when individual quotas systems are introduced, and the often strong negative attitude towards transferable quotas, the magnitudes are important for the changes in regulatory systems to be

[3] This is as expected from an economic point of view. Varian (1993, pp. 23) states that ” A basic assumption of most economic analysis of firm behaviour is that a firm acts so as to maximize its profits”

worthwhile. In this report, we will compare the results from country studies in Denmark, Iceland, Norway, Sweden and the UK, where the fisheries investigated all have some form of individual quota systems in place, but where the regulatory system otherwise has substantial differences. In particular, it is only in Iceland that quotas are close to be fully transferable.

The primary approach proposed for the study is the estimation of cost functions, from which optimal (least cost) vessel characteristics can be determined assuming a given level of output (quota). The estimation of cost functions is a part of the 'dual' approach to the estimation of production functions. In the dual approach, profit maximisation can be achieved through the maximisation of revenue for a given level of inputs, through minimising costs of production for a given level of outputs, or both simultaneously. The dual approach takes into account economic factors like prices, in contrast to the 'primal' approach. In the 'primal' approach, production or distance functions are used to investigate the technological relationships between inputs and outputs. The former is often considered to be preferable to the latter as it allows for changes in the output and input composition due to economic factors like prices, resulting in improvements in allocative efficiency and potentially greater levels of profits.

Under traditional management regimes, landed quantity is a choice variable for the fishermen. Profit or revenue functions have therefore been the preferred specifications when empirically modelling fishermen's behaviour. However, individual vessel quotas restrict the quantity the fishermen can harvest, and quantity landed is therefore not a choice variable as under traditional management regimes.[4] Since the quantity landed is given by the quota, the economic behaviour of the fishermen is to minimise the cost of harvesting. In order to determine how fishermen's behaviour under management regimes with individual vessel quotas, estimation of a cost function rather then a profit function is more appropriate.[5] The cost function is the dual of the production function, and produces identical estimates of

---

[4] In individual quota systems where transferability is possible, short-term leases are in most cases for one year (season). Hence, although it may be argued that with transferability the amount of quota and therefore output is a part of the fishermen's optimisation problem, this is will not so under the systems considered here. Moreover, one may also argue that the purchasing/selling of quota is separable from other factors, since quota will be purchased/sold given the expectations of future prices, and each vessel will have a given stock of quota after transfers.

[5] Cost function specifications have been used by Weninger (1998) and Bjørndal and Gordon (2000).

elasticities under certain conditions.[6] As noted by Grafton, Squires and Fox (2000), it is primarily data limitations that are used as argument in favour of using primal approaches, and in general one will prefer dual approaches.

Detailed knowledge of the technological and economic conditions that apply to fishing firms can be obtained by employing the dual approach, and many empirical studies of fishermen behaviour use this approach. There are several good reasons for this, which we will come back to in chapter 3. This means that information about profit, cost, and revenue functions at the firm level is used to describe technological conditions in the production process.

In this project, a cost function approach is the basic specification used to model the production technology for a fishery regulated with individual vessel quotas. Based on such an approach we will measure rent generated and potential rent in fisheries managed with individual vessel quotas at the vessel as well as the fleet level. Actual rent can be measured based on earned income and the cost of harvesting. Potential rent requires calculating a measure of optimal harvest (quota) from the fishermen's total profit function. Furthermore, optimal vessel (quota) size combined with the TAC for the fishery allows a measure of over-capacity in the existing fleet. These measures are derived in a similar fashion to those provided by Dupont (1990) in a restricted profit function framework. In contrast to Weninger (1998) we focus on rent rather then just efficiency gains and cost reduction due to the individual vessel quotas. This is important when investigating the full potential of an individual quota system since the changed regulatory structure allows the fishermen to serve different and potentially more valuable markets (Homans and Wilen, 2004).[7] This also indicates that the regulatory system itself can be a source of rent dissipation in regulated open access fisheries when it does not allow the fishermen to serve the most valuable markets.

Individual quotas are often introduced for the most valuable species, but not all species targeted by a group of fishermen. To model this requires a specification where some outputs

[6] In particular, when the production function is homogenous, such as is the case in the Cobb-Douglas production function (Grafton, Squires and Fox, 2000).

[7] For instance, Homans and Wilen (2004) show that harvest value in the Pacific halibut fishery increase substantially since fishermen are able to sell a much larger share of their fish in a fresh product form after individual vessel quotas was introduced.

can be treated as fixed, while other are treated as variable. Although this is not a common setting, the theory necessary for our analysis has largely been developed by Lau (1976). In particular, he provides a framework where distinctions between inputs and outputs are unnecessary, and hence where cost functions, revenue functions and any other representation of the firm's problem where some factors are treated as fixed are special cases of a restricted profit function. He also anticipates profit functions where some but not all outputs are treated as fixed naming pollution quotas as an example, and also raises the possibility of negative output prices, which will be the case if the quota is traded. We will here use this framework to model fisheries where there is an individual quota only on some species. To obtain information about the fishermen's behaviour and the impact of the regulations in this setting, one can provide measures of elasticities of intensity, jointness, separability and economies of scope in this context.

The report is organised as follows: First, we consider the set of incentives created by the introduction of an ITQ programme. Second, we consider the theory of the firm and duality theory to reveal economic and technological conditions of fish harvesting firms. In chapter four, we provide a review of empirical studies that utilise this theory to obtain information about fishermen behavior. In chapter 5 we discuss theoretically actual rents, optimal rents and capacity with focus on fisheries managed with individual quotas. In chapters six to ten we provide a case study using the cost function approach for Norway, Iceland, Denmark, Sweden and the UK and in chapter eleven we provide a case study of a fishery where some but not all species are regulated with an IVQ. In chapter twelve we provide discussion of the validity of the results and a comparison before some concluding remarks are offered in chapter thirteen.

This report is based on the methodological report (Asche et al. 2003), the country reports Asche, Bjørndal and Gordon (2004), Eggert and Tveteras (2004), Gudmundsson (2004), Hoff and Frost (2004) and Pascoe (2004) and Asche, Gordon, and Jensen (2004). However, for readability some sections from these reports has been shortened or omitted. This is in particular true for the model specifications to avoid to similar paragraphs. These studies will accordingly provide additional information and details on issues covered in this report.

2. Fisheries regulations in a simple bioeconomic model

The basic bioeconomic model introduced by Gordon (1954) outlines the common property problem or the tragedy of the commons, and makes it clear why economic analysis of fisheries should differ from analysis of traditional land based industries. The model can briefly be outlined as follows.[8]

The net natural growth in the biomass is

$$F(x) = rx(1 - x/k) \tag{2.1}$$

where x is the biomass, r is the intrinsic growth rate and k is environmental carrying capacity. This function also gives the sustainable yield for different levels of the biomass. The value of the sustainable yield can be found by multiplying this equation with a price p, giving the sustainable revenue curve, TR. We will here, as in most analysis assume that the price is given from a world market. Harvest H is given as

$$H = \gamma x^{\alpha} E \tag{2.2}$$

where γ is a catchability coefficient, α gives the strength of the stock effect and E is fishing effort. The fishery is in equilibrium when growth of fish stock equals harvest, $F(x)=H$. Fishing cost is

$$C = cE = cH / \gamma x^{\alpha} \tag{2.3}$$

where c is the unit cost of fishing effort. Total profits or rent are

$$\Pi = pH - cE \tag{2.4}$$

This model has two equilibriums: Under open access the equilibrium condition is that price equals average cost, and all rents are dissipated like in all competitive industries. The effort level is than E^{∞}. Under optimal management the equilibrium condition that price should equal marginal cost, leading to an effort level E^{0}. However, in contrast to the standard competitive case rents will be generated because of the biological production process. This is graphed in Figure 2.1, where the sustainable revenue curve, TR, is shown together with the cost curve,

[8] A number of reviews and textbooks gives good presentations of the bioeconomic model, including Munro and Scott (1985), Anderson (1988) and Hannesson (1993).

TC. As one can see, $E^{\infty}>E^{0}$, implying that under open access, not only are all rents dissipated, but society also waste its resources by employing to much effort.

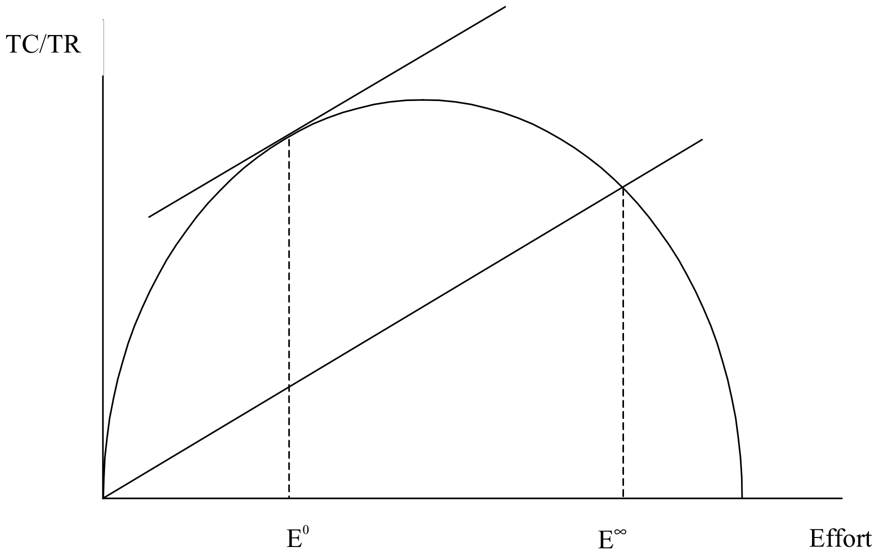


Figure 2.1 Profit maximising effort level

The key insight from this model is that the incentives of the fishermen are to move to the open access equilibrium. Because the stock level is too low, one induces higher costs than necessary and therefore waste resources. If one rather had been able to limit the effort some rent would be generated, and if effort could be reduced to E^{0}, a level that gives the Maximum Economic Yield (MEY) and the full potential resource rent in the fishery would be generated. Munro and Scott (1985) shows that fisheries with all traditional regulatory tools, regulated open access fisheries, the incentives for the fishermen will still be to dissipate rents, although one can protect the stock with a TAC. This is highlighted in Dupont (1991), where all rents are dissipated in the BC salmon fishery despite TAC and effort regulations. Homans and Wilen (1997) take this one step further by showing that the race to fish that is often created in a regulated open access fishery, the effort will often be even higher than in an open access fishery. The only known regulatory tool that changes these incentives is individual quota systems, and the full resource rent will be reflected in the quota value in a well-designed ITQ system. However, it should be noted that one can at least in principle achieve the same outcome as with an ITQ system with appropriate set output taxes. In fact, for a fisherman without quota, the optimisation problem is the same in the two cases, as he would either have to pay the quota rent to the owner of the quota, or a tax at the same level to the government.

An alternative way to see this is by regarding the Gordon-Schaefer model in the value/biomass space. Although this visualisation is equivalent to the one above, it is more straightforward to discuss rent dissipation with this approach. This is charted in Figure 2.2, where biomass, X is stock size, TC1 is the standard cost function with constant unit effort. The points of interest are the tangent (point a) of the cost function to the revenue function (TR) and the intersection of TC1 with TR, (point b). At the maximum economic yield (X_{MEY}), price equals marginal harvesting cost and generates maximum resource rent (the distance a-c). However, this acts as pure profits for the fishermen, and provides the incentive to fish the stock down to the point where total revenue equals total cost (point b), no excess profits are generated and accordingly all rents are dissipated. This is the open access equilibrium. In a regulated open access, the harvest is restricted with a TAC. If this is a binding restriction, stock size will be larger than under open access. Let us assume that regulators have managed the stock (biologically) well so that it corresponds to X_{MEY}. However, as observed by Homans and Wilen (1997), under regulated open access rents will in general be dissipated at this point because of the extra effort and capacity that are used in the "race to fish". When all rents are dissipated, the cost function can then be depicted as TC2, which defines an economic equilibrium since total cost equals total revenue and no excess profits are generated (point a). If the race to fish is removed by imposing additional restrictions such as licensing or with the introduction of individual quotas, a cost function such as TC3 will be observed, where the difference between points a and d is the rent generated by the regulations (the value of the rent will be reflected in either the license or the quota value). The distance d to c is the rent that is dissipated due to overcapacity under these regulations. However, if capacity is adjusted to optimal levels, costs will be reduced to TC1 and all rents will be captured (measured as the distance a-c). Consequently, with an IVQ management scheme, at stock level X_{MEY}, the difference between TC2 and TC3 (the distance a-d) is the rent that is captured by stopping the race to fish, while the difference c-d is the rent that is captured by a reduction in capacity to optimal levels.[9] If, in addition, the regulations result in higher quality fish selling into higher priced markets, this would result in an upward shift in the TR curve, reflecting the higher price, and generate additional rent for the fishery. One can in this approach also arbitrary insert a TAC at a stock level higher then the open access equilibrium (Asche and Tveterås, 2004). The economic incentives will then be the same, although potential rents the given TAC then will not be as high as with an optimal quota.

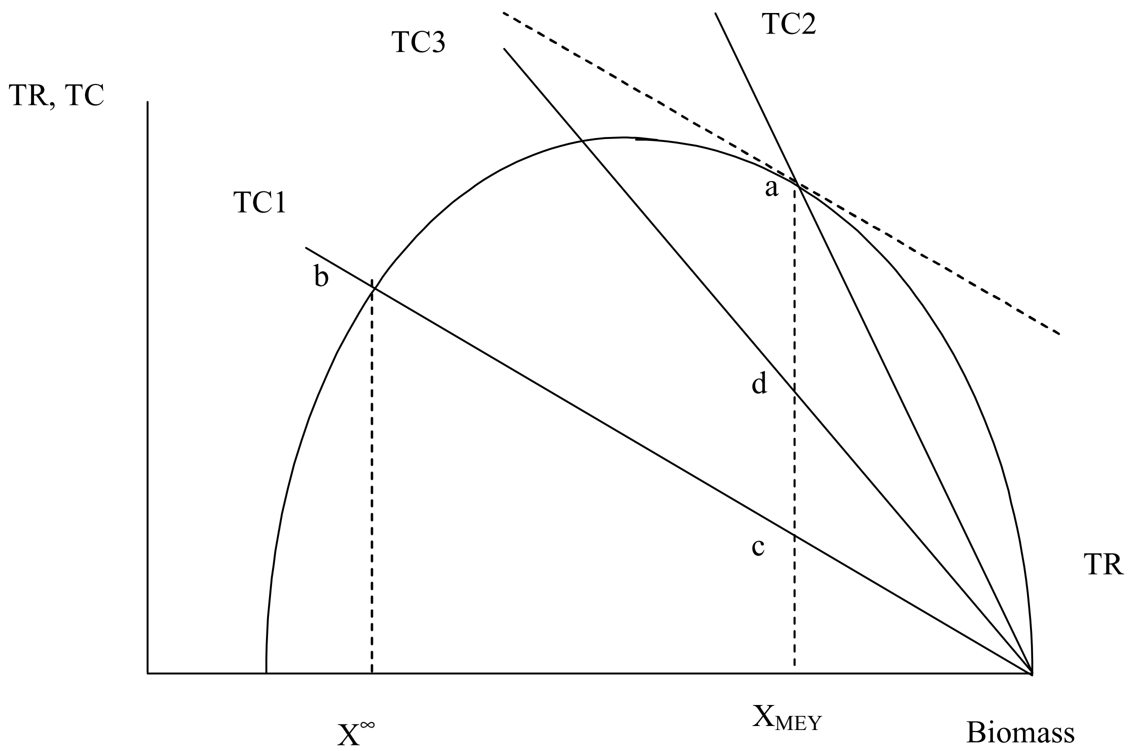


Figure 2.2 Regulated Open Access and Rent

It follows from this discussion that the main economic predictions with respect to firm behaviour that are particular to a fishery are that in general fishermen will have incentives to dissipate all rents and to employ too much effort. This is also the principal issues addressed in most general fisheries economics texts like Munro and Scott (1985), although there are of course a number of less important issues. It is also well known that in most fisheries where

---

[9] Note that Fig 2.1 shows long run steady state. If an IVQ regulation is introduced for a regulated open access fishery, starting at stock level X^{∞}, stock recovery (moving to the right) facilitates increased rents.

ITQs are introduced, the capacity reduction takes time, and one can wonder if it is ever complete so that the full resource rent is generated.

We have not discussed dynamic bioeconomic models here. However, as shown in Munro and Scott (1985), the primary insights from allowing for dynamics is that the discount factor changes the optimal equilibrium somewhat, although not very much with most commonly observed growth rates and discount rates, and one can specify the adjustment path towards an equilibrium. Hence, when one is not concerned about the optimal harvest, little is gained by using a dynamic bioeconomic model. Although economist have often been concerned about optimal harvest levels, in the real world economic considerations have little impact when quotas are set as noted e.g. by Homans and Wilen (1997). However, the two main behavioural implications, rent dissipation and too much effort persist as long as the common pool characteristics of the fishery are present.

3. The Dual Approach

3.1.Outline and assumptions

Neoclassical production theory employs two different ways of obtaining knowledge of the technological structure of a firm. The primal approach refers to the optimization problem in which the technological condition is derived explicitly from the production function. The dual approach denotes the optimization problem in which technological properties are derived by employing the envelope theorem, based, for instance, on the profit function. Diewert (1974) and McFadden (1978) show that the primal and the dual approaches represent two different ways of expressing the same technological conditions, and there is no theoretical difference regarding which approach is employed to measure the properties of the technology. However, there are often strong statistical or econometric reasons for choosing one approach over another, related to what are the agents' choice variables. Incorrect specifications can lead to inconsistent parameter estimates and therefore incorrect conclusions (Brown and Christensen, 1981). In addition, using prices will give more precise information about firm behaviour then just looking at the technology. In particular, a harvesting (production) function gives the output level based on a set of input factors, but a cost function will give the exact input factor combination that gives the lowest cost for producing this output level (Chambers, 1988). A good discussion of these issues in a different context can be found in Paul and Siegel (1999).

Campbell (1991), Hannesson (1983), and Pascoe and Robinson (1998) use the primal approach to describe the technological properties in the fish harvesting industry. A problem with using this approach to describe harvesting technology is that the regressors of input quantities are often highly collinear, which may cause multicollinearity problems in the estimation. Simultaneity bias may also be a problem of the primal approach when it is doubtful whether the input quantities are exogenous in the production process (Hoch 1958).[10] By employing prices as regressors, the dual approach offers a complementary approach that is highly suitable for dealing with problems of the input quantities. However, this does not mean

[10] The Hausmann test can be employed to test variable exogeneity of the regressors (see Hausmann 1978).

that the dual approach is without problems; for example, insufficient price variability may cause problems in estimating technological properties. The remuneration system in the fishing industry, whereby the crew takes a share of the total catch value, may also cause problems of simultaneity bias. An advantage of the dual approach is that it builds on price data, which are often more readily available and accurate than quantity data. The dual approach has the advantage of being easy to use in modelling multiproduct technology properties. Pope (1982) argues that no first-order conditions require to be solved when applying the dual approach. This means that a broad range of functional forms can be employed by the dual approach. Additional arguments for and against the dual approach can found in Binswanger (1974), Lopez (1982), and Shumway (1995).

In modelling fishing technology, it is crucial that the applied theoretical model should agree with the behavioural hypothesis and market conditions of the firm. Applications of the dual approach in the fishing industry utilize three different sets of behavioural hypotheses and accompanying objective functions to describe firm behaviour. These are: profit maximization, input constrained revenue maximization, and output constrained cost minimization.

Squires (1987a,b,c), Alam, Ishak, and Squires (1996, 2002), and Salvanes and Squires (1995) employ the multiproduct profit function, $\pi(p,w)$ to describe the profit-maximizing firm expressed by

$$\pi(p,w) = Max\{py - wx\}.$$

It is assumed that the firm is a price-taker in the input and output markets. The firm determines the demand for inputs, x, and supply of outputs, y, based on perceived input and output prices denoted by w and p, respectively. The regularity properties imply that $\pi(p, w)$ is nonnegative, nondecreasing in p, nonincreasing in w, positively and linearly homogeneous, convex, and continuous (p, w).

Kirkley and Strand (1988), Squires and Kirkley (1991), Campbell and Nicholl (1995), Diop and Kazmierczak (1996), and Thunberg, Bresnyan, and Adams (1995) employ revenue maximizing behaviour to describe the short-run multiproduct supply structure at given levels of inputs. In the short run, inputs are fixed and the firm maximizes the revenue function:

$$R(p,x) = Max\{py; x\}.$$

The firm is a price taker in the output markets, and the inputs are fixed at their short-run levels. The output supply is conditioned on perceived output prices, p. The regularity conditions imply that R(p,x) is nondecreasing in p, positively and linearly homogeneous in p, convex and continuous in p, nondecreasing in x, and nonnegative.

Bjørndal and Gordon (2000), Lipton and Strand (1992), and Weninger (1998) all use the behavioural hypothesis of cost minimization to describe firms operating under output regulation. The output-constrained firm minimizes the cost function,

$$C(w, y) = Min\{wx; y\}.$$

Such firms are assumed to base their input demand on the input prices for given output levels. The regularity properties imply that C(w, y) is positive for y>0, nondecreasing in w, concave and continuous in w, positively and linearly homogeneous in w, nondecreasing in y, and C(w, 0)=0.

It is essential to ascertain that the employed behavioural hypothesis correctly specifies the features of the multiproduct firm. The profit function is an appropriate specification with which to address the behaviour of firms that alter their input demand and output supply compositions on the basis of exogenous market prices for inputs and outputs, while the revenue function is more suitable for studying short-term behaviour; e.g., that based on fishing trip data where inputs are assumed to fixed, but the species composition can be varied. Cost minimization is a relevant option for describing firms that vary their input compositions, while output supply functions are restricted and vertical; e.g., due to output regulation or biological constraints. However, employing the cost function when it is questionable that outputs are restricted for the firm raises the question of whether outputs are exogenous or not. In cases in which outputs are endogenous for the firm, dealing with outputs as if they were exogenous outputs creates a simultaneity bias. For this reason, if not all outputs are exogenous for the firm, then employing a revenue or profit function might provide a better description of its behaviour.

3.2.Functional forms for cost functions

As with production functions, the cost function to be estimated econometrically can take a variety of functional forms. Generally, a translog functional form is preferred, as it does not impose any restrictions on the partial elasticities nor the elasticity of substitution. In contrast, the Cobb-Douglas functional form imposes constant partial elasticities, and an elasticity of substitution of 1.

The translog functional form of the cost function can be written as:

$$\ln C = \ln\alpha_o + \sum_{i=1}^{n}\alpha_i \ln w_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_{ij}\ln w_i \ln w_j + \alpha_Q \ln Y$$
$$+\frac{1}{2}\alpha_{QQ}(\ln Y)^2 + \sum_{i=1}^{n}\alpha_{iQ}\ln w_i \ln Y + e$$

where C is long-run cost, *i,j =l, k* and *m, Y* is aggregate output and *e* is a random error term assumed to be i.i.d.

Estimating a flexible dual function such as the translog cost function can be complex, due to the large number of parameters that need to be estimated. Further, the model must satisfy a range of theoretical considerations to ensure that the results are consistent with economic theory, as will be described below. More efficient estimation can be obtained by simultaneously estimating the cost function with a set of input demand equations derived using Shephard's Lemma.

The input demand equations (or cost share equations) are given by

$$S_i = \alpha_i + \sum_{i=1}^{n}\alpha_{ij}\ln w_j + \alpha_{iQ}\ln Y + u_i$$

where $S_i = w_i x_i / C$ is the cost share of the I-th input and *u* is random error term assumed to be i.i.d. One equation is estimated for each input. The system of equations (i.e. the cost equation and the set of input demand equations) is estimated simultaneously using Zellner's Seemingly Unrelated Regression (SUR) procedure.

As mention above, the cost function must satisfy a number of properties to ensure it is consistent with optimising behaviour (i.e. cost minimisation), and to ensure that it is consistent with the production function. The two main properties are homogeneity and symmetry. These are satisfied by imposing the restrictions:

Homogeneity: $\sum_{i=1}^{n}\alpha_i = 1,\ \sum_{i=1}^{n}\alpha_{ij} = 0,\ \sum_{j=1}^{n}\alpha_{ij} = 0,\ \sum_{i=1}^{n}\alpha_{iQ} = 0$

Symmetry: $\alpha_{ij} = \alpha_{ji}$

Imposing these restrictions are necessary to ensure that the resultant model satisfies economic theory. It is straightforward to extend this model to include fixed input factors or multiple outputs.

The translog is the most common functional form in empirical applications. However, the fact that it is formulated in logarithms can create problems in some application. In particular, one needs numerical routines to solve for optimal levels of fixed factors (Brown and Christensen, 1982) and one cannot impose the curvature conditions implied by economic theory. The most common alternative is the Generalized Leontief (See Diewert and Wales (1987) for a discussion). A Generalized Leontief cost function is given as

$$C = y\left(\sum_i \sum_j a_{ij} p_i^{1/2} p_j^{1/2}\right) + b_{YY}\left(\sum_i \beta_i p_i\right) y^2 + \sum_i b_i p_i$$

In this functional form the homogeneity restriction is imposed through the functional form, while the symmetry restriction is given as:

Symmetry: $a_{ij} = a_{ji}$

The β_i parameters are arbitrary constants set by the researcher. The input demand equations can be derived in a similar fashion as above using Sheppard's lemma. Since this functional form is formulated in levels, one can easily solve explicitly for Y, and also for fixed factors if they are introduced. A normalized quadratic differs from a generalized Leontief only in the second order terms, as the normalization procedure to ensure that the cost function is homogenous of degree one in prices is different (Diewert and Wales, 1987). Relatively to a translog, an advantage with these functional forms is that on can solve explicitly in a closed form expression for the levels of outputs and fixed inputs, rather then searching for numerical solutions. However, this advantage has to be balanced by the fact that the translog tends to be more stable and the consistency region where the functional form gives a reasonable approximation is larger.

3.3. Separability in inputs/outputs of the multiproduct firm

Fishing technologies are often multidimensional because several production inputs are employed to catch different species. The dual approach is highly suitable for acquiring immediate and detailed knowledge of the technological conditions of a multidimensional production process. The complexity of multidimensional production technology can be reduced if it is possible to aggregate inputs or outputs into subsets. Input-output separability is the aggregation concept most often addressed in studies of fishing technologies. The concept indicates whether input and output compositions are independent. The results shown in table 3.1 indicate that input-output separability is rejected for most fisheries and for various types of fishing gear. This invokes the dilemma that important technological structures may be overlooked if the disaggregated structure of inputs and outputs is not taken into account.

Table 3.1. Test for Separability

Study	**Gear**	**Functional Form**	**Separability**[1)]	**Details**
Alam, Ishak, and Squires (1996)	Gill net	Translog profit	Accept, Reject	Input-output separability is accepted but global separability is rejected.
Alam, Ishak, and Squires (2002)	Trawl	Translog profit	Reject	Input-output separability and global separability are rejected.
Campbell and Nicholl (1995)	Purse seine, long line	Leontief revenue	Reject	Input-output separability is rejec-ted.
Diop and Kazmierczak (1996)	Trawl	Leontief revenue	Reject	Input-output separability is rejec-ted.
Kirkley and Strand (1988)	Trawl	Leontief revenue	Reject	Input-output separability is rejec-ted.
Salvanes and Squires (1995)	Trawl	Translog profit	Reject	Rejects input-output separability and weak separability between cod and haddock.
Squires (1987a)	Trawl	Translog profit	Accept	Input-output separability is accep-ted.
Squires (1987b)	Trawl	Translog profit	Reject, Accept	Input-output and global separa-bility is rejected, but weak separa-bility between cod and haddock is accepted.
Squires and Kirkley (1991)	Trawl	Leontief revenue	Reject	Input-output separability is rejec-ted.
Thunberg, Bresnyan, and Adams (1995)	Gill net	Translog revenue	Reject	Input-output separability is rejec-ted.
Weninger (1998)	Surf clam and ocean quahog vessels	Translog cost	Reject	Output separability is rejected.

1) Accept – H_0: separability cannot be rejected; Reject – H_1: separability is rejected.

The necessary conditions for input-output separability for the profit-maximizing firm are $\delta(x_i/x_j)/\delta p = 0$ and $\delta(y_i/y_j)/\delta w = 0$ (see Chambers 1994). The first condition implies that output prices, p, do not influence the composition of inputs x_i and x_j. The second condition means that the input prices, w, will not affect the composition of outputs y_i and y_j. Rejecting input-output separability means that a change in input (output) price alters the relative composition of output (input) quantities.[11] The survey indicates that the majority of fishing technologies should be modelled in a disaggregated context. Aggregated modelling of harvesting conditions involves the potential error of misspecification, where the relationship between input composition and output composition is ignored. In a management setting, the results of input-output separability indicate that imposed regulation of aggregated output means that high-value species will be targeted (high grading). Furthermore, rejecting input-output separability means that imposed input management might, for example, alter catch composition for the firm. Generally speaking, the results of tests of input-output separability speak in favour of disaggregated modelling of fishing technologies.

Evidence in favour of accepting separability is found in a few cases. Alam, Ishak and Squires (1996) find no evidence to reject input-output separability in the gill net fishery of Peninsular Malaysia in the short run. This implies that inputs and outputs can be aggregated into theoretically consistent variables consisting of a single aggregated input and a single aggregated output. This implies that a quantity restriction on a single output will reduce the input and output at the aggregated level, but that the mix of single elements of inputs and outputs will remain the same. Aggregation over some variables permits substantial simplifications to be made in the economic modelling of the fishery, as it permits the analysis to be undertaken using fewer estimated relationships.

In two studies of New England otter trawl technology, Squires (1987a,b) indicates different separability results. Building on identical data, the diversity in the separability results of studies probably arises from slightly different output group specifications. The separability

[11] In the studies of Kirkley and Strand (1988), Campbell and Nicholl (1995), Thunberg, Bresnyan, and Adams (1995), Squires and Kirkley (1991), and Diop and Kazmierczak (1996), fishing effort is measured through the use of a single composite input, thereby implicitly assuming that inputs are separable from outputs. In these applications, the test on input-output separability is, therefore, only addressing whether outputs are separable from the composite input.

test in Squires (1987b) indicates that roundfish (cod and haddock) and flatfish (yellowtail and other flounders) are weakly separable subgroups, and input-output separability is rejected. Weak separability means that the marginal transformation between cod and haddock does not depend on inputs or outputs outside the subset. Squires (1987a) does not reject input-output separability for otter trawler technology, thereby obtaining a result that differs from Squires (1987b). On the basis of the information available in Squires (1987a,b), it is difficult to determine exactly what causes the difference in the input-output separability tests, but the specification of subgroups of outputs might be a reasonable explanation.

The specification of the output groups is often problematic in applied studies because many firms do not catch certain species, which leaves a zero value on the regressant. Using censored estimation might solve the problem of missing output observations, but econometrics packages capable of dealing with this problem have not been developed. Applied studies might instead aggregate output into groups whereby the missing observation problem is avoided. Kirkley and Strand (1988), Squires and Kirkley (1991), and Campbell and Nicholl (1994) overcome the statistical problem of zero catches of certain species by assigning them an arbitrarily small value of 0.01 tons.[12]

3.4. Nonjointness in inputs of the multiproduct firm

Fish stock regulation is often done by regulating individual species.[13] Single-species regulation is based on the assumption that distinct production functions for individual species exist. However, separate regulation of species ignores the transformation in output supply of the multiproduct firm. The condition of nonjointness in inputs is central to the task of determining whether it is appropriate to regulate the fishing industry in a single-species or multispecies context. A summary of studies that test for nonjointness is presented in table 3.2. The majority of these studies reject nonjointness in inputs for fishing technologies, thus

---

[12] Problems encountered by employing the 0.01 values might be discovered by comparing sign and statistical significance to estimates of the nonzero observations.

[13] This is, for example, seen in the fisheries of the European Community, where the species are mainly regulated in a single-species context by applying a total allowable catch (TAC) for each single species. Although multi-species TACs (MSTAC) have been introduced by 3760/92 (see Council Regulation, Official Journal L 389, 31.12 1992.), the multi-species management has not been widely used.

suggesting that imposed regulation will probably alter the multispecies composition of harvests.

Table 3.2. Test for Nonjointness in Inputs

Study	**Gear**	**Functional Form**	**Non-jointness[1)]**	**Details**
Alam, Ishak, and Squires (1996)	Gill net	Translog profit	Accept	Nonjointness for all outputs cannot be rejected.
Alam, Ishak, and Squires (2002)	Trawl	Translog profit	Reject	Nonjointness for all outputs is rejected.
Campbell and Nicholl (1995)	Purse seine, long line	Leontief revenue	Accept, Reject	Nonjointness is rejected for purse seine (specialized firms) and accepted for the generalist firms.
Kirkley and Strand (1988)	Trawl	Leontief revenue	Reject	Nonjointness for all species is rejected.
Salvanes and Squires (1995)	Trawl	Translog profit	Reject	Rejects nonjointness for all outputs in common and for each single output separately.
Segerson and Squires (1993)	Trawl	Leontief revenue	Reject	Nonjointness for all outputs is rejected.
Squires (1987a)	Trawl	Translog profit	Reject	Nonjointness for all outputs is rejected.
Squires (1987b)	Trawl	Translog profit	Reject	Nonjointness for all outputs is rejected.
Squires and Kirkley (1991)	Trawl	Leontief revenue	Reject, Accept	Nonjointness is rejected for all species expect for Dover sole.
Thunberg, Bresnyan, and Adams (1995)	Gill net	Translog revenue	Reject	Nonjointness for all outputs is rejected.
Diop and Kazmierczak (1996)	Trawl	Leontief revenue	Reject	Nonjointness for all species is rejected.
Weninger (1998)	Surf clam and ocean quahog vessels	Translog cost	Accept	Nonjointness in inputs cannot be rejected.

1) Accept – H_0: Nonjointness in inputs cannot be rejected; Reject – H_1: Nonjointness in inputs is rejected.

Nonjointness in inputs determines whether or not a firm will maximize its production for each output separately. If it maximizes each output separately, this means that there is no interdependence among its production of the various outputs. Hall (1973) set out a necessary condition for nonjointness in inputs for the profit function as:

$$\pi(p,w)=\sum_{i=1}^{n}\pi_i(p,w),$$

meaning that the firm maximizes the individual profit functions for each output. This is the same as saying that its total profit from producing all outputs is the sum of the profits generated by each output. Testing for nonjointness in inputs for the profit-maximizing firm means that a change in the price of the single output will not affect the profit or the quantities produced of other outputs. This implies the restriction:

$$\frac{\delta^2 \pi}{\delta p_i \delta p_j} = 0, \; i \neq j,$$

which is a necessary condition for:

$$\delta y_i / \delta p_j = 0, i \neq j.$$

That is, a price change in the j*th* output will not affect the firm's output supply of the i*th* nonjoint output. Similarly, a multioutput cost function will be nonjoint in inputs if

$$\frac{\partial^2 C}{\partial y_i \partial y_j} = 0, \quad i \neq j$$

The tests for nonjointness in inputs reveal that results differ, depending on the fishing gear employed. For trawlers, the null-hypothesis of nonjointness in inputs is rejected in most studies. This is not surprising, since trawl gear is designed for harvesting a wide range of species. In a management setting, the jointness in inputs implies that individual regulation of species (for example through TAC) will also change the quantity of other species landed by trawlers. This implies that fishing managers need to acknowledge the consequences of TAC regulation on a given species will have on other species landed by the firm. In order to allow this to be done, the proper specification of the joint production technology contains an explicit modelling of the transformation in production between different species.

Failure to reject nonjointness in inputs for trawlers is seen in a single case. Squires and Kirkley (1991) find that catches of Dover sole are a nonjoint production in the Pacific coast trawl fishery, implying that Dover sole are harvested independently of other species by trawlers. No intuitive explanation is given for the nonjointness of Dover sole. However, a situation that might cause nonjointness in inputs occurs when different species are harvested during different seasons of the year.

It is noteworthy that Weninger (1998) and Alam, Ishak, and Squires (1996) find evidence for nonjointness in inputs for technologies in the mussel and gill net fishery. This indicates an important difference between trawling, on the one hand, and the technologies employed in mussel and gill net fisheries, on the other.

In the mid-Atlantic surf clam and ocean quahog fisheries studied by Weninger, the nonjointess in inputs indicates that these species are harvested independently. This has the policy implication that surf clams and ocean quahogs might be regulated independently, because no spillover effect of the regulation of one species would be expected on the other species. In this sense, nonjointness in inputs traditionally legitimizes the individual regulation of species because they are harvested independently in separate production processes.

However, the study of Alam, Ishak, and Squires (1996) indicates an exception where it is inappropriate to regulation species individually, although nonjointness in inputs is found in the fishery. The reason for this is that no evidence in favour of rejecting neither nonjointness in inputs nor input-output separability is found in the Peninsular Malaysia gill net fishery examined. Therefore, there is an overlap in the technology of both nonjointness in inputs and input-output separability (see Hall, 1973). This implies that gill net technology consists of individual production functions for each species, and in addition, that the production functions are identical and scalar multiples of one another. This means that there is a consistent aggregated output in fixed proportions, and the firm cannot alter its output mix. If the regulator employs a single-species TAC, the gill netters will be forced to reduce all catches proportionally in order to satisfy the regulation. In this sense, harvests of the individual species cannot be regarded as being independent. However, regulation of a single species might prove to be costly for the firm, because in order to satisfy the regulations, the harvest of all species would have to be reduced. Instead, general biomass management might be regarded as an alternative for such fisheries. Yet, employing biomass regulation would make it difficult to ensure the sustainable development of species that are overexploited.

3.5.Modelling biological conditions constraining the multiproduct firm

Modelling the technological conditions that affect individual fishing firms requires biological conditions to be explicitly addressed. For the individual firm, the biological conditions; e.g., resource abundance, affect the production environment, but the single firm has no means of controlling stocks, which, therefore, must be treated as exogenous. In this sense, as argued by Squires (1992, 1994a), treating stock abundance as an input factor in the production process like capital, labour, or energy is inappropriate in a positive, as opposed to a normative analysis based on the theory of the firm. Biological conditions like stock abundance should rather be modelled as an exogenous component that shifts the level of production.

This put the role of biological conditions like stock size well into a restricted profit function specification, which McFadden (1978) claims is the most general representation of firm behaviour. A restricted profit function, $\Pi^R(p,w;z)$, gives profits as a function of output and input prices, p and w, and the levels of exogenous factors, z. What is of interest her is that profits are an increasing function of the exogenous factor. Hence, if the exogenous factor is the stock level, higher stock abundance gives higher profits. This is also as expected from the bioeconomic model since higher stock abundance gives lower cost and *ceteris paribus* higher profits. As such, the stock variable plays a similar role to other exogenous factors like technological change or agglomeration. It should be noted that in modelling the firm behaviour, truly exogenous factors like stocks are treated in the same fashion as quasi-fixed factors like capital which the firm can change, although it generally does not in the short run because of high adjustment costs. Capital is here a good example. In the short run, the effect of changing the levels of a quasi-fixed factor is therefore similar to the effect of changing the levels of factors that are exogenous in the long run.

McFadden (1978) and Lau (1976) also note that the separation of netputs into outputs and inputs is largely artificial, although convenient for expositional purposes. However, this implies that revenue as well as cost functions are special forms of the restricted profit function where respectively all inputs or all outputs happen to be quasi-fixed. This implies that an exogenous variable like stock size should be treated in the same manner in restricted profit functions, cost functions and revenue functions.

The obvious way to model stock effects is then to include stock size as an exogenous variable in the function that is specified. Bjørndal (1987), Dupont (1990), Weninger (1998), and Pascoe et al (2001) are examples of studies that employ indices to measure fluctuations in stock abundance.

However, somewhat surprisingly given the use of stock indices close link to theory, most applications of the dual approach use annual or seasonal dummy operators to measure fluctuations in resource stocks (see Squires 1987a,b,c; Bjørndal and Gordon 1993; Salvanes and Squires 1995; Campbell and Nicholl 1995; Squires and Kirkley 1996; Diop and Kazmierczak 1996). There are several reasons for this that mostly relates to data and statistical issues. In many fisheries, particularly multi-species fisheries, information on stock abundance of all species (or in some cases any of the species) may not be available. In such cases, deriving a composite stock index is not straightforward.[14] As a result, other means of estimating the effect of changes in stock abundance on production need to be employed.

A stock variable is exogenous to all firms, but since all firms fish the same stock(s), the variable(s) are identical for all firms. Hence, there is no variation in this variable in each cross section. Hence, if one has observations for only one year (or season), the variable will be perfectly collinear with the constant term, and accordingly one cannot explicitly model the effect of the stock size in such a situation. When one has observations over several seasons, the stock variables are identical for all vessels within a season. One can then model the effect of the changes almost as precise with dummy variables as with stock indices. When one take into account that there are also other factors that can vary between seasons like weather, oceanographic conditions etc., that changes in a similar fashion as stock size but which is very difficult to obtain measurements for, one will econometrically be better of by modelling the combined effects of all these variables with dummies. Indeed, if one estimates a specification which only includes stock indices, the estimated parameters is likely to be inconsistent as estimates of the stock influence. This is because the weather effects etc. give an omitted variable problem, and the estimated parameters will the pick up some of the effect of the omitted variables. Finally, it is often hard to obtain data for the stock in the relevant geographical area, and given that the statistical issues, it may then be preferable to use dummy variables to represent these effects.

A problem with the use of dummy variables to capture stock change is the loss in degrees of freedom. In the case of production functions and frontiers, models are often estimated using monthly landings data. While a series of month and annual dummy variables could be used, this assumes that seasonal conditions do not vary from year to year. A dummy variable for

[14] Pascoe and Herrero (2001) developed a method for compensating for stock changes in multispecies fisheries when stock information was unknown. The method was developed for use in production functions, but could be equally adapted to cost functions.

each time period, which allows for interannual variations in seasonal conditions, adds considerably to the number of parameters to be estimated in the model. This problem is less prevalent in cost functions as costs are generally only available at an annual level. As a result, the potential loss of degrees of freedom is less significant than in studies based on production functions.

A further problem with the use of dummy variables is that it does not allow for interactions between the inputs and stock. For example, larger boats may be more able to capitalise on a stock increase, and be more heavily affected by a stock decrease, than smaller boats. Failure to capture this interaction may result in misspecification of the underlying production process, and hence the elasticity estimates. This problem is relevant to both production and cost functions.

An alternative approach is to derive an index of stock abundance based on relative catch rates. Kirkley, Squires and Strand (1995, 1998) developed such an index based on the catch rate of survey vessels undertaking routine stock monitoring. Pascoe and Coglan (2002) developed an index based on the average value per hour fished of the boats that operated in the same month in the same métier. Hence, it takes into account the differences in the composition of the catches taken by the different gear types at each point in time and in each area, as well as the different set of prices in each time period. Were price changes not accounted for in the model, then changes in the set of prices may have affected the estimates of efficiency (as the output measure may change without any change in the physical inputs). The index was calculated as a geometric mean of the observed values in each period/métier to limit the effects of extreme observations on the mean.

Sharma and Leung (1999) argue against the use of catch per unit effort (CPUE) as a measure of stock abundance on the basis that average CPUE is affected by the characteristics of the boats in the area at the time. A change in CPUE from one period to the next may reflect the different composition of the boats from which the CPUE was derived as well as changes in the stock abundance. While this was recognised as a problem, the advantages of using the measure were that the effects of changes in prices can be factored into the model, and greater flexibility in terms of interactions between gear use, month and year effects can be incorporated. Use of dummy variables for these assumes fixed effects across the data, whereas seasonal effects are likely to vary in their timing between years, while catch compositions may vary between years differently for the different gear types based on previous exploitation patterns.

As the index is the average of the catch rates of the boats operating together, deviations from the average that cannot be attributed to the boat characteristics are either differences in efficiency or stochastic error. In this way, the stock index assumes the same role as the set of dummy variables (which account for systematic changes in average performance), with the added advantage that interactions with the other inputs can also be incorporated through the translog function and substantially fewer degrees of freedom are lost.

4. Applications of the dual approach in fisheries

The dual approach has been used in numerous studies of fisheries to consider a wide range of issues. These include examination of the supply elasticities in fisheries, input demand and the effects of effort controls, cost structures in fisheries and, also, the organisational structure of the fisheries. In this chapter, these studies are summarised.

4.1. Transformation between outputs of the multiproduct firm

The condition of jointness in inputs found in most studies of trawl fisheries indicates that there is dependence between production functions for the various outputs. This has implications for fisheries management, because regulations imposed on single species also have an impact on landings of other species. This follows because firms do not produce their catches of individual species as separate outputs, but there are interactions in harvesting decisions regarding different species. For this reason, regulators ought to take account of the technological ability of the firm to alter its harvesting pattern within a given fishing season. One way to clarify the features of joint production is to describe substitutions and complementary transformations in output supply.

Table 4.1. Product Supply Elasticities

Study	Gear	Elasticity with Respect to Outputs [1)]	Own-price Elasticity	Cross-price Elasticities	Fishery Featured by:
Kirkley and Strand (1988)	Trawl	SH	Inelastic	Substitutes, Complements	Flexible catches
Alam, Ishak and Squires (2002)	Trawl	SM	Inelastic	Mainly Complements	Inconclusive[2)]
Salvanes and Squires (1995)	Trawl	SM	Inelastic[3)]	Substitutes, Complements	Flexible catches
Squires (1987b)	Trawl	SM	Inelastic	Not reported	Not reported
Squires (1987c)	Trawl	LM	Elastic, Inelastic[4)]	Substitutes, Complements	Flexible Catches[5)]
Segerson and Squires (1993)	Trawl	SH	Inelastic	Substitutes, Complements	Flexible catches
Squires and Kirkley (1991)	Trawl	SH	Inelastic	Substitutes, Complements	Flexible catches
Squires and Kirkley (1996)	Trawl	SH	Inelastic	Substitutes, Complements	Flexible catches
Thunberg, Bresnyan, and Adams (1995)	Gill net	SH	Elastic, Inelastic[6)]	Complements	Key species
Diop and Kazmierczak (1996)	Trawl	SH	Inelastic	Substitutes, Complements	Flexible catches

1) SM – short-run Marshallian, LM - long-run Marshallian, SH – short-run Hicksian, LH – long-run Hicksian.
2) The Marshallian cross-price elasticities indicate that the output effect dominates the substitution effect, whereby increased landing of high- or medium grade species will increase the landings of low-grade species indicating bycatch of low-grade species.
3) The own-price elasticities of the most important species cod and haddock are inelastic but insignificant.
4) The own-price elasticity for roundfish is elastic, but inelastic for flatfish and all other outputs.
5) Based on Allen elasticities.
6) The own-price elasticity for the "key species" is elastic.

The output supply elasticities presented in table 4.1 are based on the assumption that firms maximize their production supply based on exogenous market prices for landings. The table discloses inelastic own-price elasticities in most studies, indicating that a 1% increase in the output price increases the output supply by less than 1%.[15] The fairly small price reaction in output supply indicates rigidity in the firm's ability to alter its harvesting pattern in the short run. There are various reasons for rigidity in harvesting patterns. Squires (1987c) stresses that search costs in exploiting new species or fishing grounds imply rigidity in the harvesting pattern because search costs outweigh the gain in revenue that could be obtained by the

[15] There are two exceptions. Thunberg, Bresnyan, and Adams (1995) find an elastic short-run elasticity for the output of mullet in the gill fishery of Florida. Squires (1987c) finds elastic long-run elasticities in the otter trawl fishery of New England. The latter confirms that the elasticities are higher in the long run.

search.[16] Insufficient price variability might be an empirical explanation for the inelasticity given that the studies are based on cross-section data that cover a rather short time span. Kirkley and Strand (1988) also argue that aggregation of outputs might cause potential aggregation bias and thereby inelastic output supply elasticities. Further, multicollinearity might cause problems of inadequate variability in the output prices and thus insignificant parameter estimates.

The cross-price supply elasticities reveal the interaction in the supply of different outputs for the multiproduct firm. The cross-price elasticities clarify an important technological difference between trawl and gill net technologies. For trawl technology, the cross-price elasticities uncover a “flexible” fishery of both substitution and complementary relationships in the output supply of the various species (Hicksian elasticities).[17] For the gill net technology, all outputs are produced as complements. Although Thunberg, Bresnyan, and Adams (1995) is the only study to have revealed cross-price elasticities for gill net technology, it is important to stress the difference in results obtained for trawl and gill net technologies. The possibility of substituting between outputs expressed for the trawl technology indicates that the firm switches between targeting different species. In doing so, trawler technology involves a degree of flexibility that may enable the firm to change its target species, for example, as a result of regulations imposed on a particular species. This kind of flexibility is not found in gill net fisheries, where outputs are produced as complements and it is difficult for the firm to change its target species. In this sense, the gill net fishery is characterized as a “key” fishery where one or two key species are targeted and other species are harvested as bycatches.[18, 19]

The feature of “key” or “flexible” fishery has implications for fisheries management. In a “flexible” fishery, the regulator should take into account the substituting/complementary relationship that exists between outputs. This means that regulation that restricts a single

---

[16] Search cost in the form of energy consumption, risk, quality deterioration for some species, opportunity cost foregone, and labors cost.

[17] The Hicksian elasticity measures the pure substitution effect (see Lopez 1984).

[18] If there are two ”key” species, they are produced as complements.

[19] The missing ability to substitute between outputs is also found in the gill net fishery described by Alam, Ishak, and Squires (1996).

target species often implies that a firm has the option of increasing its harvest of some other species. This possibility does not exist in “key” species fisheries that consist of complementary outputs. Thus, in a “key” fishery, the regulation of a single output implies that the firm will either discard the regulated species or reduce its fishing effort, with the latter option reducing its total earnings.

4.2.Input demand of the multiproduct firm

Restricting fishing effort is often put forward as a means of preventing overexploitation of stocks. However, effective effort management is hindered by the multidimensionality of fishing efforts. Pearse and Wilen (1979) emphasize that the successful reduction of fishing effort depends on the regulator’s ability to simultaneously restrict all dimensions of fishing effort. Strand, Kirkley and McConnell (1981) demonstrated the multidimensionality of fishing effort though the marginal rate of substitution to plot isoquants between input pairs. The success of imposed effort management depends on the disaggregated structure of fishing effort. Employing the dual approach, the disaggregated structure of fishing effort is often uncovered by addressing the own-price and cross-price elasticities of the input demand functions summarized in table 4.2.

Table 4.2 Factor Demand Elasticities

Study	Gear	Variable Effort Items	Functional Form	Elasticity with Respect to Inputs[1),2)]	Own-Price Elasticity	Cross-Price Elasticities
Alam, Ishak, and Squires (2002)	Trawl	Labor, energy	Translog profit	SM, SH	Elastic[3)]	Substitutes
Bjørndal and Gordon (1993)	Purse seine	Fuel	Translog profit	SM	Elastic, Inelastic[4)]	Not reported
Bjørndal and Gordon (2000)	Purse seine, trawler, coastal vessel	Fuel, vessel maintenance	Translog cost	SH	Inelastic	Not reported
Dupont (1991)	Seine, gill net troll	Fuel, labor, gear	Quadratic profit	SM	Inelastic	Substitutes, Complements
Squires (1987a)	Trawl	Labor, energy, capital services	Translog profit	SM, SH	Elastic[5)]	Substitutes, Complements
Squires (1987b)	Trawl	Labor, energy, capital services	Translog Profit	SM	Elastic	Complements
Squires (1987c)	Trawl	Energy and labor	Translog profit	LM	Elastic[6)]	Complements
Weninger (1998)	Surf clam and ocean quahog vessels	Fuel, gear	Translog cost	SH	Inelastic	Substitutes

1) SM – short-run Marshallian, LM - long-run Marshallian, SH – short-run Hicksian, LH – long-run Hicksian.
2) Marshallian elasticity includes substitution and expansion effects. Hicksian elasticity includes the pure substitution effect (see Sakai 1974; Lopez 1984).
3) Marshallian elastiticies are elastic except for energy in the east coast fishery.
4) Elasticity is estimated on an annual basis for several years.
5) Marshallian elasticities are elastic for capital and labor but inelastic for energy.
6) Squires (1987c) estimates long-term elasticities from the restricted (short-run) profit function following the outline of Brown and Christensen (1981).

The firm's use of inputs such as fuel, labour, technical equipment, etc., builds on the exogenous market prices for these inputs. Deriving input demand functions can be obtained for firms that minimize costs or maximize profits. However, input demand function cannot be disclosed for firms that going for revenue maximization, e.g., during the fishing trip, because all inputs are fixed within this short period.

The results of the own-price elasticities reveal that input demand is influenced by whether the fishery is regulated or not. For unregulated fisheries, Bjørndal and Gordon (1993), Squires (1987abc), Alam, Ishak, and Squires (2002) find elastic own-price elasticities for trawlers and purse seines while in the input-regulated fishery studied by Dupont (1991), the own-price elasticities for the unrestricted inputs were inelastic.[20] These results follow as a natural consequence of the Le Chatelier effect; i.e., the regulatory restrictions imposed create rigidity in the production process and thereby restrict the ability to alter composition of unrestricted input components (see Lau 1976; Squires 1994b). In this sense, input regulations will tend to reduce the flexibility (e.g., elasticities) of the unconstrained inputs compared to an unregulated industry. This is also the case in the output-regulated fishery studied by Weninger (1998) and Bjørndal and Gordon (2000). However, when reporting the inelastic own-price elasticities in the output-regulated fishery, it must be emphasized that these are Hicksian elasticities.[21] Hicksian elasticities will normally be smaller than Marshallian elasticities. This follows because Hicksian elasticities do not incorporate the reduction in production that follows an increase in input price.

The cross-price elasticities reveal the internal structure among disaggregated factors that make up fishing effort. The cross-price elasticities presented include both Hicksian and Marshallian elasticities.[22] The Hicksian elasticities reported by Squires (1987a) Weninger (1998), and Alam, Ishak, and Squires (2002) show substitution between input factors.[23] This is not surprising since Hicksian elasticities measure the pure substitution effect between inputs at a given level of output. What is more interesting is to observe that the Marshallian elasticities in Squires (1987b,c) indicate a complementary relationship between capital, labour, and fuel in the otter trawler fishery. This implies that imposing input regulation on the single input will not be compensated for by increases in other inputs. The complementary Marshallian elasticities indicate that the expansion effect outweighs the substitution effect; i.e., the reduction in input demand that follows from a change in production level outweighs the expected change in input demand due to the substitution effect. Dupont (1991) finds a mixture of complementary and substitutional input demand relationships in the Canadian seine and

[20] Bjørndal and Gordon report the own-price elasticity on fuel, which varies on a yearly basis between -0.713 and -1.108.

[21] The Hicksian elasticities, or constant output demand function, is derived from the cost function.

[22] The Marshallian and Hicksian elasticities of input build respectively on the profit and cost function. Lopez (1984) shows how to estimate Hicksian elasticities from the profit function.

[23] Squires (1987a) reports the Allen partial elasticities as well as Marshallian elasticities. The Allen partial elasticity is like the Hicksian elasticity, focusing on the pure substitution effect for the given level of product. The Hicksian and Allen elasticities are related by $\sigma_{ij} = \varepsilon_{ij}/s_j$, where ε and σ are the Hicksian and Allen elasticities

gill net troll salmon fishery, thereby revealing that individual regulation of gears, fuel, or labour might be circumvented by substituting other inputs. Input management imposed on the gill and seine fishery should, therefore, be done by restrictions on the use of several inputs at the same time.

The Elasticity of Intensity

Another achievement of Dupont (1991) is to clarify the relationships between regulated and unregulated inputs. This is accomplished by use of the elasticity of intensity, which describes the impact that a change in a restricted input will have on an unrestricted input (Diewert 1974). The elasticity of intensity is defined as:

$$E_{ij} = \frac{\delta x_i (p_v, w, z_i)}{\delta z_i} \frac{z_i}{x_i},$$

where x_i is the variable input that is conditioned on the output price, p_v; input price, w; and z. z_i is the quantity of the restricted input. A negative elasticity indicates a substituted relationship and a positive elasticity, a complementary one.

In the Canadian salmon fishery, both the number of fishing days and vessel tonnage are restricted by regulation. Based on the estimation of elasticity of intensity, the study of Dupont (1991) reveals that restricting the number of fishing days is an effective way to reduce the fishing effort for seines and gill net-troll vessels, the reason being that the vessels find it difficult to compensate for a restriction in number of fishing days through an increase in the unregulated input of fuel, labour, and gear. Dupont suggests that estimates of elasticity of intensity could be used to implement input limitation programs aimed at regulating inputs, which have few or limited substitution possibilities, preventing fishermen from compensating for the restricted input by increasing their use of unrestricted inputs

4.3.The cost structure of multiproduct firm

Another important means of revealing the technological conditions of the multiproduct firm is via its cost structure. The cost advantage of certain categories of vessel may be a good indicator of competitive advantages; thus indicating which categories of vessel are most likely

---

respectively and s_j is the cost share of the j*th* input. The Allen partial elasticity separates the relative impact of the price changes.

to survive in the future fleet structure. From a normative view, management authorities might also use information about cost structures for different vessel categories as an important building block in the industrial organization of the fishing fleet. Certain applications of the dual approach are devoted to revealing conditions for economies of scope and economies of scale. This means revealing the extent to which diversity in outputs embodies cost savings compared to specialized production plants, or whether relative cost savings in expanding the scale of outputs exist. A summary of the applications that reveal cost structures of harvesting technologies is presented in table 4.3.

Table 4.3 The Cost Structure of the Multiproduct Firm

Study	**Gear**	**Functional Form**	**Economies of Scope**	**Multiproduct Economies of Scale**	**Product Specific Economies of Scale**
Alam, Ishak, and Squires (2002)	Trawl	Translog profit	Economics of scope 1)	Decreasing returns to scale	Both increasing and decreasing 2)
Bjørndal and Gordon (2000)	Purse seiners, trawlers, coastal boats	Translog cost	Not reported	Increasing returns to scale for each vessel group 3)	Not reported
Diop and Kazmierczak (1996)	Trawl	Leontief revenue	Not reported	Not reported	Decreasing and constant 4)
Segerson and Squires (1993)	Trawl	Leontief Revenue	Not reported	Not reported	Decreasing for all
Squires (1987b)	Trawl	Translog profit	Economies of scope 1)	Decreasing returns to scale	Both increasing and decreasing 5)
Squires (1987c)	Trawl	Translog profit	Diseconomies of scope	Decreasing returns to scale	Both increasing and decreasing 6)
Squires (1988)	Inshore and offshore trawlers	Translog profit	Economies of scope 1)	Decreasing returns to scale for each vessel group	Both increasing and decreasing 7)
Squires and Kirkley (1991)	Trawl	Leontief revenue	Economies of scope 1)	Decreasing returns to scale	Both decreasing and constant 8)
Weninger (1998)	Surf clam and ocean quahog vessels	Translog cost	Diseconomies of scope	Increasing returns to scale	Increasing for all 9)

1) The economies of scope are verified due to weak cost complementarity in a subset of outputs.
2) Increasing for high-grade species on east and west coasts, and medium-grade species on east coast.
3) Increasing for multiproduct returns to scale for spring-spawning herring and other catches.
4) Constant returns to scale for finfish, decreasing returns to scale all other species.
5) Increasing returns to scale for yellowtail flounder, decreasing returns to scale for all other species.
6) Decreasing returns to scale for roundfish and flatfish, increasing returns to scale for residual catches.
7) Increasing returns to scale for flatfish, decreasing returns to scale for roundfish and other species.
8) Constant returns to scale for thornyheads and other rockfish, decreasing returns to scale for all other.
9) Increasing returns to scale for surf clams and ocean quahogs.

The economies of scope reveal whether cost advantage exists in producing several outputs or not. The definition of economies of scope follows from the condition: $C(y_T) + C(y_{v-T}) > C(y_v)$, where C(.) is a cost function and T is a subset of v (see Baumol, Panzar, and Willig 1982). The condition means that producing outputs y_T and $y_{y\text{-}T}$ in separate productions results in higher costs than employing a joint production of y_T and $y_{y\text{-}T}$.[24]

The results of economies of scope for fish harvesting technologies are ambiguous. Squires (1987b,c and 1988) indicate that there is a discrepancy in the tests for economies of scope for the otter-trawling fishery of New England. The reason for the statistical discrepancy in the studies follows because different output compositions and fleet categories are specified. Squires (1987b, 1988) undertake the most detailed specifications of output compositions and fleet categories, verifying the hypothesis of economies of scope. In this sense, an aggregation bias in Squires (1987c) might explain why economies of scope are rejected in this study. The presence of economies of scope in a fishery might be explained on the basis of seasonal harvest patterns or the spatial distribution of different fish stocks that cause cost complementarity in harvesting several outputs jointly.

Weninger rejects the idea that economies of scope are present in the mid-Atlantic surf clam and ocean quahog fisheries, where fishermen are restricted by output regulation. This result is not surprising, due to the condition of nonjointness in inputs previously reported for these fisheries, indicating that surf clams and ocean quahogs are produced in separate production processes. In this sense, cost complementarity in harvesting the two species can be excluded.[25] Moreover, the imposed output regulation might limit the possibility of achieving complementarity in production, but might instead create a cost disadvantage in joint production due to the Le Chatelier effect. In a management setting, imposing regulation such as bycatch limitation may distort the complementarity of jointly harvested species, leading to increased production costs. In this sense, imposed regulation has consequences for the cost structure of the firm, and thereby might distort cost efficiency and create cost disadvantages

[24] The economies of scope are satisfied for one of two reasons, either because of fixed costs or due to weak cost complementarity. Firstly, in case the fixed costs do not depend on the quantities of outputs produced, but do vary depending on which outputs are chosen. This means that the fixed costs of multiproduct technology are less that the sum of costs from two specialized product technologies. Expressed by $F_T + F_{v\text{-}T} > F_v$, where F_T, $F_{v\text{-}T}$ and F_v are the fixed costs when producing the submatrices of output of {T}{v-T}, and {v}, respectively. Secondly, weak cost complementarity means that the marginal cost of producing the *ith* output will decrease with an increase in the production of the *jth* output. Weak cost complementarity can be expressed by $\delta(\delta C[.]/\delta y_i)/\delta y_j \leq 0$, where C[.] denotes the multiproduct cost function, and y_i and y_j denote the production of the *ith* and *jth* outputs.

[25] Still, economies of scope cost could prevail due to sharing fixed costs in the harvesting of the two species.

for certain categories of vessel. Thus, regulation will have unintended impacts on the relative competition between vessel categories operating in the fishery.

Other elements of the cost structure addressed in the applications are the concepts of product-specific economies of scale and multiproduct economies of scale. The cost improvement due to product-specific economies of scale for the i*th* output, $S_i(y)$, is based on the condition: $S_i(y) = AIC_i(y)/C_i$. $AIC_i(y)$ is the average incremental cost and C_i is the marginal cost. The condition states that the firm experiences decreasing cost in producing the last unit of output i, if the marginal cost of producing the last unit is less than the average incremental cost. This means that whenever $S_i(y) > 1$, the firm has an incentive to increase production. Likewise, the concept of multiproduct returns to scale, $S_M(y)$, measures the development of costs for proportional changes in all outputs and inputs.

The results of the product-specific economies of scale indicate that most species are harvested under conditions of decreasing returns to scale. In the multiproduct trawler fishery, increasing product-specific returns to scale is frequently found for individual species, which makes these species vulnerable to over harvesting due to decreasing marginal production costs. For the trawlers, the conditions of increasing product-specific returns to scale and economies of scope often overlap (see e.g., Squires 1987b, 1988; Alam, Ishak, and Squires 2002). However, the development of trawling specialized for harvesting a single species is unlikely because economies of scope create cost advantage in jointly harvesting several species.

Increasing multiproduct economies of scale is rejected in most studies. However, Bjørndal and Gordon (2000) and Weninger (1998) find indications of increasing multiproduct returns to scale in the cases of the North Sea herring fishery and a mid-Atlantic mussel fishery. In both studies, the behaviour of the firm is restricted by output regulation, meaning that they minimize their production costs. The results of increasing economies of scale are expected, given that vessels minimize their costs by operating in regions of increasing returns to scale. However, insufficient management of overall capacity might induce certain vessels to operate in regions of decreasing returns to scale.

As a curiosity, the cost structure also determines the extent to which a natural monopoly will develop in the fishing industry. The condition necessary for a natural monopoly to prevail is subaddivity of cost, which is expressed in the condition: $C(y) < {}_i\Sigma_k C(y_i)$, where ${}_i\Sigma_k y_i = y$. $C(y)$ measures the cost of the single firm producing y, and ${}_i\Sigma_k C(y_i)$ measures the aggregated cost of the k firms producing the output vector y. The condition means that if it is cheaper for a single firm to produce the output vector y rather than distributing production over k different firms, a natural monopoly might be suitable.[26]

Squires (1998), and Alam, Ishak, and Squires (2002) reject for the presence of cost subadditivity in trawler fisheries of New England and Malaysia, respectively. Although economies of scope and scale in both fisheries are suggested, these conditions are insufficient to satisfy the conditions required for a natural monopoly to exist, the reason being that the technologies exhibit decreasing multiproduct returns to scale. Moreover, it is indicated that the cost surfaces are not convex due to the absence of positive-definite diagonal elements measured in the Hessian submatrix of the cost function.

The lack of the appropriate cost data in output supply is often regarded as a hindrance to indicating the cost structure of the multiproduct firm. However, Squires (1988) and Squires and Kirkley (1991) demonstrate that it is possible to reveal conditions of economies of scope and scale based on information contained in the revenue and profit functions. Building on findings by Sakai (1974), the relationship between the cost function, C, and the long-term profit function, π, follows as: $\delta^2 C^*[.]/\delta y_i \delta y_j = [\delta^2 \pi[.]/\delta p_i \delta p_j]^{-1}\ \forall\ i, j\ \varepsilon\ M$. This means that the inverse Hessian matrix of the long-term profit function π is identical to the Hessian matrix of the cost function, C. Therefore, given that the profit function is in long-term equilibrium, the conditions of the cost function can be revealed.

[26] A sufficient condition for cost subadditivity is the of presence transray convexity and ray subadditivity. Transray convexity embodies cost convexity and economies of scope, these conditions imply that when the monopoly changes its output composition and at the same time keep the level of some aggregate output fixed, costs will be lower for diverse rather than for specialized output mixes. A sufficient condition for ray subadditivity is increasing multiproduct returns to scale (see Baumol, Panzar, and Willig 1982).

4.4. The industrial organization of the fishing industry

Welfare improvements resulting from reorganizing industrial structure are addressed in different applications. Restructuring of the fishing fleet and reallocation of catches between different categories of vessels are sources of welfare gains at the industry level. The potential welfare gains are revealed by disclosing the specific production conditions for vessels of different types and sizes. For example, conditions of economies of scope and scale reveal whether a fleet containing specialized or generalized vessels is efficient in the fishery (Lipton and Strand 1989). Inefficient fleet structures due to overcapacity or an inefficient mixture of vessel categories are examined. An overview of the various applications on industrial organization is provided in table 4.4.

Table 4.4 Industrial Organization of Harvesting Technologies

Study	**Gear**	**Regulatory Regime[1)]**	**Functional Form**	**Description**
Campbell and Nicholl (1995)	Long line, purse seine	None	Leontief revenue	Addresses reallocation of catch between vessel groups in presence of a stock externality.
Dupont (1990)	Seine, gill net, troll, gill net troll	Input regulation	Quadratic Profit	Addresses rent dissipation due to input regulation based on Kulatilaka test.
Lipton and Strand (1992)	Surf clam and ocean quahog vessels of different sizes	Output regulated	Quadratic cost	Compares open-access and limited-access management in a fishery with a stock externality.
Weninger (1998)	Surf clam and ocean quahog vessels of different sizes	Output regulation	Translog cost	Addresses the transition of regulation from limited entry to ITQ management.

1) Addresses the regulatory regime predominating the firm behaviour under study.

Different regulatory regimes are addressed in the applications. Each regulatory regime imposes certain behavioural restrictions on the behaviour of the firm. In the output regulated industry, addressed by Lipton and Strand (1992) and Weninger (1998), the firm is assumed to minimize its costs for pre determined outputs. Under input regulation, examined by Dupont (1990), the firm is assumed to maximize profit at given levels of regulated inputs.

Lipton and Strand (1992) and Weninger (1998) both find an inappropriate mix of vessel categories and reluctant capacity in the mid-Atlantic surf clam and ocean quahog fisheries.

Approaching different management regimes implies that there is a discrepancy in recommendations regarding fleet structure in the two studies. Theoretically, the total harvesting capacity is derived from the imposed TAC regulation. Lipton and Strand (1992) calculate the fleet capacity required under a limited-access management regime. To be of value over a longer time horizon, the capacity recommendation of Lipton and Strand needs to be adjusted for productivity growth in the industry, which is not done. The introduction of individual transferable quotas, addressed by Weninger (1998), implies that reluctant capacity due to productivity growth is dealt with through the quota market. Vessels that do not achieve minimum operating costs will earn a residual return that is less than the market lease in the ITQ market, and these firms will be bought out of the market (Weninger and Just 1997). In this sense, an efficient ITQ market ensures that reluctant capacity is bought out of the industry. The findings of Weninger (1998) indicate diseconomies of scope, increasing returns to scale of variable cost, and declining fixed costs for larger vessels. The transformation of regulation from limited-access management to ITQ management leads to significant cost reductions in the industry to be operated by large specialized vessels.

Dupont (1990) considers whether input regulation creates a nonoptimal industrial organization in a case study of the Canadian salmon fishery. The study rejects the hypothesis that restrictions on vessel tonnage create a welfare loss in the industry. The finding is based on a Kulatilaka test, indicating that there is no significant difference between the actual level of regulated vessel tonnage and optimal vessel tonnage.[27] On the other hand, inappropriate fleet structures due to nonoptimal fleet composition and reluctant fleet capacity are found in the fishery.[28]

Campbell and Nicholl (1995) address the connection between stock externality and industrial organization in a case study of the yellowfin tuna fishery in the western Pacific. The stock externality implies that it is beneficial in terms of welfare to reduce catches of juvenile fish by purse seine vessels in order to increase catches of adult fish by long line vessels. A test on nonjointness in inputs for the purse seine vessels indicates that they are multiproduct firms producing several outputs. Two ways of reducing the multiproduct purse seines' catch of

[27] The Kulatilaka test is described more carefully in the section that addresses testing of full static equilibrium.

[28] Reluctant fleet capacity is derived based on the TAC in the fishery.

juvenile fish are addressed: A royalty tax on landings of yellowfin or an effort tax based on the number of fishing days for the purse seines.[29]

The empirical results indicate that the economic losses of the purse seines will be lower under a royalty tax than under an effort tax regulation. This follows due to jointness in inputs, which implies that the royalty tax impacts, the vessels to harvest the non-taxed species. In contrast, the effort tax will reduce landings of all species, thus resulting in lower effort and earnings than under the royalty tax.

[29] If the production is characterized by diminishing marginal productivity of effort, the marginal cost of reducing the fishing effort of each vessel will be less than reducing the number of fishing vessels.

5. Capacity utilisation and rent dissipation

The dual approach has also been used to examine levels of capacity utilisation and rent dissipation. This is particularly relevant to this study, which aims to examine how ITQs may change the rent dissipating behaviour. A overview of the methods that have been employed are presented below, along with examples that relate explicitly to the ex-ante evaluation of individual vessel quota programmes. The implications for the situation, common in many fisheries, of quotas being only applied to some species is also considered.

5.1. Testing capacity utilization/full static equilibrium of quasi-fixed input

Applications of the dual approach mainly outline the firm's short-term behaviour, treating vessel capacity as quasi-fixed. The incentive for a firm to alter the quasi-fixed input is addressed by analyzing capacity utilization or testing for full static equilibrium of the quasi-fixed input. Comparing the observed level of the quasi-fixed input with its optimal long-term level is an essential element in deriving incentives for investment in the quasi-fixed input. The different applications that investigate capacity utilization/full static equilibrium are presented in table 5.1.

Table 5.1 Tests for Full Static Equilibrium/Capacity Utilization

Study	**Gear**	**Quasi-Fixed Input**	**Functional Form**	**Full Static Equilibrium/ Capacity Utilization[1)]**	**Details**
Alam, Ishak, and Squires (1996)	Gill net	GRT-capacity	Translog profit	Reject	Conrad and Unger test[2)]
Alam, Ishak, and Squires (2002)	Trawl	GRT-capacity	Translog profit	Reject	Conrad and Unger test[2)]
Bjørndal and Gordon (1993)	Purse seine	GRT-capacity	Translog profit	Reject	Conrad and Unger test[2)]
Dupont (1990)	Seine, troll, gill net, gill net-troll	GRT-capacity	Quadratic profit	Accept	Kulatilaka test[3)]
Segerson and Squires (1990)	Trawl	GRT-capacity	Translog cost	Reject, Accept[3, 5)]	Capacity utilization[4)]
Segerson and Squires (1993)	Trawl	GRT-capacity	Leontief revenue	Accept[3)]	Capacity utilization[4)] Kulatilaka test
Squires (1987c)	Trawl	GRT-capacity	Translog profit	Accept	Capacity utilization[4)] Kulatilaka test[3)]
Squires (1988)	Trawl	GRT-capacity	Translog profit	Accept	Kulatilaka test[3)]
Squires and Kirkley (1991)	Trawl	GRT-capacity	Leontief revenue	Accept	Kulatilaka test[3)]

1) Accept means that the H_0 hypothesis of complete capacity utilization/full static equilibrium of the quasi-fixed input cannot be rejected.
2) The test is employed as based on Conrad and Unger (1987).
3) The test is based on Kulatilaka (1985).
4) See Morrison (1985).
5) Segerson and Squires (1990) employ alternative tests of primal and dual concepts on capacity utilization.

All applications specify GRT capacity (Gross Registered Tonnage) as the single quasi-fixed input.[30] The test of the quasi-fixed input is based on the behaviour of the firm in the short run; i.e., when vessel capacity is quasi-fixed.[31] Applying the dual approach to revenue, profit or cost functions can be accomplished to identify incentives for the expansion or reduction of capacity. The test addresses the question of whether the actual level of vessel tonnage is equal to the optimal long-term level. The null hypothesis is that the observed vessel size is equal to the optimal level in the long term. In the case that the null hypothesis cannot be rejected, the firm has no incentives to alter tonnage capacity. If the firm has an incentive to expand its capacity, this has implications for the public management of fishing effort. Regulators might consider limiting the aggregated fishing effort by restricting the number of fishing vessels. To do so, there also needs to be an assessment of the firm's incentives to expand their individual

[30] The GRT measures the size of the vessel indicating its storage capacity.

[31] It is possible to address the situation where several inputs are quasi-fixed.

capacity (size in GRT-capacity). Ignoring the firm's incentives for capacity expansion might lead to underestimation of the realized long-term fishing effort (number of vessels times GRT capacity) in the industry.

Mixed results of the capacity utilization/full static equilibrium are found. Alam, Ishak, and Squires (1996) and Bjørndal and Gordon (1993) identify incentives for capacity expansion for gill netters and purse seines. Squires (1987c, 1988), Alam, Ishak, and Squires (2002), and Dupont (1990) indicate no incentive of capacity expansion for trawlers, seines, gill net vessels, and trollers. However, the survey does not reveal any connection between fishing gear and incentives for capacity expansion. Mere incentives for expansion of the firm's capacity are closely related to stock abundance and capital costs in the specific fishery. A weakness with regard to identifying investment incentives in most applications is that these build on only one to two years of data. To be relevant in a management setting, incentives for capacity expansion should remain in place for several years, since the adjustment of fishing capacity is a long-term process (Jensen 1998). Bjørndal and Gordon (1993) estimate the development of optimal vessel size over several years. Their study emphasizes the importance of conducting tests on full static equilibrium over several years, and the results reveal substantial variations in predicted annual optimal vessel size due to differences in the definition of the user cost of capital.

Several theoretical refinements of capacity utilization approaching conditions in fisheries have been made. Segerson and Squires (1990) emphasize the straightforwardness in defining the dual measure of capacity utilization for the multiproduct fishing firm, whereas it is difficult to apply the primal measure of capacity utilization to the multiproduct firms. Segerson and Squires (1995) develop the capacity utilization concept for the revenue-maximizing firm describing decisions made on the individual fishing trip, where input composition during the trip is assumed to be fixed. Segerson and Squires (1993) measure the capacity utilization under trip quota regulation imposed *ex ante* on the individual fishing firm.

5.2. *Ex ante* assessment of production quota on the multiproduct firm

Quantity restrictions on inputs or outputs are often proposed as a means of regulating fish harvesting. Imposed on the multiproduct firm, assessments of the behavioural implications of quantity regulation are often complicated. Assessments of regulation *ex ante*; i.e., before quantity regulation is imposed, is often demanded by regulators. Different applications of the dual approach utilize *ex ante* assessments of quota regulation that provide information about how the unregulated multiproduct firm would react to quantity restriction. Impacts of production quota on output composition and investment incentives are among the aspects that are addressed. A summary of the different contributions is provided in table 5.2. All applications address the short-run behaviour of the firm that maximizes revenue during the fishing trip, assuming fixed input composition.

Table 5.2. Applications Using ex ante Assessment of Production Quota on Firms

Study	**Gear**	**Functional Form**	**Contribution Addressing the Impact of Trip Quota on:**
Squires and Kirkley (1991)	Trawl	Leontief revenue	A single output for a) the reorganization of output supply, b) demand of effort.
Segerson and Squires (1993)	Trawl	Leontief revenue	A single output for c) incentives to invest in quasi-fixed inputs.
Squires and Kirkley (1995)	Trawl	Leontief revenue	Several outputs for d) aggregated rents and gains from quota trading.
Squires and Kirkley (1996)	Trawl	Leontief revenue	Several outputs for e) equilibrium market price for trade transferable quotas.

Combining the dual approach with rationing theory offers a basis for predicting the implications of quantity restriction. For the unregulated firm, output supply and other production decisions are based on exogenous prices. Imposing output regulation binds the output supply of the firm. Therefore, in order to determine the consequences of production quotas for the unregulated firm, the *ex ante* assessment should transform the quantity restriction into a price restriction. Using the framework of a virtual price, the output constraint is transformed into an equivalent price constraint (see Neary and Roberts 1980). The virtual price, φ_i, is defined as the price that would induce an unconstrained firm to behave in the same manner as when facing an output constraint. In this sense, the methodology considers how a primal constraint is translated into a dual constraint.

Various implications of the trip quotas are considered. Squires and Kirkley (1991) looked at how a trip quota on a single output impacts the production conditions of the multiproduct firm. Two aspects are dealt with. First, they considered the impact of a trip quota on the multiple output supply of the firm. Secondly, they examined the extent to which the trip quota shifts a firm's output supply curve, thereby reducing effort and the supply of all outputs. Campbell and Nicholl (1995) considered similar problems in the context of price restriction that are more immediate to employ in a dual setting.

Segerson and Squires (1993) identify the consequences of production quotas on the capacity utilization of the multiproduct firm. This is accomplished by using the virtual price combined with the shadow value of the quasi-fixed input to measure impact on capacity utilization. Their results show that output quotas on individual species will not necessarily lead to disincentives for investment. For outputs with large revenue shares, output regulation will have strong disinvestment incentives. On the other hand, production quotas for outputs that have small revenue shares do not seem to induce any disinvestment incentives. The result is consistent with the findings of Segerson and Squires (1995) that the impact of price change on capacity utilization is critically dependent on the revenue share of the output relative to the shadow cost of the quasi-fixed input.

Squires and Kirkley (1995, 1996) contribute by making an *ex ante* assessment of ITQ regulation imposed simultaneously on several outputs. The success of introducing ITQ management on various species is critically dependent on whether the technology embodies nonjointness in inputs. Under conditions of nonjointness in inputs, the ITQ markets for multiple outputs can be managed separately for each output. Introducing ITQ management when the technology embodies jointness in inputs involves the problem that ITQ management does not meet the criterion of optimal market clearance in all markets. This means that well-functioning ITQ markets for each species will not necessarily be found. Squires and Kirkley emphasize that a necessary condition for well-functioning ITQ markets exists if the marginal rate of transformation between outputs is equal to the relative ITQ market prices. However, given that ITQ markets do not necessarily match the product transformation of the firms, this brings up the problem that species managed by ITQ will not be fully exploited. This is the case in the study of the ITQ management of sablefish and thornyheads in the Pacific coast trawler fishery, where sablefish are underfished under ITQ management. The result is not surprising given the technological feature of the trawlers, which are characterized by their ability to shift target species. ITQ management means that the trawlers will be precommitted to target thornyheads but this will happen at the cost that they will not be able fully utilize their technological potential in sablefish fishery (an example of the Le Chatelier effect). Therefore, underexploitation of sablefish implies that the potential welfare gain of the sablefish fishery is not fully obtained.[32] On the other hand, if sablefish and thornyheads are produced in separate production functions, jointness in inputs would not cause problems of underexploitation and incomplete exploitation of potential benefits of ITQ regulation.[33]

5.3. Rent dissipation and capacity

During the 1990s, individual vessel quota (IVQ) schemes, where the quota may or may not be transferable, have become an important management tool. For these schemes, each participant in the fishery is entitled to a *quantity or quota* share of the TAC. This eliminates the race to fish as fishermen are ensured their quota share and, moreover, can lead to rent generation. However, to ensure rent generation, capacity in the fishery cannot be too high. This is a problem as there tends to be substantial overcapacity in fisheries when individual vessel quotas are introduced. In most cases, the practice has been to initially allocate quota shares to fishermen *gratis*, usually based on historical catch records.

As seen above, when modelling the harvesting process, an assumption of profit maximisation is often the starting point and production parameters are estimated using a profit function specification. Without restrictions on the profit function all inputs used in harvesting and the harvest level are choice variables for the fishing vessel. The total profits can be written as

$$\Pi(p,w) = Yp - \sum_i q_i w_i$$

[32] The gains by introducing ITQ management arise, as firms will reallocate their fishing activity to the most favourable periods of the year. Moreover, economic rent will also arise since the most efficient vessels will purchase quota from less efficient vessels.

[33] Vestergaard (1999) develops the framework to measure welfare effects of individual quotas in multiproduct industries.

where p is the price of fish, Y the harvest level, and w_i the price of the ith input factor, q_i. This tells us that profit is the difference between revenue and cost of production. Observed profits are often taken as an estimate of realised rent in a fishery (Dupont, 1990).

In open access or regulated open access fisheries, resource rents will be dissipated by the common property nature of the fishery and profits, defined by the above equation, are zero. However, with individual vessel quotas fishing vessels are ensured a share of the resource, so that profits can be positive, representing resource rent.

In many empirical applications, the above equation is modified to account for restrictions in the actual harvesting process. Often capital (the vessel) is treated as a fixed factor in harvesting, recognising that regulations prevent adjustment or that second hand markets often are limited and adjustment costs accordingly high (Squires, 1988; Dupont, 1991, Bjørndal and Gordon, 1993). Under this scenario, a restricted profit function is specified where the fishing vessel is assumed to maximise profits by choosing inputs and harvest level subject to the size of the vessel used in harvesting. Total profit can be calculated from the restricted profit function, $\Pi^R(p,w;z)$, by accounting for the cost of the vessel or

$$\Pi(p,w,w_z) = \Pi^R(p,w;z) - w_z z$$

where w_z is the user price for purchasing capital stock (i.e., the vessel), and z represents the size of the vessel. Since this equation defines the long-run profit relationship, resource rents can be measured in the same manner as in the previous equation.

The equation can also be used to derive the optimal level of the fixed factor by maximising it with respect to the fixed factor(s) (Lau, 1976; Brown and Christensen, 1981). This was utilised by Dupont (1990), who noted that by finding the optimal level of the fixed factor, one can compute potential rent for a vessel if the regulatory system allows this factor to be adjusted to its optimal level. Hence, the revised equation can be used both to compute actual rents harvested under a regulatory system and the potential rents if the system is changed so that a (quasi-) fixed factor is allowed to adjust to its optimal level. Moreover, the fish stock or the TAC is in most cases given, and total catch cannot be increased. If vessels are to operate optimally, the number of vessels in the fleet has to be reduced. Dupont (1990) shows that this can be used to calculate optimal fleet size and potential rents obtainable with an optimal fleet.

With individual vessel quotas harvest is an exogenous or restricted factor. For price taking fishermen, the optimization problem is to maximize profits for a given catch level or equivalently, to minimize the cost of harvesting the given quota, assuming the quota is the only fixed factor. With these modifications the total profit for a fisherman under an IVQ scheme can be written as

$$\Pi(p,w) = Yp - C(w;Y)$$

where *C(w; Y*) represents the cost function where the individual fishermen decide the mix of input quantities for a given quota. The cost function contains all the choice variables for the fishermen under an IVQ scheme. Moreover, these variables will contain all information about behaviour from the observed data. It is well known that a cost function is a special form of a restricted profit function with (output quantity) harvest level treated as a fixed factor (Lau, 1976). Therefore, the structure of this equation is the same as for the previous equation with the restricted profit function. The only difference is due to different decision variables for the fishermen because of the different regulatory schemes.

This provides total profits, and observed profits can therefore be regarded as actual or realised rents. However, in contrast to the problem considered by Dupont (1990), the regulatory scheme now restricts the output. One can find the optimal output level by finding the cost minimizing output (Weninger, 1999), giving *Y*(p,w)*. This can be done either by finding the output level associated with constant returns to scale, or by maximizing the unit quota value using the virtual price approach of Fulginiti and Perrin (1993).[34] The constant returns to scale condition is an advantage when employing a single output translog cost function , as a closed form solution then exists. This is given as:

$$RTS = 1/(\partial C/\partial R) = 1/(\beta_y + \beta_{yy}\ln Y + \sum_i \beta_{iy}\ln w_i) \qquad (5.1)$$

The terms involving the prices of inputs, w_i, will disappear if the expression is evaluated at the mean input prices and all right hand side variables are normalized at their means. However, the translog requires numerical solutions if one are to model more then one output. In such cases other functional form ware then to be preferred.

[34] This condition will then also implicitly define the demand for quota (Arnason, 1990).

Furthermore, if one knows the TAC and assumes that the data set is representative, one can find how many vessels are necessary to take the TAC with the current technology. This will then be a measure of optimal fleet size. The total profits of these vessels will then be the potential rent in the fishery with the observed type of vessels. This is important information in fisheries managed with IVQs, as it will provide information about the extent to which one has been able to collect the resource rent and how much resource rent is dissipated due to overcapacity in the fishery.

5.4. Fisheries where individual quotas are present for some outputs

Society are increasingly concerned with the effects of a firm's activity that are consequences of but not a part of the firm's economic decision problem. Regulating the quantity that a firm can produce of a specific output is a commonly employed regulatory tool employed by the society to enforce its preferences. Hence, multioutput firms increasingly face restrictions on some of its outputs. However, this is not to any extent reflected in the way we model firm behaviour. In this chapter we will therefore address modelling of multioutput firms that face regulations on some of its outputs. Furthermore, the impacts of the regulations are of interest and we therefore investigate elasticities of intensity, separability, jointness and economies of scope in this context.

Following Beamol, Panzar and Willig's (1982) seminal work, substantial interest was focused on the impact of regulations in multioutput industries. However, the analyses were typically conducted assuming either that all outputs are fixed or variable. Hence, a cost minimization framework was used e.g by Kim (1987), assuming that the regulations applied for all outputs. Squires (1987) and Squires and Kirkley (1991) used respectively profit and revenue function specifications, conducting the analysis prior to the implementation of the restrictions. However, to our knowledge the case when restrictions have been imposed on some but not all of the multioutput firms outputs have not received much attention. This is important as such regulations are in operation in a number of industries. Examples are firms with pollution quotas, fishermen for which some species are regulated by quota, and farmers that face restrictions on some outputs (e.g. milk quotas). Econometrically, when modelling firm behaviour, it is important to not model (quasi-) fixed factors as variable and vice versa if one are to avoid inconsistent parameter estimates, tests and elasticities (Brown and Christensen, 1981). Hence, modelling all outputs as either as variable or fixed as in profit or cost functions are not good alternatives for industries with this structure.

The theory necessary for our analysis has largely been developed by Lau (1976). In particular, he provides a framework where distinctions between inputs and outputs are unnecessary, and hence where cost functions, revenue functions and any other representation of the firm's problem where some factors are treated as fixed are special cases of a restricted profit function. He also anticipates profit functions where some but not all outputs are treated as fixed naming pollution quotas as an example, and also raises the possibility of negative output prices, which will be the case if the quota is traded. Our contribution is to provide specification usable for empirical analysis, and to provide measures of the impact of the regulations through using elasticities of intensity, jointness, separability and economies of scope in this context.[35]

Let y be a vector of outputs and x a vector of inputs. The technology of a firm can be represented by a transformation function

$$F(y,x)=0 \qquad (5.2)$$

We assume that standard regulatory conditions apply for the transformation function.[36] Let the vector of variable output prices be denoted p, the variable input price vector as w and the vector of fixed outputs (quota restricted) denoted as $\bar{y}$. Following Lau (1976), the firm's optimization problem can be represented with a constrained profit function $\pi^R(p,\bar{y},w)$, where some outputs are fixed.[37] Following standard theory (i.e. Hotelling's Lemma) a set of supply functions for variable outputs and a set of demand functions for variable inputs can be defined and written as:

$$y_i = f(p,\bar{y},w) \qquad \text{for } i=1,\ldots,I \quad \text{variable outputs,}$$

$$x_m = h(p,\bar{y},w) \qquad \text{for } m=1,\ldots,M \quad \text{variable inputs,}$$

[35] Lau (1978) provides a good discussion of separability and jointness with respect to a profit function.

[36] See e.g. Lau (1976) or McFadden (1978) for a discussion of regularity conditions for the transformation function.

[37] This expression reduces to a long-run profit function if there are no fixed outputs and a long-run cost function if there are no variable outputs. One can of course introduce fixed inputs into this expression. Fulginiti and Perrin (1993) also show the relationship between the long-run and the constrained profit function.

In addition, the marginal cost or virtual price[38] associated with an incremental change in the quota allocation can be defined by differentiating the constrained profit function with respect to a restricted output:

$$\lambda_t = \Lambda(p, \bar{y}, w) \qquad \text{for } t=1,\dots,T \text{ restricted outputs}$$

Given that p_t is the market price of a unit of the restricted output, the potential rent (r_t) available for an incremental change in quota allocation can then be defined as

$$r_t = p_t - \lambda_t \tag{5.3}$$

This measure is of particular interest in natural resource industries like a fishery, where there is potential for a resource rent to be realized. In single-species fisheries regulated by open access[39], all rents are dissipated (Munro and Scott, 1985; Homans and Wilen, 1997). A quota regulated fishery has the potential to generate positive rents for restricted outputs. However, it is possible in multi-species fisheries, where economies of scope are important that one may observe the odd occurrence of positive and negative rents for different quota restricted outputs, as discussed in a cost function specification by Weninger (1998). As the effect of economies of scope is likely to be relatively moderate compared to the potential rent in a well managed industry, the quota rent for each species can be used as a measure of the success of quota regulations.

In characterizing the structure of production, we are often interested in the effect of relaxing the t^{th} quota. This can be found by deriving what Diewert (1974) refers to as elasticities of intensity.[40] These are given as

$$e_{it} = \frac{\partial \ln y_i}{\partial \ln \bar{y}_t} \quad \text{for all } i, t \text{ and}$$

$$e_{mt} = \frac{\partial \ln x_m}{\partial \ln \bar{y}_t} \quad \text{for all } m, t.$$

[38] The virtual price is defined as the price that would make it optimal for the firm to produce the regulated quantity of the output in question.

[39] Rent dissipation is also characteristic of other weak and poorly implemented regulatory fishery schemes, e.g. input restrictions.

[40] Diewert derived the elasticities of intensity to measure the effect of changing a fixed factor on the variable netputs. However, it seems natural to use the same terminology with respect to fixed netputs.

The e_{it} elasticity measures the percentage change in the i^{th} variable output due to a one percent increase in the t^{th} quota level, while e_{mt} measures the percentage increase in the use of variable input m due to a one percent increase in the t^{th} quota level. The e_{it} elasticities are of particular interest in a fishery, as a negative elasticity indicates that fishing pressure on the unregulated species will increase if the quota is reduced, while it will be reduced if the elasticity is positive. In addition, standard price elasticities can be computed and are conditional on fixed output and fixed input factors.

The elasticities of intensity and quota rent are useful but we also want information on the multi-output structure in the industry. A number of summary statistics are available to characterize the multi-output fishery and provide valuable information for optimal regulatory structure. One measure is testing for input-output separability. Evidence of separability indicates that the output side and the input side of the technology can be modeled separately and represented by an aggregate output index and an aggregate input index. With separability the production possibility set can be written as

$$F(y,x) = G(y) - H(x) = 0 \tag{5.4}$$

where *G(.)* and *H(.)* are aggregate index functions over the vectors y and x. In the restricted profit function, input-output separability implies the following structure (Lau, 1978; Denny and Pinto, 1978)

$$\pi^R(p,w;\bar{y}) = \pi^R(f(p;\bar{y}), g(w)) \tag{5.5}$$

In words, this means that the composition of outputs is not influenced by the composition of inputs. Squires (1987) shows that if separability is satisfied, the industry can be regulated efficiently with a total quota for all outputs. Lower levels of separability are possible over sub-groups of outputs and if statistically verified allows more precise targeting of regulations (Squires, 1987). In the current case, it is of particular interest to investigate whether the quota outputs can be treated as a group that is separable from the non-quota outputs.

Another test of a multi-output technology is nonjointness. If the technology is nonjoint in outputs, it implies that there exists a separate production function for each output (Lau, 1972). What is more, efficient regulation of the industry can be achieved with each output in isolation. Similarly, in a profit function setting it implies that there is a separate profit function for each output. For the restricted profit function considered here, this implies that there is a separate profit function for each of the unregulated outputs, while there is a separate cost function for each of the regulated outputs. It follows from Lau (1972; 1978) and Moschini (1988) that nonjointness can be defined as

$$\frac{\partial^2 \Pi^R}{\partial p_i \partial p_j} = 0, \quad \text{for all } i \neq j, \ \frac{\partial^2 \Pi^R}{\partial \bar{y}_t \partial \bar{y}_s} = 0, \quad \text{for all } t \neq s \text{ and } \frac{\partial^2 \Pi^R}{\partial p_i \partial \bar{y}_t} = 0, \ \text{for all } i, t. \tag{5.6}$$

One can also investigate the hypothesis of nonjointness between groups of outputs. Of particular interest in this setting is the hypothesis that the unregulated outputs are nonjoint with the regulated outputs.

If nonjointness is rejected in the data, there is the possibility of economies of scope in the production structure. Economies of scope can arise from two sources, weak cost complementarities and fixed costs. A sufficient condition for weak cost complementarities between variable and regulated outputs is

$$\frac{\partial^2 \pi^R}{\partial \bar{y}_t \partial p_i} \leq 0 \qquad \text{for all } i, t. \tag{5.7}$$

This indicates that increased production of a variable output reduces marginal cost for a regulated output. As the Hessian of the restricted profit function is symmetric, weak cost complementarities implies that an increased quota for a regulated output will reduce the cost for an unregulated output.

If the equality is reversed, there will be a cost anti-complementarity, indicating that it is more expensive to produce the outputs jointly. This is particularly relevant in industries with an allocatable fixed factor as discussed by Shumway, Pope and Nash (1984). In particular, Moschini (1988) shows that when the fixed input is normal,

$$\frac{\partial^2 C}{\partial y_i \partial y_j} \geq 0 \tag{5.8}$$

This can be relevant also in fishing, where the vessel can be an allocatable factor, depending on the fishing practice.

Product specific economies of scale measure the change in cost due to variation in one output holding the others constant. Firms with increasing (decreasing) product specific returns to scale have a cost incentive to increase (decrease) the scale of production for this output.

Define incremental cost (IC) of product i as: $IC_i(y)=C(y)-C(y_{I-i})$, where y_{I-i} is the output vector with the i^{th} output set to zero. Product specific economies of scale (S) for product i, $S_i(y)$, is calculated by $S_i(y)= IC_i(y)/y_iC_i$, where C_i is marginal cost for output i (Baumol et al., 1982). Product specific returns to scale will be increasing, decreasing or constant as $S_i(y)$ is greater than, less than or equal to 1.

By defining incremental marginal costs, information can be obtained on product specific scale economies for the variable outputs. Beaumol, et al, (1982) note that one cannot directly measure product specific returns to scale from a profit function. However, the diagonal elements of the Hessian submatrix for outputs provide a measure for incremental marginal costs. Squires (1988) notes that $\left[\partial^2\pi/\partial p_i^2\right]^{-1} = \partial^2 C/\partial y_i^2$, and accordingly; if $\left[\partial^2\pi/\partial p_i^2\right]^{-1} < 0$, this indicates $S_i(y^*)>1$ (increasing returns to output i); if $\left[\partial^2\pi/\partial p_i^2\right]^{-1} > 0$ indicates $S_i(y^*)<1$ (decreasing returns to output i); and if $\left[\partial^2\pi/\partial p_i^2\right]^{-1} = 0$ indicates $S_i(y^*)=0$ (constant returns to output i). In the constrained profit function, this implies that for variable outputs we use the measure $\left[\partial^2\pi^R/\partial p_i^2\right]^{-1}$, while for the restricted outputs we can use the measure $\left[\partial^2\pi^R/\partial \bar{y}_t^2\right]$.

6. Empirical estimation of capacity and capacity utilization

The economic theory underpinning the estimation of capacity and capacity utilisation presented in the previous is well established. However, deriving these estimates from data requires a number of assumptions about functional forms and behaviour of the fishers. Several methods have been developed for empirically deriving estimates of capacity and capacity utilisation. The dual methods – the focus of the previous sections – largely focus on the estimation of cost functions. Most previous studies, however, have tended to focus on primal measures of capacity, mostly through the non-parametric approach of DEA. In this study, the main focus was on the estimation of the dual cost function. The main functional form adopted was the translog cost function, although one case study (Denmark) applied the Leontief cost function approach. In another case study, the UK, both the cost function and non-parametric DEA approach was used. In this chapter, the techniques for empirical estimation of capacity are described.

6.1. Parametric estimation: cost functions

With tradeable quotas, vessels can adjust output levels, but have incentives to produce this output at the lowest cost possible. For this reason, the estimation of the cost function can be considered a more appropriate means of assessing capacity under an individual quota system. Relatively few applications of the cost function approach have been made in fisheries (see Weninger 1998, Lipton and Strand 1992, Segerson and Squires 1990, Bjørndal and Gordon 2000), largely due to difficulties in obtaining cost and revenue data for commercial fishing vessels.

The specific form of the cost functions is most often unknown, and must therefore be approximated by a flexible continuous and twice differentiable functional form. Often encountered flexible forms are the translog and the generalised Leontief cost functions. Neither of these are by construction concave in input prices and must therefore often be forced to be so through restrictions on the function parameters[41]. The translog form moreover

[41] The generalised McFadden cost function (Kumbhakar, 1994) is yet another possible flexible form, which is by construction concave in the input prices. This form has however not been applied in the present context as the

has the disadvantage that it cannot include zero output values, which is in itself a disadvantage when the catch of some species is zero, and secondly makes it difficult to calculate economies of scale (cf. Kumbhakar, 1994).

6.2. The translog cost function

The translog cost function for a single output industry[42] can be specified as

$$LnC = \beta_o + \sum_i^n \alpha_i \ln w_i + \frac{1}{2}\sum_i^n \sum_j^n \alpha_{ij} \ln w_i \ln w_j + \beta_y \ln y + \frac{1}{2}\beta_{yy} (\ln y)^2 + \sum_i^n \beta_{iy} \ln w_i \ln y + \varepsilon \qquad (6.1)$$

where C is the total cost, w_i is the price of input i and y is the (aggregated) level of output. By differentiating equation 5 with respect to the input prices and using Shephard's lemma, the set of cost-minimising factor cost shares can be derived, given by

$$S_i = \alpha_i \ln w_i + \sum_j^n \alpha_{ij} \ln w_j + \beta_{iq} \ln Q + \varepsilon \qquad (6.2)$$

where S_i is the cost share of the ith input, given by $w_i x_i / C$.

The cost function and the associated set of share equations need to be estimated simultaneously. As the input shares sum to 1 (one), one of the share equations needs to be excluded in order to avoid problems of singularity. A number of restrictions also need to be imposed on the system to ensure consistency with economic theory. Homogeneity in input prices and output requires $\sum_i^n \alpha_i = 1$, $\sum_i^n \alpha_{ij} = 0$, and $\sum_i^n \beta_{iy} = 0$, while symmetry in input prices requires $\alpha_{ij} = \alpha_{ji}$.

employed Leontief function has in most cases been shown to be naturally concave in prices, without imposed restrictions.

The set of coefficients from estimating the system provides additional information about the nature of the production system, including the propensity to respond to input price changes by changing input use or even substitute inputs, and the returns to scale associated with different production levels. The Allen partial elasticities of substitution between the factor inputs (σ_{ij}) are given by

$$\sigma_{ii} = (\alpha_{ii} + S_i^2 - S_i) / S_i^2,\ \sigma_{ij} = (\alpha_{ij} + S_i S_j) / S_i S_j \tag{6.3}$$

and the partial price elasticity of demand for input factor i (η_i) are given by

$$\eta_i = \sigma_{ii} S_i,\ \eta_{ij} = \sigma_{ij} S_j \tag{6.4}$$

A positive elasticity of substitution and cross price elasticity indicates substitution possibilities exist, while negative values indicate a complementary relationship.

The returns to scale of an individual vessel can be given by

$$RTS = 1/(\partial C / \partial R) = 1/(\beta_y + \beta_{yy} \ln Y + \sum_i \beta_{iy} \ln w_i) \tag{6.5}$$

6.3. The Generalised Leontief Function

When one output y is produced by the firms in the technology, the restricted generalised Leontief short run variable cost function, with fixed capital k and time variable t, is defined as (Diewert and Wales, 1987, Larsson, 2003):

[42] The cost function can also be developed for a multi-output industry. The single output case is presented for the sake of simplification.

$$VC_L^1(y, w_1, ..., w_N, k, t) =$$

$$y\left[\sum_{i=1}^{N}\sum_{j=i}^{N} b_{ij} w_i^{1/2} w_j^{1/2} + t\sum b_{it} w_i + t^2 \sum_{i=1}^{N} b_{itt} w_i + k\sum b_{ik} w_i + k^2 \sum_{i=1}^{N} b_{ikk} w_i\right] + \tag{6.6}$$

$$\sum_{i=1}^{N} a_i w_i + t\sum_{i=1}^{N} a_{it} w_i + k\sum_{i=1}^{N} a_{ik} w_i + y^2 \sum_{i=1}^{N} \beta_i w_i$$

When more than one output is present (6.6) can be extended following the approach given by Kumbhakar (1994) and Larsson (2003). The resulting *M*-output generalised Leontief variable cost function has the form:

$$VC_L^M(y_1, ..., y_M, w_1, ..., w_N, k, t) =$$

$$\left(\sum_{r=1}^{M} \delta_r y_r\right)\left[\sum_{i=1}^{N}\sum_{j=i}^{N} b_{ij} w_i^{1/2} w_j^{1/2} + t\sum_{i=1}^{N} b_{it} w_i + t^2 \sum_{i=1}^{N} b_{itt} w_i + k\sum b_{ik} w_i + k^2 \sum_{i=1}^{N} b_{ikk} w_i\right] +$$

$$\sum_{i=1}^{N} a_i w_i + t\sum_{i=1}^{N} a_{it} w_i + k\sum_{i=1}^{N} a_{ik} w_i + \sum_{i=1}^{N}\sum_{r=1}^{M}\sum_{s=r}^{M} \beta_{irs} w_i y_r y_s \tag{6.7}$$

The total short run Leontief cost function, including the cost of the fixed capital, is then given by:

$$C_L^M(y_1, ..., y_M, w_1, ..., w_N, k, t) =$$

$$\left(\sum_{r=1}^{M} \delta_r y_r\right)\left[\sum_{i=1}^{N}\sum_{j=i}^{N} b_{ij} w_i^{1/2} w_j^{1/2} + t\sum_{i=1}^{N} b_{it} w_i + t^2 \sum_{i=1}^{N} b_{itt} w_i + k\sum b_{ik} w_i + k^2 \sum_{i=1}^{N} b_{ikk} w_i\right] +$$

$$\sum_{i=1}^{N} a_i w_i + t\sum_{i=1}^{N} a_{it} w_i + k\sum_{i=1}^{N} a_{ik} w_i + \sum_{i=1}^{N}\sum_{r=1}^{M}\sum_{s=r}^{M} \beta_{irs} w_i y_r y_s + w_k \cdot k \tag{6.8}$$

This function is by construction homogeneous of degree one in the input prices. It is however not by construction concave in prices. The condition for concavity is that the matrix of second order partial derivatives of C with respect to input prices is negative semi definite[43]. The second order derivatives for the variable costs are given by:

$$\frac{\partial^2 C_L^M}{\partial w_i \partial w_j} = \left(\sum_{i=1}^{r} \delta_r y_r\right) \begin{cases} -\frac{1}{4}\sum_{j \neq i} b_{ij} \frac{\sqrt{w_i w_j}}{w_i^2} & ; \quad i = j \\ b_{ij} \frac{1}{4\sqrt{w_i w_j}} & ; \quad i \neq j \end{cases} \tag{6.9}$$

while the second order derivatives including w_k are all zero:

$$\frac{\partial^2 C_L^M}{\partial w_k^2} = \frac{\partial^2 C_L^M}{\partial w_i \partial w_k} = \frac{\partial^2 C_L^M}{\partial w_k \partial w_i} = 0 \tag{6.10}$$

The matrix composed of the elements (6.9) and (6.10) must be negative semi definite for each observation in the sample, i.e. for each set of output values and input prices, for the cost function to be globally concave in input prices. It is however not enough to claim that the matrix M given by (cf. equation 6.9):

$$M = \begin{bmatrix} -b_{11} & b_{12} & \cdots & b_{1N} & 0 \\ b_{12} & -b_{22} & & & 0 \\ \vdots & & \ddots & & \vdots \\ b_{1N} & & & -b_{NN} & 0 \\ 0 & 0 & \cdots & 0 & 0 \end{bmatrix} \tag{6.11}$$

is negative semi definite as the sum $\sum \delta_r y_r$ can be positive as well as negative depending on the output values and the parameters δ_r. Thus the claim for concavity is not always met for the generalized Leontief cost function of more than one output[44].

---

[43] A negative semidefinite matrix is a Hermetian matrix with non-positive eigenvalues.

Further it is seen that the generalised Leontief cost function (6.8) is not by construction increasing in the outputs or in the input prices. The structure of the function shows that it is not an easy task to ensure these two conditions, and the restrictions imposed in order to do so must therefore depend on the actual data at hand. In some cases the cost function will by nature be increasing as a function of y and w and in other cases it is necessary to impose restrictions on the functional parameters to ensure this increasing behaviour.

The input demand equations for the variable inputs are derived from (6.7) by Shepard's lemma

$$x_n = \frac{\partial VC_L^M}{\partial w_n} =$$
$$\left(\sum_{r=1}^{M} \delta_r y_r\right)\left[b_{nn} + \sum_{j \neq n} b_{nj} \frac{w_j^{1/2}}{2w_n^{1/2}} + t \cdot b_{nt} + t^2 b_{ntt} + k \cdot b_{nk} + k^2 b_{nkk}\right] + \tag{6.12}$$
$$a_n + t \cdot a_{nt} + k \cdot a_{nk} + \sum_{r=1}^{M} \sum_{s=1}^{M} \beta_{nrs} y_r y_s$$

The input demand equations are often estimated together with the variable cost function (6.7) using seemingly unrelated regression (SUR) to optimise the efficiency of the parameter estimates, which may be poor due to the large number of parameters in the generalised *n*-output Leontief function.

6.4. Non-parametric primal approaches: Data Envelopment Analysis

DEA is a non-parametric (linear programming) technique for deriving a production frontier from empirical data. As such, it is a primal, rather than dual, approach to estimating capacity. Although the estimation of capacity in fisheries using DEA is relatively new, a number of studies have already emerged (e.g. Pascoe *et al.*, 2001; Dupont *et al.,* 2002; Feltoven, 2002; Vestergaard *et al.,* 2003; Tingley *et al.*, 2003; Kirkley *et al.*, 2003; Walden *et al.,* 2003, Reid *et al*. 2003).

[44] For one output Diewert and Wales (1987) claims that the condition of global concavity is met for the function

Following Färe *et al.* (1992, 1994), the traditional DEA model of capacity output given current use of fixed inputs is given as:

$$Max\ \theta$$

subject to

$$\begin{aligned}
&\theta_1 y_{0,m} \leq \sum_k z_k y_{k,m} \quad \forall\ k \\
&\sum_k z_k x_{k,i} \leq x_{0,i} \quad i \in \alpha \\
&\sum_k z_k = 1 \\
&z_k \geq 0
\end{aligned} \tag{6.13}$$

where θ_1 is a scalar denoting how much the output of the target boat (i.e. $k=0$) can be increased, where $y_{k,m}$ is the output m produced by boat k, $x_{k,i}$ is the amount of input i used by boat k and z_k are the weights that relate the target boat to the set of peers (i.e. the vessels against which it is compared). The restriction $\sum z_k$ = 1 allows for variable returns to scale (VRS). In contrast, excluding this constraint implicitly imposes constant returns to scale (CRS) while $\sum z_k \leq 1$ imposes non-increasing returns to scale (NIRS) (Färe *et al.*, 1994). The sum of the weights when CRS is imposed provides an indication of the returns to scale. $\sum z_k < 1$ implies the vessel is subject to increasing returns to scale while $\sum z_k > 1$ implies decreasing returns to scale. The ratio of the θ_1's with VRS and CRS imposed provides a measure of the scale efficiency (i.e. scale efficiency = $\theta_{VRS} / \theta_{CRS}$).

Inputs are divided into fixed factors, defined by the sub-set α, and variable factors defined by the sub-set $\hat{\alpha}$. For the purposes of estimating capacity, only fixed inputs are considered. The value of θ is estimated for each vessel separately (i.e. so effectively a set of θ_k are estimated), with the target boat's outputs and inputs being denoted by $y_{0,m}$ and $x_{0,i}$ respectively. (Färe *et al.,* 1994).

---

(14) when all b_{ij} are nonnegative.

Capacity utilisation (*CU*) is defined as $CU=1/\theta$. The measure of CU ranges from zero to 1, with 1 being full capacity utilisation (i.e. 100 per cent of capacity). The capacity output of each vessel is determined by $y'_{k,m} = \theta y_{k,m}$ where $y_{k,m}$ is the current catch of each species *m* made by boat *k* and $y'_{k,m}$ is the potential full capacity catch of species *m* by boat *k*.

A firm's outputs may not be produced efficiently and hence some of the apparent capacity under-utilisation may actually be due to technical inefficiency (i.e. not producing to the full potential given the level of both fixed and variable inputs) (Färe *et al.* 1994). If all inputs (both fixed and variable) are not being used efficiently, then it would be expected that output could increase even without an increase in the level of variable inputs through the more efficient use of these inputs.

By comparing the capacity output to the technically efficient level of output, the effects of inefficiency can be separated from capacity under-utilisation. Further, the ratio of these measures has been found to be less susceptible to bias due to random error than the initial capacity utilisation and efficiency estimates (Holland and Lee, 2002).

The technically efficient level of output requires an estimate of technical efficiency of each firm, and requires both variable and fixed inputs to be considered. The DEA model for this is given by:

$$Max\ \theta_2$$

subject to

$$\begin{aligned} &\theta_2 y_{0,m} \le \sum_k z_k y_{k,m} \quad \forall\, m \\ &\sum_k z_k x_{k,i} \le x_{0,i} \quad \forall\, i \\ &\sum_k z_k = 1 \\ &z_k \ge 0 \end{aligned} \tag{6.14}$$

where θ_2 is a scalar outcome denoting how much the production of each firm can increase by using inputs (both fixed and variable) in a technically efficient configuration. In this case, both variable and fixed inputs are constrained to their current level and θ_2 represents the extent to which output can increase through using all inputs efficiently. The technically efficient level of output (y_{TE}^*) is defined as θ_2 multiplied by observed output (*y*). As the level of variable inputs is also constrained, $\theta_2 \leq \theta_1$ and the technically efficient level of output is less than or equal to the capacity level of output (i.e. $y_{TE}^* \leq y'$). The level of technical efficiency is estimated as $TE = 1/\theta_2$.

An estimate of capacity utilisation excluding efficiency effects (*CU**) is derived by:

$$CU^* = \frac{CU}{TE} = \frac{1}{\theta_1} \bigg/ \frac{1}{\theta_2} = \frac{\theta_2}{\theta_1} \tag{6.15}$$

As $\theta_1 \geq \theta_2 \geq 1$, $CU \leq CU^* \leq 1$. That is, this measure of capacity utilisation is greater than the original measure (which includes efficiency effects), but less than 1. The difference between the measures reflects the degree to which random variation and technical inefficiency affect the output levels of the different firms.

An implicit assumption of a primal approach such as implicit in the DEA model illustrated above is that output can increase to the full utilisation level. Under a system of individual quotas, economic efficiency is determined by cost minimisation given the fixed quota allocation rather than output maximisation given the set of inputs available to the fisher. While the DEA model can be specified with an input orientation, and hence can provide a measure as to the extent to which input use can be reduced to achieve efficient production, this does not provide information on the capacity of the vessel.

7. The Norwegian Case

There are three main sectors in the Norwegian Fisheries, demersal, pelagic and shrimps. Although there are some shrimp trawlers that are participating in other fisheries, there are in general several fleets targeting the species groups. Each fleet is further separated by vessel size and gear used. Regulations are varying with these groups so that in the fishery after a given species, there can be different regulations for different vessels depending on size and gear. However, there is a tendency that the regulations are more similar for vessels at the same size, independently of which fishery they are participating in. Hence, the regulatory system for large cod trawlers is more similar to the system for large purse seines than for coastal vessels targeting cod.

There are two primary tools that regulate Norwegian Fisheries. The Marine Fish Act of 1983, and the Participation Act of 1999. The Participation Act regulates the participation in commercial fishing with Norwegian vessels. For smaller vessels a general licence is required, while for large vessel specific licences to participate in a given fishery is necessary. After 1999 the following types of licences were in operation for larger vessels:

- Eleven types of trawl licences
- Three types of purse seine licences
- Licences for deep water prawn fishing, sealing and whaling

All licences, except for sealing and whaling, are assigned to a particular person or a company and a particular vessel. A licence does not follow the vessel with change of ownership. Licences for sealing and whaling are assigned to persons but not to vessels.

The Marine Fisheries Act is used to manage the resources in the sea using different quota regimes. Norwegian fisheries management is primarily based on output restrictions, that is, a TAC. Each year the International Council for the Exploration of the Sea (ICES) suggests TACs for all the regulated species. As most of the important stocks are shared stocks, with northern saithe as the only major exception, the final Norwegian quota is set after international negotiations. EU, Iceland and Russia are the most important countries in the negotiations, and the participants change by species.

The second layer of regulation is a grouping of the vessels by size and gear type, and shares of the TAC are distributed to the different vessel groups. In the larger vessel groups entry are restricted using the participation act as described above, while form most smaller vessels (less then 28 meters) there has been free entry. However, from January 2004, entry was restricted for all but the smallest vessel groups. For the different groups, additional restrictions on effort could be introduced.

Until the mid 1980s, there was a race to fish in all groups, but by the end of the decade the authorities started experimenting with individual vessel quota schemes for the largest vessels, that it, the larger purse seines and trawlers. As there were strong opposition among fishermen against transferability of quotas, such schemes were initially avoided. However, after introducing individual vessel quotas it soon became obvious that overcapacity was a major problem. As full transferability of quotas was not an option, one then introduced a system where in periods the quota for one vessel that was permanently removed from the fishery, could be used for 13 or 18 years, depending on fishery, by other vessels.

7.1.Data

In this report we will look closer at the Norwegian fresh fish trawlers. This is a group of trawlers with no onboard processing or freezing capabilities. The main species these trawlers are targeting is cod, but saithe, haddock and other whitefish species are also important.

The northeast Arctic cod stocks are managed jointly by Norway and the Russia. The two countries take 45 per cent of the total quota, leaving ten per cent to other countries.[45] The Norwegian share of the quota is divided between the coastal fleet and the trawlers using the so-called trawl ladder, introduced in 1990. The trawl ladder divides the quota after the following model:

- Below 100 000 t: 80 per cent to the coastal fleet / 20 per cent to the trawlers
- 100 000 – 150 000 t: 75 / 25
- 150 000 – 200 000 t: 72 / 28
- 200 000 – 300 000 t: 69 / 31

[45] France, UK, Spain and Germany take the main part, while fishers from the Faeroe Islands and Greenland take the rest.

- Over 300 000 t: 65 / 35

Hence, the coastal fleet will receive a higher share of the quota in years with a low quota. The total Norwegian quota and the division between the coastal and trawler fleet is shown in table 7.1. The group of fresh fish trawlers contains about half the vessels in the trawler fleet.

Table 7.1 The distribution of the Norwegian quota of cod north of 62ºN

	Coastal vessels		Trawlers		Total
	1000 t	**%**	**1000 t**	**%**	**1000 t**
2004	152	69,8	66	30,2	218
2003	138	70,4	58	29,6	196
2002	137	70,3	58	29,7	195
2001	138	70,4	58	29,6	196
2000	136	70,5	57	29,5	193
1999	164	69,2	73	30,8	237
1998	211	67,4	102	32,6	313
1997	267	66,9	132	33,1	399
1996	224	67,1	110	32,9	334
1995	226	66,9	112	33,1	338
1994	218	64,9	118	35,1	336
1993	180	69,5	79	30,5	259
1992	137	72,1	53	27,9	190
1991	98	76,0	31	24,0	129
1990	85	75,2	28	24,8	113

Source: Directorate of Fisheries

The data covers the three-year period 1997-99 and has been provided by the Norwegian Directorate of Fisheries. Annual observations are available at the vessel level on revenue and quantity as well as cost and quantity of fuel, bait, insurance, provisions, maintenance (vessel and gear), miscellaneous costs, labor.[46] The value of the vessel, measured by replacement value and tonnage units, is also provided. This provides a total sample of 98 observations. table 7.1 provides summary statistics for some key variables.

Input expenditure data are used to build three price indices; labour, capital and miscellaneous. The price index for labour (w_l) is defined as annual labour costs including captain divided by man-years of employment. The price index for capital (w_k) is defined as the replacement value of the vessel multiplied by the interest rate plus vessel depreciation. The interest rate is

[46] The data does not allow us to follow the vessels over the years, and hence, we cannot estimate firm specific effects.

set at 3% over the inter bank market rate and depreciation at 10%.[47] Finally, the price index for fuel and miscellaneous (w_m) is defined as the expenditure on fuel, maintenance for gear, vessel provisions, insurance and other costs divided by operating days. Long run Costs (C) are defined as the sum of expenditures on labour, user cost of capital, fuel, maintenance for gear, vessel provisions, insurance and other costs. Some summary statistics are provided in table 7.2.

Table 7.2 Summary Statistics Norwegian Cod Trawlers, 1997-99

Year	Number of vessels in sample	Number of vessels in fleet	Average Days Operation	Average Harvest (tonnes)	Average Gross Register Tonnes (GRT)	Average Value of Vessel (million NOK)	Costs (mill. NOK)
1997	32	44	268	2757.7	636	52.90	15.34
1998	31	39	279	2134.0	648	53.62	17.12
1999	35	35	270	1886.3	648	56.36	18.78
Total	98		272	2249.2	644	54.36	17.13

Source: Directorate of Fisheries

7.2. Empirical results

The price and harvest variables used in estimation are centred on the mean of the variable in the data set. Equation (5.5) is combined with the cost share equations for labour and capital and estimation is carried out using an iterative Seemingly Unrelated Regression procedure.[48]

The estimated parameters are provided in Table 7.3, and with a system R^2 of 0.976 the fit of the model is reasonable. In Table 7.4 the price elasticities are reported. All elasticities are statistically significant at a 5% level. All own price elasticities are negative and rather inelastic, as expected, and all input factors are substitutes. Hence, the model performs well and we can turn to the main topic of the paper, rent generation and capacity.

[47] The inter bank rate is used as the base rate on loans to the fishing industry as well as most other industries. For different industries one then adds a premium, which for fishing vessels normally is 3% (personal communication with K. Giskeødegard in Nordea).

[48] We also investigated whether there where structural differences between the years in the data set. However, the specification without annual dummies was preferred.

Table 7.3 Estimated Coefficients Long-Run Cost Function

α_o	9.962 * (0.05)[a]	α_{ll}	0.109* (0.009)	α_{Ql}	0.92E-4* (0.16E-4)
α_l	0.286* (0.002)	α_{kk}	0.134* (0.013)	α_{Qk}	-0.12E-4* (0.011E-4)
α_m	0.274* (0.0003)	α_{mm}	0.135* (0.009)	α_{Qm}	0.26E-4* (0.14E-4)
α_k	0.439* (0.005)	α_{lk}	-0.055* (0.007)	N	98
α_Q	0.256* (0.089)	α_{lm}	-0.055* (0.007)		
α_{QQ}	0.722* (0.276)	α_{km}	-0.079* (0.009)		

[a] Standard error in parentheses

* Statistically significant at the 95% level.

Table 7.4 Estimated Elasticities at mean values

	Labour	Fuel & miscellaneous	Capital
Labour	-0.330 (0.032) [a]	0.082 (0.026)	0.248 (0.025)
Fuel & miscellaneous	0.086 (0.027)	-0.235 (0.033)	0.149 (0.032)
Capital	0.162 (0.016)	0.093 (0.020)	-0.254 (0.029)

[a] Standard error in parentheses.

The first measure of relevance to capacity considered here are returns to scale. The scale elasticity is found to be 3.906, which indicates very substantial scale economies. This is in contrast to what is reported in most of the literature on fishermen behaviour (e.g. Squires and Kirkley, 1991, Salvanes and Squires, 1995). However, it may not be too surprising if one takes the change in regulatory structure into account. When modelling fisheries with a profit or revenue function, the fishermen mostly operate under a regulated open access structure with a race to fish. One then often finds substantial diseconomies of scale.[49] In the fishery considered here, on the other hand, there is no longer a race to fish. However, there are few incentives to reduce capacity, and given that regulated open access fisheries often will have a very high overcapacity (Homans and Wilen, 1997), this capacity to a large extent still exists within the fishery. The high returns to scale are therefore probably just a sign of substantial overcapacity in this fishery. It is also of interest to note that Weninger (1998) and Bjørndal and Gordon (2000), who also investigate fisheries managed by individual vessel quotas, find increasing returns to scale.

We then turn to optimal landings for a vessel.[50] As noted in section II, to find the optimal output one puts equation (5.5) exponentiated into equation (5.4), and maximises this with respect to Y. The translog does not have an analytical expression for optimal levels of fixed factors (Brown and Christensen, 1981). The optimal level therefore has to be found numerically. We find that optimal landings at average prices are 6,296 tonnes, about three

[49] For instance, Salvanes and Squires (1995) report a short-run returns to scale at 0.26.

[50] With our data set we are not able to model vessel heterogeneity. This is often reckoned to be of importance in the fishery literature through the notion of skipper effects. However, we are in line with Dupont (1990) and Bjørndal and Gordon (1993) in the fisheries literature and the technical efficiency literature in general (Kumbhakar and Lovell, 2000) in that heterogeneity disappears for an optimal industry if it is not characterised by constant returns to scale.

times the average quantity actually landed in the fleet. Hence, as expected there seems to be substantial overcapacity in this fleet.

7.3.Optimal Harvest and Fleet Size

When investigating the potential rents in this fishery we start by looking at the vessel level, and compute all measures for average prices (Table 7.5). All measures are reported both for the full period, and at the prevailing prices and quotas for each of the three years.

Table 7.5. Actual and potential rents at the vessel level

	Full period	1997	1998	1999
Output	2249.2	2757.7	2134.0	1886.3
Actual revenue	17.6	15.4	17.7	17.8
Actual rent	-1.7	-2.2	-1.5	-0.9
Potential revenue	49.2	35.1	52.3	59.5
Potential rent	29.9	17.5	33.0	40.7
Rent as % of potential revenue	60.8	49.8	63.1	68.4

Values are in million Norwegian kroner and quantities in metric tonnes.

The actual rent in each of the years is negative. This is most likely caused by the fact that we use opportunity cost of capital rather than actual cost. Many of the vessels are old (on average, boats were constructed in 1976), and most of them received subsidies when they were acquired. As noted above, the optimal landings for the average vessel are found to be 6,296 tonnes, about three times the quantity actually landed by each vessel. It is then not surprising that the vessel earns a substantial rent if it is allowed to increase landings. On average, potential rents are 60.8% of total revenues, although there is some variation between the years.

Let us then turn to the fleet. We here follow the approach of Dupont (1990), and assume that our sample is random, and use the mean of the prices in our sample as an estimate for the mean of the population. Given that we know the number of vessels in the population, we can derive aggregate measures. However, since the quota is set based on biological considerations, the actual landings cannot exceed the total quota. Hence, the optimal fleet is the number of vessels landing an optimal quantity necessary to land the whole quota, rounded to the nearest integer. The results are reported in Table 7.6. On average, 64.4% or almost two thirds of the vessels are redundant. However, this varies substantially over the years as the quota in 1997 is almost twice the quota in 1999. These results gives at least three insights; a) there is substantial overcapacity in the fleet, b) no rent is generated so that in this fishery, overcapacity is the main problem, as ending the race to fish has not allowed rent to be generated, and c) given that the total quota varies substantially, it is not possible to have a stable number of vessels and at the same time harvest optimal resource rent.

Table 7.6. Actual and potential rents at the vessel level

	Full period	1997	1998	1999
Actual rent	-199.7	-97.4	-60.3	-33.0
TAC	265,405	121,338	83,226	66,020
Potential rent	1,257	332	429	407
Actual no. of vessels in the fleet (population)	-	44	39	35
Optimal no. of vessels	-	19	13	10

Values are in million Norwegian kroner and quantities in metric tonnes.

That almost two thirds of the vessels are redundant and that on average 60% of the revenues is potential rent seems rather dramatic. The predicted optimal harvest is higher than what is observed in the data set, which indicates that the numbers should be regarded with some caution.[51] However, in fisheries regulated with individual transferable quotas, the price of a one year lease of quota will be equal to rent per unit of fish that the quota gives an entitlement to. We have therefore collected average ex-vessel prices and one year quota lease prices from the Icelandic cod fisheries, as these can provide some evidence with respect to the reliability of the results. The Icelandic cod fisheries are regulated with individual transferable quotas, but have otherwise many similar characteristics with the Norwegian fisheries. The prices are shown in Table 7.7 together with the share of rent in revenue. As one can see, this is very high as it varies between 72% and 84%, which is higher than our estimates for the Norwegian cod trawlers. There are several signs that the Icelandic quota market has not reached long-run equilibrium (Asche, 2001), and one can also argue that the willingness to pay for an additional unit of quota in the short run may be higher than the long-run rent, as fixed costs may not be relevant. However, even if the price of a quota lease id somewhat higher than

[51] The maximum catch level observed in the data set is 4140.5 tonnes. However, the regulatory system discriminates agains larger vessels, and hence this is below the maximum capacity of the vessel.

rent, it is fair to say that it indicates that the share of rents in total revenue is substantial, and it may well be higher than our estimates for the Norwegian cod trawlers.

Table 7.7 Ex-vessel price and quota price, Iceland, Icelandic kroner

Year	Quota price	Ex-vessel price	% quota price of price pr/kg
1997	82	98.3	83.4
1998	88	119.6	73.5
1999	100	137.4	72.7

Source: The Icelandic Fresh Fish Price Directorate

Few studies have empirically investigated the potential for rent or efficiency gains in a fishery, with Dupont (1991) and Weninger (1999) as two exceptions. Although their results are not strictly comparable, it is of interest to mention some of their results that shed light on some of the issues we consider here. In particular, Dupont (1991) finds that in the Canadian Pacific salmon fishery, potential rents are about 42% of total revenue. Weninger (1999), for the US surf clam and quahog fisheries, finds that a fleet of 128 vessels can be reduced to between 21 and 25, i.e., a reduction of about four-fifths of the number of vessels when individual vessel quotas were introduced. Hence, it seems clear that both the potential rent and the overcapacity in most traditionally regulated fisheries are substantial.

The total allowable catch quota (TAC) varied substantially in the three year period under investigation. As a consequence, optimal fleet size also varied over time. A constant optimal fleet size relies on the notion of a steady state for fish stocks. However, natural variations are likely to make stock size variable, even in a well managed fishery.[52] The questions of optimal capacity and potential resource rent generation over time in a fishery with natural fluctuations in stock size are not considered here, but represent an interesting avenue for future research.

7.4. Concluding Remarks

An empirical application is provided for Norwegian cod trawlers that are regulated with individual vessel quotas, but with very limited transferability. This is of interest since it provides some evidence with respect to what is the most important factor for rent dissipation in traditionally managed fisheries – the incentives due to the race to fish or overcapacity. The empirical results indicate that no rent is generated for this fleet. Hence, in this fishery overcapacity is the main problem and ending the race to fish has not allowed rent to be generated. The results indicates that the rent potential is substantial at between 60 and 70% of total revenues, and that there is substantial overcapacity as the number of vessels in the fishery should be reduced by about two thirds. However, due to natural variations that influence the TAC and harvesting conditions, potential rent and optimal capacity change substantially from year to year. Hence, if vessels cannot move between fisheries, as is often the case, the issue of optimal fleet size becomes an important one.

[52] For instance recruitment and mortality will be dependent on a number of variables including water temperature, abundance of food and predators etc.

8. The Icelandic Case

8.1. Introduction

It is now twenty years since an individual quota system was established in the Icelandic groundfish fisheries. What started out as an individual quota (IQ) system, for a trial period of one year, is today an individual transferable quota system, or an ITQ. The system itself has developed continuously over these twenty years and it is only in the last four years that relative stability has been obtained in the legal framework for the quota system.

As expected there have been many debates and controversies over the ITQ management system. The debate in the popular media has focused on the equity and distributional issues of the management system and to some extend the effectiveness of the system to rebuild fish stocks. The debate on the improvements in efficiency and profitability of the Icelandic groundfish fisheries has not been as noticeable in the popular media, but rather been focused within the academic literature. Most of the research that has investigated changes in productivity and efficiency has examined the fishery as a whole using aggregate data to measure efficiency gains. This paper looks at the behavior of individual fishing companies in order to look in more details on how large fishing companies operate under an ITQ fisheries management scheme.

The paper begins with an overview of the Icelandic fisheries and its management over the past decades. In the section that follows the development of effort is analyzed for several fleet segments from 1980 through 2000. The next section looks at the efficiency of the trawler fleet during the period from 1995 through 2000. The question on resource rents is examined, followed by a concluding section on efficiency gains and economic behavior of individual fishing companies under individual transferable quota system.

8.2. Overview of the Icelandic Fisheries

The literature on the Icelandic fishing industry has grown quite substantially over the past three decades. However, much of the academic and empirical research on the subject has been focused on specific problems rather than a general overview of the industry, with a few exceptions. Jonsson (1981) wrote a detailed account of the development of the Icelandic fishing industry prior to 1940. He extended his work to include the period from 1940 through 1984 (Jonsson 1984). Sections on the general structure and development of the Icelandic fishing sector, from 1984 through 1999, can be found in several publications. These include Arnason (1995), Hannesson, (1996) and Runolfsson et al. (1999).

Icelandic fisheries developed rapidly after 1945. Figure 8.1 below shows the catch from 1945 - 2003, identifying four distinct phases; "The golden years", Cod wars, the Black report and emergence of private property rights. The catch is categorized as Groundfish, Pelagic and other fish species. The four major species in the groundfish category are cod, haddock, saithe and redfish. The pelagic category contains herring and capelin. The herring stands for majority of the pelagic catch from 1945 – 1969, but after 1969 the majority of the pelagic catch is capelin. Commercial harvest for capelin started in the late 1960s.

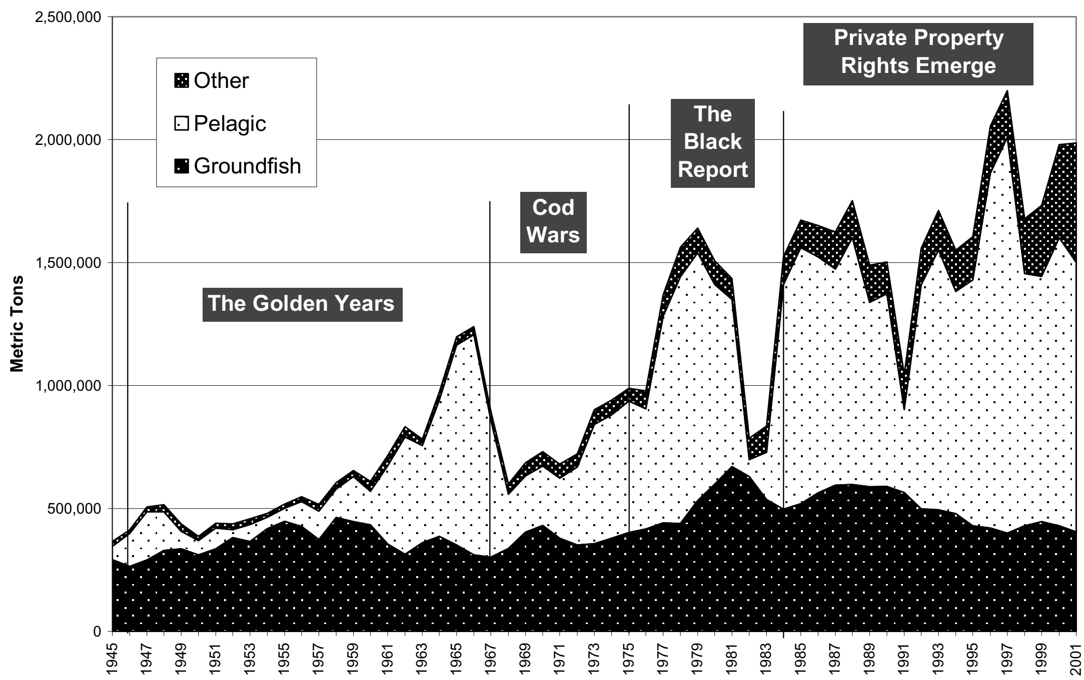


Figure 8.1: Total catch by Icelandic vessels, all fishing grounds.

Source: *Útvegur 2000*, The Icelandic Statistic Bureau.

Each of these phases is described in more details in the following sections.

8.3.The Golden Years

The period between 1945 and 1967 is often called "the golden years" or the "herring" years, referring to a huge expansion in the herring fisheries off Iceland. Several innovations and technological advantages, along with increased demand for fishmeal and fish oil, and large markets for cured herring in the Soviet Union, Sweden and Finland, contributed to a large expansion in the Icelandic herring fishing fleet. The catch came mainly from two stocks, the Icelandic spring herring stock, harvested in local waters and the Icelandic-Norwegian herring stock harvested off the eastern part of Iceland, and in Norwegian waters. These stocks collapsed completely in 1967-1968, leading to a considerable economic depression in Iceland. During this same period, the Icelandic demersal fisheries were developing, though the major economic benefits came from the herring fisheries. All exporters had to get a license from the Icelandic government in order to be allowed to export fisheries products from Iceland. In practice, the government granted the license mostly to producer organizations, in order to coordinate sales to foreign markets, and avoid competition among the Icelandic producers, and hence, influence the final price in the foreign market. The government usually did not grant any export licenses to individual companies, except in the fish meal industry. Each organization specialized in its own field (frozen groundfish, salted groundfish, salted herring, etc.).

These companies started to build markets mostly in the U.S., but also in Germany and later in the Soviet Union, using frozen groundfish products. Groundfish fisheries were not profitable (for boat owners) at that time so developments in the groundfish fisheries came slowly. There were several reasons for the lack of profitability in the groundfish fisheries at the time. Some of the reasons were decreased prices for fresh products in the U.K. (due to lower demand and higher tariffs), use of inefficient equipment, and due to domestic economic policy, which was centralized at the time, and favored the herring fishery (see Jonsson (1984)).

8.4.Cod Wars and the Black Report

When Iceland expanded its exclusive economic zone (EEZ) from 4 to 12 miles in the 1950s all trawlers, both Icelandic and foreign, were excluded from fishing within that zone for any species. Icelandic herring vessels were allowed to harvest within the new 12 mile EEZ.

Between 1960 and 1970 the political environment in Iceland changed substantially. Trade with the Eastern European countries was still important, but Iceland was in its beginning stages towards a market economy, a step away from the barter trade system with the Eastern Block. With the collapse of the herring stocks, cod became the most important resource for the Icelandic economy.

In 1970 Iceland expanded its EEZ to 50 nautical miles, and in 1975 to 200 nautical miles. This time the objective was to gain control of the fishing grounds in order to be able to manage total catch from the Icelandic waters. In 1958, 1972 and 1975 Iceland fought the infamous *Cod wars* with the British Navy. The Icelandic Coast Guard chased the foreign trawlers out of the newly established EEZ, and the British sent in the navy with frigates and tugboats. Only a few shots were fired in those wars and no ships were sunk.. Iceland was able to hold its ground against the British and chased the last British trawler out of the EEZ by the end of 1975.

At the same time the new stern trawlers were introduced to the Icelandic fisheries. Those vessels were better suited for trawling, and were designed as wetfish trawlers. Their primary role was to supply onshore processing plants with a stable year-round supply of raw material. The period between 1970 and 1980 is therefore one of expansion where new fishing techniques were introduced into the Icelandic demersal fisheries. The markets in the U.S. and Europe expanded during the period, especially the wet-fish markets in the UK due to the lack of domestic supply after the British were chased out of the Icelandic fisheries. Icelandic catch of demersal species increased from 422.000 tons in 1970 to 670.000 tons in 1980.

In 1976, the so-called "Black Report" was issued by the (Icelandic) Marine Research Institute. This report warned that too much effort was being used for harvesting cod. A collapse was inevitable if the fisheries were not brought under control. Despite the biologists' warnings, the fishing fleet and catch continued to increase. The new vessels were mostly financed by support from the government, either indirect or direct. The results of high efforts were soon realized and by 1983, a sharp decline in cod landings was evident.

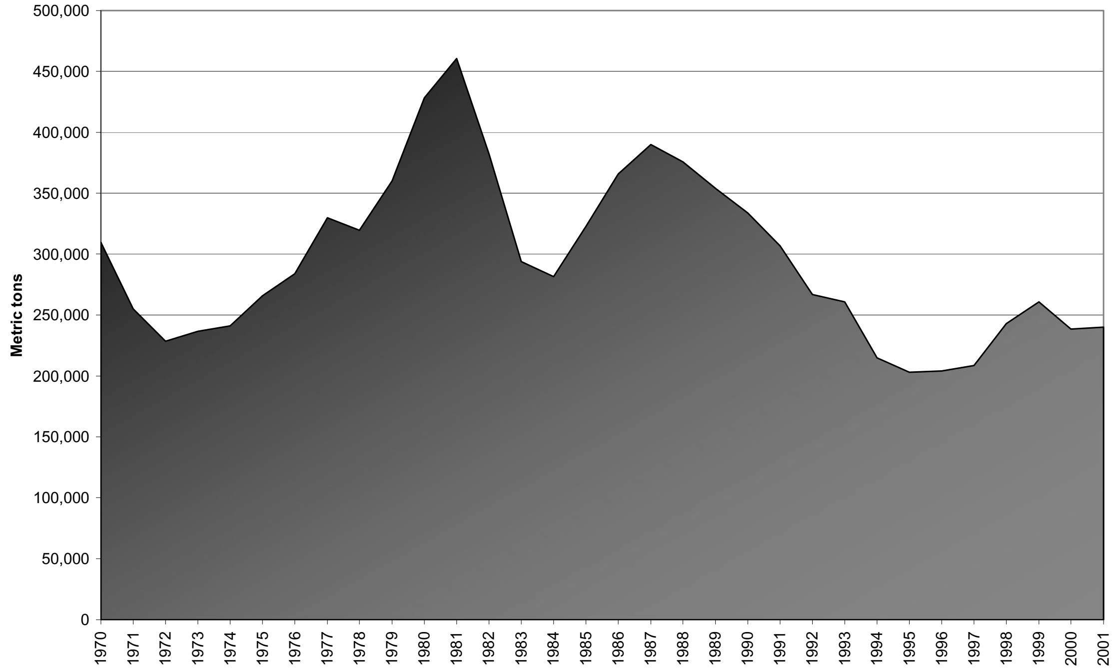


Figure 8.2: Cod landings, Icelandic Vessels, all fishing grounds 1970 - 2001

Source: *Útvegur 2000*, Statistics Iceland.

Another fishery also developed in this same period. After the collapse of the herring stocks, some of the herring vessels started to experiment in the capelin fishery. This fishery developed quickly and by 1980 Iceland harvested over one million metric tons of capelin. Capelin became an important fishery for the Icelandic economy. The capelin season in 1982/1983 was disastrous, when no capelin was found on the fishing grounds, resulting in a moratorium on landings.

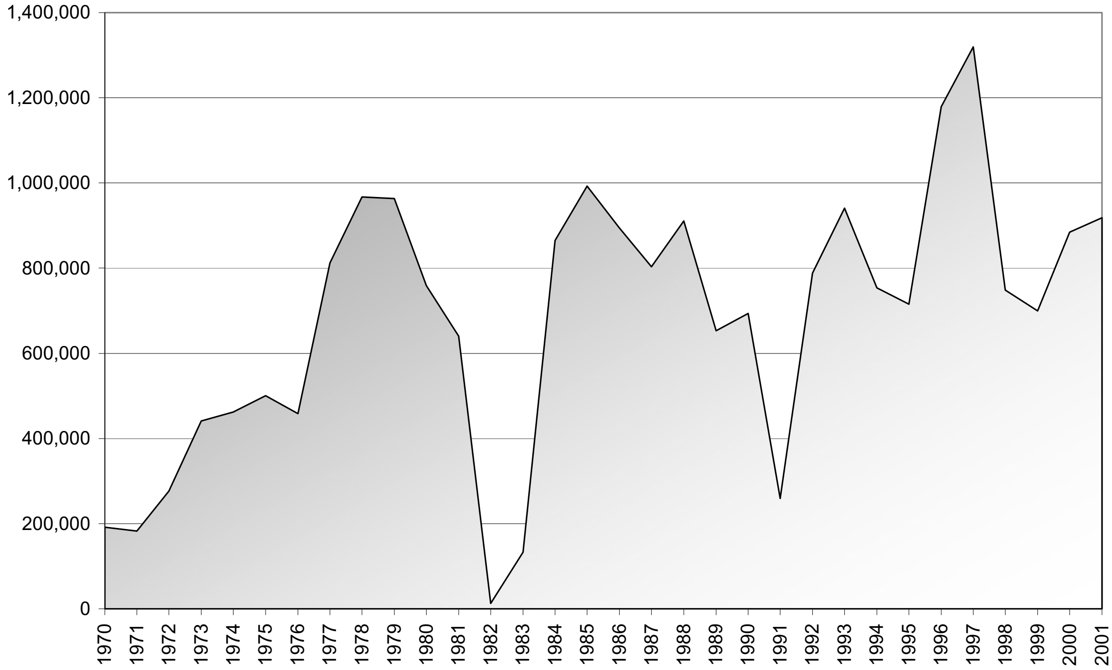


Figure 8.3: Total Catch of Capelin 1963 - 1998

Source: *Útvegur 2000*, Statistics Iceland

8.5.Emergence of Private Property Rights

In the late 1970s and early 1980s the fishing grounds around Iceland were mostly harvested by Icelanders. This created a much easier environment for the government to manage the fisheries. At the same time, huge expansion in the Icelandic fishing fleet was being fueled by the Icelandic government, and though catch continued to increase, the biologists continued to warn of ever-increasing overharvesting, especially in the cod stock.

Between 1982 and 1983 the now important capelin resource collapsed. At the same time, the cod fishery was in decline. In 1982 and 1983 fishermen were unable to harvest the total allowable catch of 450,000 and 350,000 MT of cod, respectively. The total catch in 1982 was 388,000 MT and 292.000 MT in 1983 (Útvegur 1983). Export prices for cod products decreased both in 1982 and in 1983 (Útvegur 1984). By the end of 1983, the outlook for the Icelandic fishing industry was not too good.

It is in this environment that Icelanders started to experiment with individual quotas, i.e. where the total catch is divided up among the participants in the fishery. These measures were considered temporary or seen as an experiment while fisheries management method where being developed.

8.6.Management of the Icelandic Fisheries

8.6.1. Management prior to 1984

The first law concerning utilization of fisheries resources can be found in the "old law" of the Icelandic Commonwealth (Icel.: Grágás) which dates back to medieval ages. This law covered harvesting with shore-based methods, and the jurisdiction landowners had over the coastal waters. Overall, the open ocean was for everyone to use (Durrenberger et al. 1987). The first modern laws for the Icelandic fishing-sector are from the mid-to-late 19th century. Under this series of laws local authorities were given the right to set rules and regulations on harvesting in coastal waters, and rules on the processing of the catch. These laws generally covered harvesting and processing methods in order to help increase the value of the catch, and to protect local harvesters. Some of these laws are still in place today.[53]

The economic inefficiencies of Olympic style fishing became clear to Icelandic fishermen before biological overfishing was a real concern to them. In the early 1930s, congestion on the fishing grounds southwest of Iceland was becoming a problem. Better technology allowing for longer lines to be laid and for the boats to go further from homeport was creating congestion on the best local fishing grounds. Vessels from two ports could now go back and forth on the same fishing grounds, within a day. This led to a voluntary self-imposed regulation on when vessels were allowed to sail for the fishing grounds. These regulations later became laws, and versions of those laws are still in place today (for more details see Durrenberger et al. 1987).

Overfishing became a concern among scientists and fishermen alike. They all realized that with multinational fleets harvesting the fishing grounds, chances for cooperation for

[53] An example are the "Lög um bátfiski á fjörðum." Nr. 6, 19. Júní 1888 (e. "Laws on fishing on fjords." Own translation of title.)

protecting stocks were slim. Foreigners became an easy target, since they were the ones depleting the resource, according to Icelanders. The fisheries laws and regulations between early 1900 and 1948 were all aimed at getting the foreign fishing vessels away from Icelandic waters. At the minimum they were set to limit inshore and close-to-shore harvesting by foreign vessels in Icelandic coastal waters.

The major turning point for Icelandic fisheries management came in 1948 when Althing, the Icelandic Parliament, voted in laws that required the management of the Icelandic fisheries resources to be set on a scientific basis (Althing, law nr. 44, April 5, 1948). Based on the laws from 1948 Iceland expanded its exclusive economic zone in incremental steps. The table below shows the year and extent of each expansion. The final expansion came in 1975 when the EEZ was moved from 50nm to 200nm , causing tension between two NATO allies, Iceland and United Kingdom.

The law from 1948 also changed the approach to fisheries management. Based on research by government scientists and in cooperation with international organizations such as ICES, the government started to use area closures, restrictions on mesh sizes and trawling in coastal waters and sensitive nursing grounds.

From 1950s through the 1970s the fisheries management in Iceland was based on effort control and limitation of entry of foreign vessels. Domestic vessels had de facto open access to all major fisheries. The major steeping points in the development of the Icelandic fisheries management system are listed in Table 8.1.

Table 8.1: Major events in Icelandic fisheries management

Year	Event
1948	Law that emphasize Icelandic jurisdiction over fish stocks in Icelandic water, and that the management of those stocks should be on scientific basis
1952-1972	Exclusive Economic Zone Expanded to 50 nm
1965-1975	Initial steps using effort control, total and producer quotas for controlling catch. Harvesting moratorium on herring.
1975	The "Black Report" issued by the Marine Research Institute. EEZ expanded to 200nm.
1976	De-facto recognition of Icelandic authority over 200nm EEZ by the British Government
1976	Protection of juvenile fish through temporary area closures. Total catch quotas for cod.
1977	Individual Effort Restrictions in the demersal fisheries
1983	Individual Vessel Quotas to be implemented in 1984 for one year. Quota shares based on catch history from 1981 through 1983.
1985	The Individual Vessel Quota system extended for one year. Effort Quotas introduced as an alternative.
1986	Individual Vessel Quotas extended for two years
1988	Another two year extension for the Individual Vessel Quota system. Transferability for quota shares made easier. Effort Quota system is still in place as a option. New fisheries law is passed where it is emphasized that the Icelandic fishing grounds are the common property of the Icelandic nation.
1990	New fisheries management law passed, this time without any time limits on allocation of share quotas. Quota shares are divisible and fully transferable. Effort Quota system discontinued. New system takes place on January 1st 1991.
1993	Government committee recommends the ITQ system to be kept in place, indefinitely.
1998	The supreme court rules that only granting fishing licenses to vessels that were fishing between 1981 and 1983, or replacement vessels for such a vessel, is unconstitutional. The supreme court explicitly states that they are not ruling on distribution of quota shares.
1999	Addition to the fisheries management laws grants the authority to issue licenses to fish to all Icelandic citizens. Distribution of quota shares is not affected and fishing without a quota share is illegal.
2000	The supreme court rules that fishing without quota is illegal, putting an end to a dispute that started with the supreme court ruling from 1998. The verdict strengthens the legal basis of the quota system.
2002	A resource rent tax becomes a part of the fisheries management law, to be implemented by the fall of 2004.
2004	The last fleet segment (boats under 6 GRT) is changed from a days-at-sea system to a ITQ based management system.

Source: Adapted and extended from Arnason (1995) and Helgason (1995)

8.6.2. The Birth of Private Property Rights 1984 – 1990

In the early 1980s, it became clear to the fishing industry that the management system in place would not rebuild the cod stock in the Icelandic waters. Although foreigners were out, the Icelandic fishing fleet kept increasing, often with government loans and other financial incentives from the government.

In the wake of declining catch of demersal species, the fishing industry, through an annual meeting of the Icelandic Fisheries Association, asked the government to establish a legal framework allowing the Minister of Fisheries to establish an individual vessel quota system for management of demersal fisheries. The request was made in the beginning of December 1983, the law was passed on December 22, and the new legislation was implemented by January 1, 1984 (Runolfsson 1996). Under this new fisheries management system all vessels over 10 gross registered tonnage (GRT) had to operate under quota systems, either on catch or number of days at sea fishing. Under the individual quota (IQ) system individual vessels were allocated a certain percentage of the total allowable catch for that category, for the days-at-sea (DS) system each vessel was allotted a total number of days fishing for specific species. The initial allocation was based on a three-year catch history (November 1980 - October 1983) where the individual quota was allocated to each vessel. Both of these systems were superimposed onto the current management system which included mesh size restrictions, area closures and gear restrictions. In addition some restrictions and loopholes existed within the IQ system, such as a 10% penalty (every kilogram landed counted as 1.1 kilogram towards the vessel quota) on fish caught in Icelandic waters landed in foreign ports, and a 50% increase in quota for vessels using longline to harvest (every kilogram landed from longline fisheries counted as 0.5 kilograms towards the vessel quota).

It is important to note that the initial system was only set for 1 year. The system was reinstated for 1985, where the allocation was more or less based on the initial allocation from 1984, even though some reallocation occurred between different vessel categories. In 1985 the fisheries management using IQ and DS systems was reinstated for two years (1986 and 1987). During 1985, 26 trawlers elected to be under the IQ system and 80 elected to operate under the DS system. Overall 277 vessels were under the IQ system and 365 vessels were under the DS (Útvegur 1986). The system was reinstated in 1988 for two years (1988-1990) without any significant changes.

The period from 1984 through 1990 can be seen as an evolution period for the current Individual Transferable Quota system. All players within the system (fisheries managers, vessels owners, fisherman, etc.) learned by doing, and in the process some gained and some lost. It was seen as a crucial point, in order to increase efficiency in the Icelandic fisheries, that uncertainty of the ownership of the harvesting rights (the ITQ share) be minimized. Experience from the IQ system, as well as the ITQ system in the capelin and herring fisheries favored a private property right system to be implemented in all Icelandic fisheries. In 1990, Althing passed a law implementing an ITQ system in all major fisheries within Icelandic waters, under one set of principal rules and regulations, to take effect from January 1, 1991.

8.6.3. Icelandic Fisheries Management 1991- Present

Several significant changes in the management of the Icelandic fisheries occurred under the new fisheries management legislation from 1990. This included that the statistical year for quota holdings was changed from the calendar year to begin on September 1 and end on August 31 the following year. The days-at-sea system was abolished for all larger vessels, and vessels between 6 GRT and 10 GRT were offered to enter an separate ITQ system, or a temporary hook and line system (1991 - 1993), where vessels were only allowed to fish with hook and line on specific days of the year (Runólfsson 1999, *Útvegur 1990-1997)*.

Over the next few years several regulations were issued to implement the fisheries management laws from 1990. These regulations dealt with renewal of fishing vessels, reducing the loopholes in the system, such as abandoning the regulation which allowed for doubling the quota if it was caught using longlines (in 1996), and regulations for the small-scale inshore fleet. Overall the actions taken during this period have had two general goals: first to force the total catch to coincide with the total allowable catch, and second, to respond to ever increasing criticism on the distributional effect of the quota system.

In 1996 a local fisherman applied for a license to fish, along with a substantial amount of groundfish quotas. The individual was denied the license, and quota, on the ground that fishing vessels, not individuals, are issued licenses. The case went to the Supreme Court in Iceland in 1998. The Supreme Court ruled in favor of the individual. The court ruled that only issuing licenses to vessels that were in the system in 1983 was unconstitutional (Palsson 1999). The court explicitly stated that it was only ruling on the issue of a license, not the quota. Hence, after the verdict the Icelandic government had to issue a license to all individuals interested in obtaining a commercial-fishing license. However, the government still required quota in order to be allowed to land fish in port.

Another individual decided to challenge the quota requirement, and went fishing without quota. He was charged with illegal fishing. The municipal court did not find him guilty of illegal fishing, in part based on the Supreme Court verdict from 1998. This case went before the Supreme Court in February of 2000 and the Supreme Court gave its verdict in April that same year. This time the Supreme Court ruled[54] that it was legal to limit fishing by a system, such as the quota system. This strengthened the legal ground for the quota system, but the moral and ethical arguments are still unresolved.

The developments described above have had significant impact on the management of the Icelandic fisheries. The current situation is as follows. The first article of the fisheries management law from 1990 states that all ocean resources are the common property of the Icelandic nation. The objective of the management laws is to promote efficient and sustainable use of the resources, in order to enforce employment and livelihood in the country. It explicitly states that the rights to harvest those resources does not give the holder property rights over it, and that the government can recall the harvesting rights. Fisheries are allocated total allowable catch, which is then divided among those who hold the right to catch the specific species. These harvesting rights, or quotas, are divisible and transferable, both on an annual basis and in perpetuity. There are limitations on how much individual companies can hold. In groundfish, no individual or legal entity can hold more than 10% of the quota for each species.[55] The Minister of Fisheries sets the annual total allowable catch, based on recommendations from fisheries scientists and usually includes discussion with user groups within the fishing industry. The Ministry of Fisheries is responsible for implementation and enforcement of the fisheries management act. Every year various regulations are issued in order for the fishing industry to comply with the requirements of the fisheries management act. Included are regulations on mesh sizes, closure of sensitive areas, regulation on how to weigh the catch, etc.

[54] As an example of how important this issue is to the Icelanders the supreme court had 7 justices, as compared to 3, or 5 justices in other cases. The court did not reach consensus, and hence the majority ruling (4 out of 7) stated the verdict.

[55] For the fishing year of 1998/1999 this was not a binding restriction since the largest company held less than 6% of total groundfish quotas at the time.

Permanent quotas are sold through quota brokers. Annual lease quotas are required, by law, to be sold through a quota exchange. The annual lease quota exchange was established in order to make the transactions with annual quotas more transparent, in response of accusation by crewmembers that they were forced to participate in quota leasing by the vessel owners.

8.7. The Use of TAC Rules in Icelandic Fisheries Management

A unique feature of the Icelandic fisheries management system is the use of a total allowable catch (TAC) rule for determining annual quota for the most important species, cod. The Icelandic Minister of Fisheries requested a proposal from the Marine Research Institute on how fish stocks should be exploited in order to achieve maximum (economic) yield over the long-term. The Marine Research Institute (MRI), in cooperation with the National Economic Institute (NEI) -both of Iceland-, established a working group to answer the Minister's request (Danielsson et al. 1997).

The unique feature of the Icelandic catch rule is not the rule itself, but how it was derived. Several technical articles have been published based on the work of the joint working group of the NEI and MRI (Baldursson et al. 1996, Danielsson et al. 1997.) In order to find the optimal way of utilizing the Icelandic cod stock the working group used bioeconomic modeling and optimization techniques to come up with long run equilibrium for the optimal stock size. The group then used a simulation method in order to find the "best" path of annual catch quotas to reach the optimal stock size.

The optimization process indicated that the most economical spawning stock biomass is about 820,000 MT, and total fishable biomass of 1,600,000 MT. An interesting observation is that the most economical optimization path would be to stop harvesting cod for two years, and then gradually start increasing the annual quotas after that. This confirms research done by Arnason (1980) where he showed that the most economical way of rebuilding the fish stocks would be to cease all fishing for a period of time, and then gradually increase the annual TAC. So ten years later, the Icelandic government is faced with the same recommendation; a drastic cut in the total allowable catch for the Icelandic cod stock, the single most important species of all the Icelandic fisheries.

Baldursson et al. (1996) and Arnason (1980) noted that, though economically optimal, a moratorium on cod fishing might not be socially feasible. Hence, both suggested a minimum catch that would balance short-term economic profits versus long-term sustainable use of the resource. The MRI and NEI working group used a social utility function, constrained by economic and biological factors to find the optimal path for total allowable catch that allowed the fish stocks to grow fairly rapidly. The social utility function they used to reflect risk aversion is:

$$u(y) = \frac{(y^{1-\sigma} - 1)}{1-\sigma}$$

where u is social utility, assumed to be a direct function of export income, y and σ is a risk aversion factor (Lucas 1987), u and y are both function of time, t (Baldursson 1993). Export revenue is:

$$y = P_t \cdot Q$$

$$\textit{where}$$

$$P_t = P_0 \cdot \left(\frac{T_0 + Q_t}{T_0 + Q_0} \right)^{-\left(\frac{1}{\varepsilon}\right)}$$

Here P_0 is the average price for cod product in the initial year (in the original case 1992), T_0 is the total supply of cod products from the North Atlantic ocean, estimated at 1.5 million MT in 1992, Q_0 is the total catch in 1993, and Q_t is the total allowable catch at time t. ε is the price elasticity for demand of cod products, assumed to be 2, based on research done by Danielsson (1993).

The biological model used is similar to the one used by the MRI. It is a version of the Beverton-Holt model, which uses multiple cohorts and age structure analysis. It was also assumed that recruitment is related to the spawning stock biomass (SSB) (Baldursson et al. 1996). The simulations indicated that even under a high level of risk aversion, there should be a drastic cutback in total allowable catch, or around 100,000 MT annually, slowly increasing towards 350,000 MT in 2003, or eleven years later.

The final recommendation by the MRI/NEI group therefore used rational arguments based on the simulation results, that the total allowable catch should be set as the average of 25% of the total harvestable biomass and the previous year catch. The minimum TAC was suggested as 155,000 MT and the maximum TAC would be 450,000 MT. The government adapted the 25% rule and the min/max TAC settings, but abandoned the idea of using the average catch between the last year and the recommended TAC. The fisheries minister changed the rule in the spring of 2000 by ordering that annual changes should not be more than ±30,000 MT. The significance of this TAC rule is that it uses market-related information, namely prices, and the price elasticity, to calculate the best path to reach the optimal size of the SSB.

8.8.Management of the Trawler Fleet – Current Situation.

The management of all Icelandic fisheries is based on two sets of laws; the first passed in 1948[56] and the second passed in 1990[57]. The law from 1948 sets the basis for scientific management of the fish stocks in Icelandic waters, and became the domestic legal ground for Iceland's claims to extend its EEZ to 200 miles in 1975. The law from 1990 regulates how the EEZ is managed through output, effort and capacity regulations. However, there are more than 30 different laws and almost 150 regulations that form the framework for fishing and fish processing in the Icelandic fishing industry as a whole.

Management for Icelandic fish stock is based on output control (Individual Vessel Quotas). According to the fisheries management law from 1990 the minister of fisheries sets annual TAC for all species harvested within the Icelandic EEZ. The TAC must be set after the minister receives advice from the Marine Research Institute (MRI), but the wording of the law does not require the minister to comply with the MRI, a fact which several ministers of fisheries have utilized over several decades. The TAC for the cod stock is set according to the quota rule as described in the previous section. Total Allowable Catch for other demersal species is set directly by the minister for a period of one fishing year, which starts September 1st and finishes August 31st next calendar year.

[56] Law nr. 45, april 5th 1948
[57] Law nr. 38, mai 15th 1990

Anyone who wants to fish commercially must obtain a fishing license. Fishing licenses are issued to an owner of a legally registered fishing vessel, and are valid for a period of 12 months, after which the owner must re-apply for the fishing license. Fishing licenses are not issued to foreigners since foreign ownership of fishing vessels is restricted by law[58].

The total allowable catch is divided into quota shares (in percentage) by boat. The quota shares are dividable and can be traded among those who hold a fishing license. Some restrictions and limitations are in place for the quota trade. The quota for each vessel is based on last year holdings of that boat plus any changes during the last fishing year[59].

There is also limitation on quota holdings for each individual or legal entity. Each vessel can not hold so much quota that it is obvious that the vessel can not harvest the quota within a fishing year. The exact wording in the legal text is wake, and no quantities or percentages are given to help define what is "obviously" to high quota holding per vessel. In addition the total quota holdings by an individual, legal entity and/or related individuals or through indirect ownership can never exceed a certain percentage of the TAC for a given species. This percentage is different for individual species as is shown in the table below.

Table 8.2: Maximum share an individual or a company can hold

Species	Maximum quota share holdings by related individuals or companies
Cod	12%
Haddock	20%
Pollock	20%
Redfish	35%
Greenland Halibut	20%
Herring	20%
Capelin	20%
Deep water Shrimp	20%

[58] Law nr. 22, april 8th 1998

[59] For more detailed information on the initial allocation of quota to fishing vessels see. Matthiasson (2003) "Closing the open sea: Development of fishery management in four Icelandic fisheries" *Natural Resources Forum*. 27:pp. 1 - 18

Total quota holding by related individuals or companies can not exceed 12% of the overall TAC for all species, as measured in cod equivalent values[60]. Each fishing vessel must fish 50% of its own quota over a period of two years. If a vessel does not fish this share of its own quota the remaining quota will be reissued to other vessel owners. This restriction was put in place in order to restrict the lease market and minimize speculative trading. There are also restrictions on how much can be transferred from a vessel within a given fishing year. In any given fishing year no more than 50% of the total quota holding of an individual vessel can be transferred (leased or sold) to another vessel.

In the fishing year of 2004/2005 a fishing fee will be charged to quota owners. This fee is put in place in order to capture some of the resource rent generated in the fishery. There are several technical restrictions in place for trawlers, both general and specific laws and regulations. Minimum mesh size for trawl nets is 135mm for all demersal fisheries and other specific restrictions on the rigging of fishing gear for bottom trawling. In the current management of the Icelandic trawler fleet there are no provisions for restriction of effort use beyond restrictions that are aimed at protection of fishing areas or temporary closures. I.e. time of fishing and hours used are not limited.

Trawlers are categorized into three different categories according to length and fishing capacity (calculated based on engine power and type of propeller). Each category must obey to the general restrictions and category specific restrictions on fishing areas. In addition temporary closures of fishing areas are used to close areas where under-sized fish has been detected, or for other reasons related to fisheries management issues. There are no restrictions on vessel capacity.

8.9. Catch

This section examines catch data for the time period in question. Figure 8.4 shows total groundfish catch by species.

[60] Cod equvalent values are used to measure relative value of any species to cod prices. These values are calculated by the Fisheries Directorate and are based on last year relative prices between species.

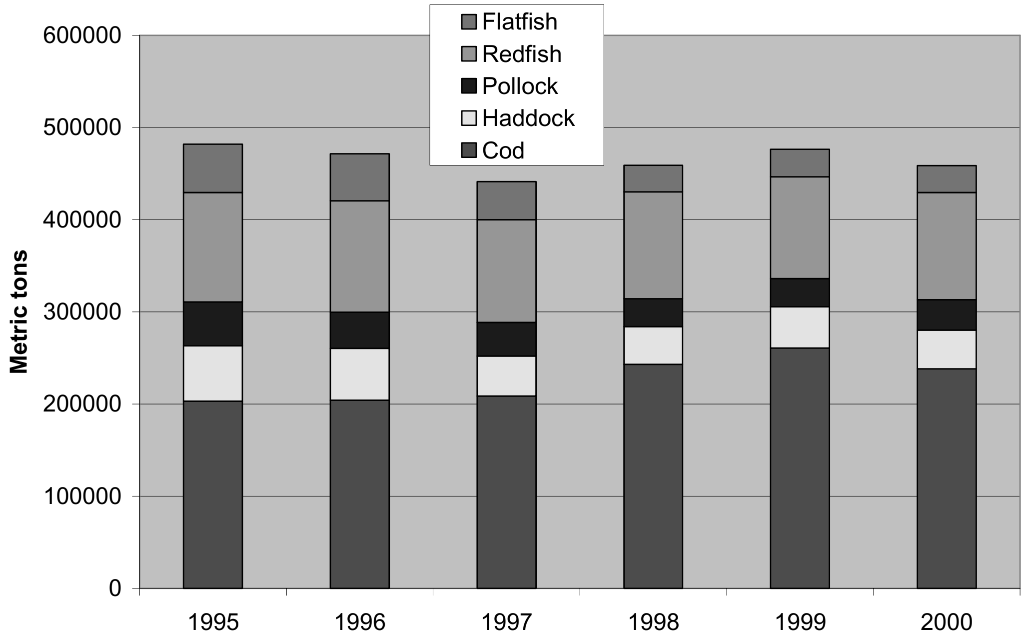


Figure 8.4: Total groundfish catch (MT) in Icelandic waters, 1995 - 2000, all fleet segments.

The figure shows that the total groundfish catch was relatively stable over the period, ranging between 440.000 metric tons to 480.000 metric tons. There is though a notable increase in the cod harvest from 1998 through 2000. This increase is explained in more details in chapter 0. The groundfish catch is harvested by vessels that can be categorized into three different fleet segments; trawlers, decked fishing vessels and coastal fishing vessels. The share of each of these segments is shown in Figure 8.5.

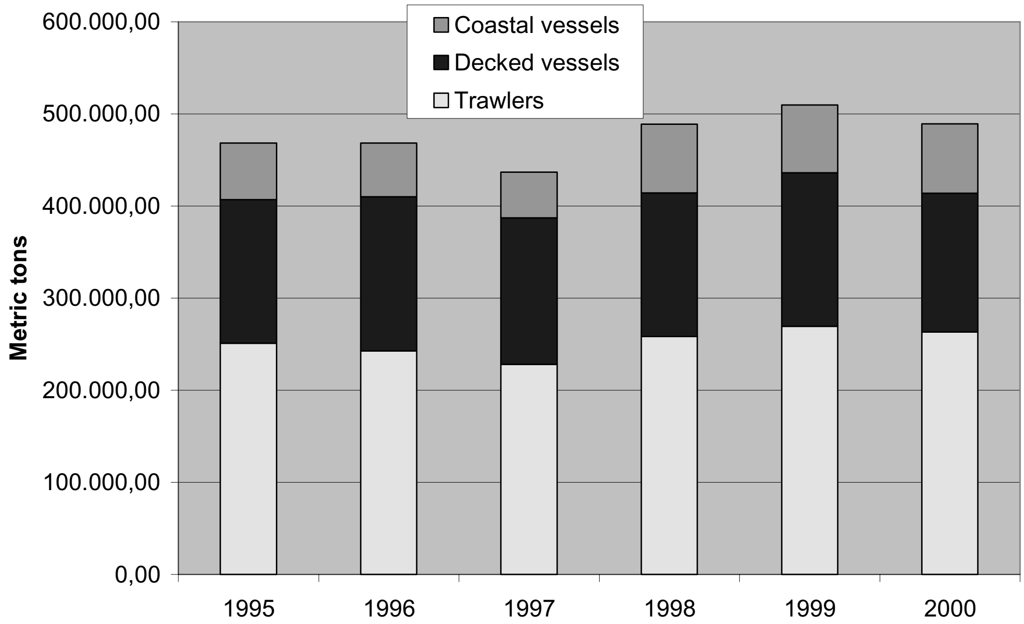


Figure 8.5: Total catch by fleet segments, 1995-2000

Source: Útvegur 1995 - 2000

Looking at total groundfish catch the share of each segment is relativel stable. Trawlers have just over 50% of the annual groundfish catch, decked fishing vessels have about 33% share on the average and coastal vessels have about 14% of the catch on the average. However the story changes somewhat when we look at the species composition in the catch for each fleet segment.

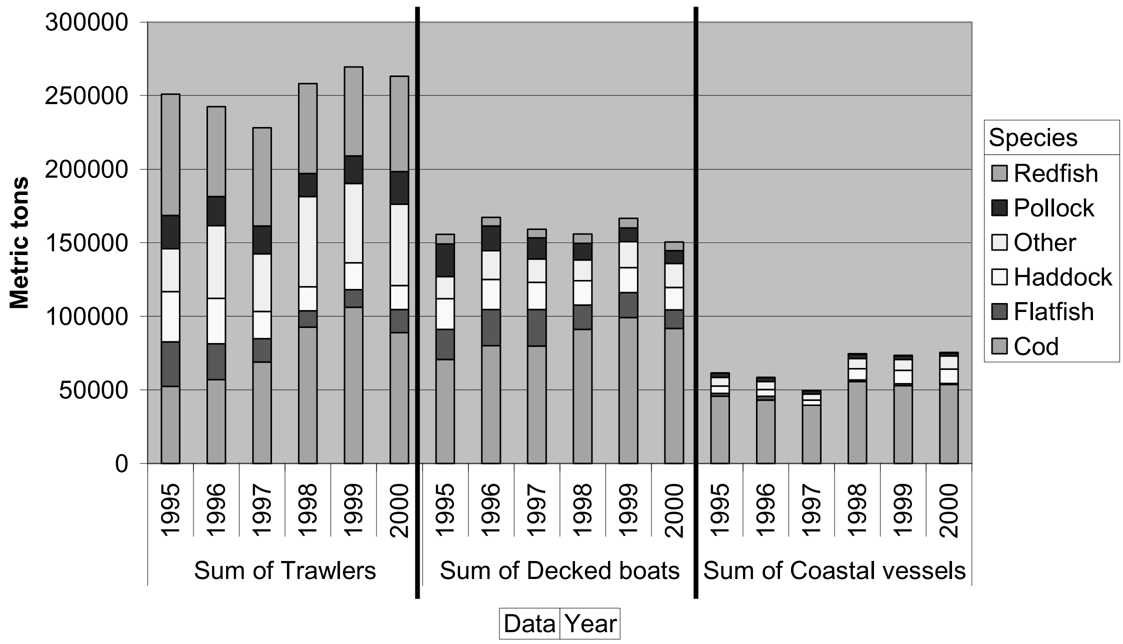


Figure 8.6: Total groundfish catch by species and fleet segment, 1995 – 2000

Source: Útvegur 1995 – 2000

Figure 8.6 shows that the increase in total catch is primarily due to an increase in cod catch in all fleet segments. For this study we are interested in the trawler fleet.

8.10. Development of the Cod Stock from 1995 through 2000

Icelandic waters are at a boundary between warm Atlantic waters in the south and colder waters from the north. Interannual variability in oceanic conditions thus vary highly depending on the strength of the currents. The environmental conditions in Icelandic waters during the 20th century can roughly be divided in to four periods. A cold period from the beginning of the century until around 1925, a warmer period until 1964, a brief very cold period until 1971. After this the climate has been intermediate but fluctuating. A warming trend then seems to be occurring again during the first years of the 21st century (Anon, 2004a).

The period under consideration here is during the end of the 20th century and the fluctuating nature of this period is apparent in the very cold oceanic temperatures in 1995. Cold conditions like that are termed Arctic conditions and are notorious for low ocean productivity (Malmberg and Valdimarsson 2003). The temperatures improved the year after but were still cool until 1998, conditions named Polar conditions. The last two years, 1999 and 2000 were the warmest, with so-called Atlantic conditions. There is thus a general warming trend during our period.

The cod was at that time, as it has been for most of them time, the most important stock followed by haddock and other stocks. The cod stock (Figure) had been declining for a long time and various methods used to try to limit the effort. With the advent of the ITQ system, quotas were severely reduced as the stock was declining to its lowest levels recorded. This did pay off as the stock was increasing again at the beginning of the period considered here. The rate of this increase was however severely overestimated after 1996 and as a consequence the stock got only a temporary relief from overexploitation. The TAC was set by a catch rule, 25% of the catchable stock was supposed to be catched each year so the stock and catch trajectories were supposed to follow the same track. But as can be seen in Figure this broke down after 1997 as the size of the stock was then overestimated. The seriousness of this overestimate of the stock size was first fully realized in 2000. Hence although we now know that the real stock size evolved in a Λ-shape from 1995 to 2000 it did not appear like that to fishermen or fishery managers at that time but rather as a increase which leveled off in 1997 (Figure 8.8).

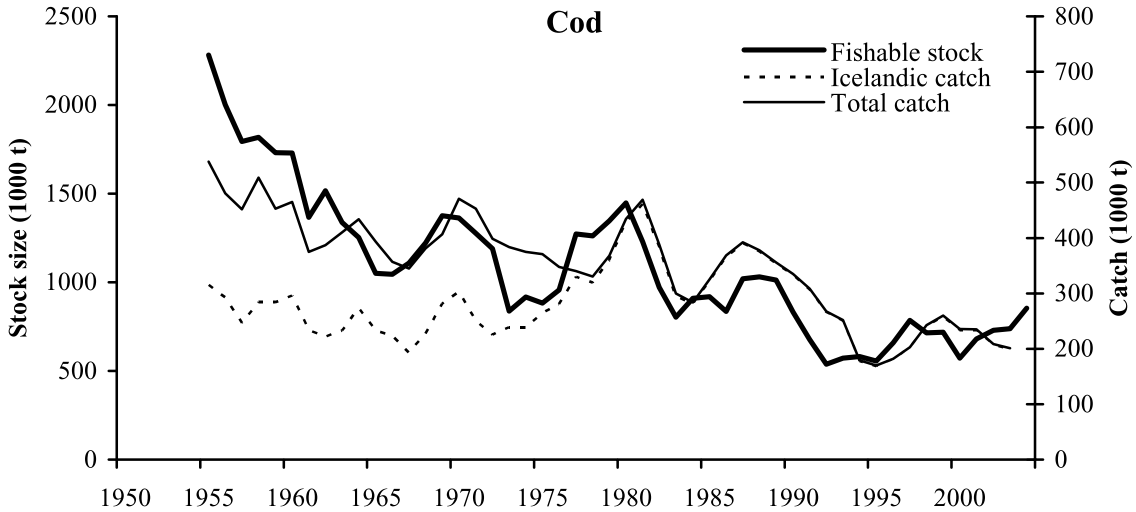


Figure 8.7: Fishable stock (4+ year old) and catches for Icelandic cod since 1950

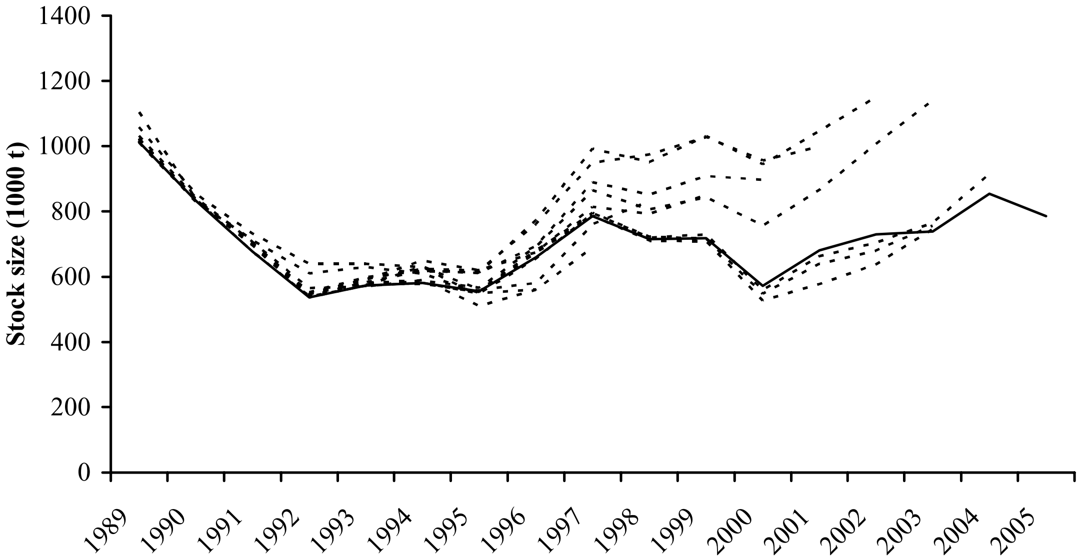


Figure 8.8: Retrospective pattern of fishable biomass (4+, thous. tonnes) estimates, whole line is current assessment.

The poor status of the cod stock in 1995 was mainly due to high fishing mortality during the prior decades, but generally poor recruitment from 1985 until 1998 did make matters worse. No definite single cause for this low recruitment has been found. Rather cool ocean temperatures can take part of the blame as good year classes are claimed by some (Planque and Frédou 1999) to more often born in warm years. Others studies do however not support this (Begg and Marteinsdóttir 2002). It is however quite possible that low spawning stock size during this period, due to heavy fishing pressure did effect the recruitment (Begg and Marteinsdottir 2002, Brander 2000).

Many theories have been put forward to explain the overestimate of the cod stock after 1997, but none has been proven to be conclusive. All of this debate has been in the realm of the grey literature or in newspapers, hence there are no peer-reviewed studies available. The theories put forward are as following:

1. Genetic degeneration of the stock due to high exploitation rate on the faster growing proportion of the stock. This might cause a growth overestimate in predictions.

2. Excessive discarding of small fish during the beginning of our period caused the actual fishing mortality to be underestimated and the stock subsequently overestimated.

3. Wrong model used. A tuned VPA model was used when the stock was overestimated. This is by far the most commonly used model in the North Atlantic, although there are many variants. These models have had its critiques, mainly since they seem to have a tendency to overestimate stock sizes and it is very dependent on accurate catch reporting.

4. Increased effort for the large and old cod. The mesh size of the gill net fleet increased from 1996 to 1998 since there were younger year classes were rather small and also due to relatively higher prizes for large fish. In stock assessment with VPA this can temporarily indicate that the older age classes were larger than previously thought.

5. Slower growth than was anticipated. Future projections are dependent on the average weight of the fish in the stock, which mainly depends on the size of the capelin stock, the main prey of the cod. If it slows down unexpectedly the stock size will be overestimated. The average weight of many year classes declined unexpectedly from 1997 to 1999, although the capelin stock was healthy. The calpelin stock did however drastically change its migration route which might explain the slower growth for cod. This was however not enough to explain but a part of the decline of the cod stock.

6. Migration. Many claim that the stock did not actually decline but migrated to other areas. The hypothesis on where these other areas are vary, some claim that a large part of the stock migrated to deeper waters, some claim to shallower waters while still others claim to foreign waters such as to the Faeroes or the Barents Sea. There have been no formal studies on this but some of these claims have some merits. CPUE in cod fisheries north of Iceland did for example increase after 1996 and stayed high long after the stock decline was found out. Similarly the cod catch in biannual inshore shrimp surveys has been very high from around 1997 until today and the same goes for CPUE in annual sea-angling competitions.

7. Wrong parameters used

8. The arithmetic mean used for a survey index might cause errors if distribution of catch is not normally distributed. It has been suggested to use a median instead of a mean.

9. The natural mortality rate used (M=0.2) was incorrect

    a) CPUE from the fishing fleet used to tune the VPA estimate. This definitely caused the stock assessment error to be unusually high, but the stock assessment would still have been too high if the CPUE had not been used.

    b) Starvation due to a larger stock size than the ecosystem could sustain. The correct remedy would then be to fish more so the rest would have enough to eat.

    c) Unusually high catchability from 1997 to 1999.

It is undisputed that it was unusually easy for the fleet to find cod during this period so that CPUE was maintained high despite a decline of the stock. This could rather easily be explained away by increased efficiency of the fleet (technological creeping) if it was not for the fact that this can also be seen in the trawl survey index for these years. I.e. the survey indicated a larger stock during this period than later VPA estimates suggested. This catchability increase of course brings new questions, why did it increase? Many theories were put forward (Pope 2000), none proved conclusive but all were deemed worth further consideration. The theories were as follows:

d) Oceanographic conditions. The behavior of cod differs with temperature, which might again effect availability to trawl.

e) Unusually high proportion of the stock in the waters north of Iceland might skew the trawl survey as the catchability might be different in the warmer south than in the colder north.

f) Depth distribution of the stock. The trawl mouth opening varies by depth, which might then skew the survey index if the distribution was unusually deep.

g) Clumped distribution of the stock. If the distribution of the stock is clumped the CPUE of the commercial fleet will stay high although the stock might be declining. This mechanism might in certain cases also cause errors in standardized trawl surveys.

h) Unusually high proportion mature, but spawning fish might be less available to trawls.

There are thus many possible explanations on the unexpected decline of the stock, and it is quite possible, or actually very likely that two or more of them were at work at once. Other demersal stocks were generally low or declining. The stocks of haddock, saithe and plaice were at low levels in 1995 but declined further to their lowest levels recorded in 2000, as did their catches. The two demersal redfish stocks (*Sebastes marinus* and demersal *S. mentella*) were also at very low levels in 1995. Both stocks did however recover somewhat during our period, probably due to restricted catches. The two other important demersal fish stocks, Atlantic catfish and Greenland halibut were all at low levels in 1995 but did recover somewhat in the next five years similar to the redfish stocks.

Several species of invertebrates are harvested in Icelandic waters but only the shrimp (*Pandalus borealis*) is catched by the trawler fleet. This is also economically the most important invertebrate fishery. As opposed to the fish stocks the shrimp stock was at a very high level in 1995, and catches were at all time heights. The stock continued to be high until it collapsed in 1997 due to much increased predation by the growing cod stock (Jakobsson and Stefánsson 1998, Anon 2004b). The shrimp and cod fisheries are thus tightly linked since similar and in many cases the same boats are fishing both and these species are ecologically linked as the cod is the most important predator on shrimp.

The pelagic stocks were also generally in a good shape during the last decade of the 20th century. Only two stocks were fished in 1995. The capelin and the Icelandic summer spawning herring, both primarily targeted by the purse seine fleet. The stock of Icelandic summer spawning herring had slowly grown quite large after the almost total collapse in the mid 1960´s. The size of the capelin stock was generally large during the beginning of our period but then declined somewhat. The capelin is quite important for the ecosystem as it is the most important food for cod as well as for many other marine species. This can bee seen in the close link between the growth of cod and size of the capelin stock, the more capelin the faster the cod grows (Jakobsson and Stefansson, 1998).

It is also noticeable that during the period under consideration here three new pelagic fisheries developed, all of which had grown to quite important in 2000. These were the fishery for the oceanic *Sebastes mentella* which began in 1995*,* fishery for the Norwegian spring spawning herring which began again by Icelanders in 1995 after the collapse in the mid 1960´s, and fishery for the blue whiting which began on a large scale in 1997.

In summary, most demersal fish stocks were at low levels in 1995, some continued to decline until 2000, while other were rather stable or did increase somewhat. No spectacular recoveries did occur during this period, although it did seem for a while to be happening to the cod stock. The main cause for these low stock sizes were mostly heavy fishing effort in the previous decades, but in some cases this was exaggerated by low recruitment rates. The invertebrate and pelagic stocks were however in a generally good shape and stayed that way until 2000, with the important exception of the shrimp stock which collapsed. Three new and important fisheries also developed between 1995 and 2000.

8.11. Development of Effort in the Icelandic Trawler Fishery

8.11.1. Defining fishing effort

Fishing effort is defined in different ways between different research disciplines and even within the same disciplines. For the fisheries biologist effort is measured as fishing mortality due to fishing activities, the infamous $F_{0,1}$. Fishing mortality in the Icelandic cod fishery is shown in Figure 8.9.

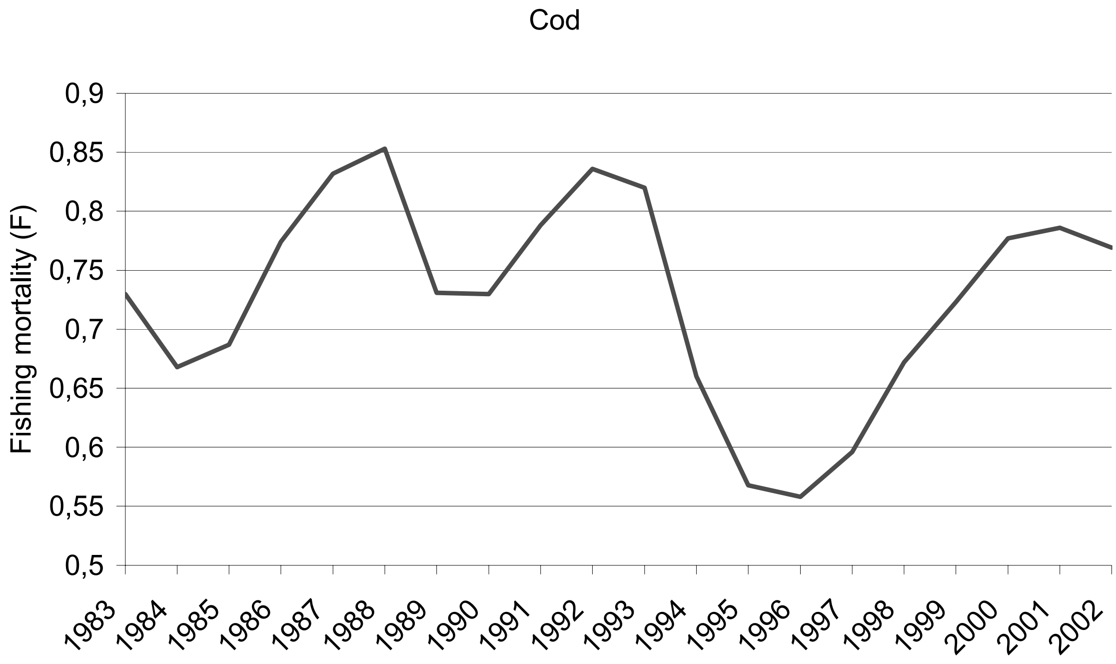


Figure 8.9: Fishing effort defined by fishing mortality.

Source: Marine Research Institute

The Icelandic Marine Research Institute has indicated that fishing mortality should not exceed $F_{0.4}$, but as can be seen from the figure the actual fishing mortality has often been considerably higher than the target fishing mortality.

Economist look at effort as the inputs (capital and labor) used to harvest the catch in any given fishery. Technical measures, such as vessel characteristics (length, width and engine power) are also used to measure fishing effort. Due to this wide variety in definitions of fishing effort one has to look at several measures when trying to examine the development of fishing effort over long periods. In this paper we have chosen to use 7 definitions of effort which all focus on the economic aspect of effort. The seven definitions are; number of vessels; number of trips; man-days-at-sea; engine-power-days-at-sea, man-power-days-at-sea and capital value. Each of these definitions are discussed below.

Number of vessels

In a perfectly homogenous fleet with identical fishing gear the number of vessels would be an indicator of total capacity and hence potential effort for a given fishery. As the number of vessels increase the potential effort increases and if all vessels fish the same number of days in a given year, the total effort increases as well. In a multi-gear fishery with heterogeneous fishing fleet the number of vessels might easily change without significant effect on the fishing mortality. Vessels could increase, but still use the same fishing gear as before and hence not affect fishing mortality (unless there is a net increase in the engine power). Additional small vessel might have insignificant effect on total fishing effort; where as one large vessels might have substantial effect on the fishing mortality. And finally a vessel might be seaworthy and registered but not be used in a given year for fishing, hence not contributing to total effort in that year. The number of vessels is used in this context as a baseline to compare other measures of fishing effort, but is not seen as being a good indicator by itself.

Number of trips

Number of trips takes into account the use of each vessel in the fishery. As such it is a better measure than number of vessels, but it fails to measure the effort by individual vessels if there is difference in the characteristics of the vessel in the fishing fleet.

Days-at-sea

Days-at-sea measures the time spent fishing and traveling to and from the fishing grounds. It is similar measure as the number of trips.

Man-days-at-sea

Man-days-sea measures the use of labor applied in the fishery. Total number of crewmembers, multiplied by number of days at sea, gives the total man-days-at-sea. These measures shows changes in effort, and combined with the number of vessels and number of trip are starting to give a good indication for total changes in effort. However, technological change is still unaccounted for.

Kw-days-at-sea

Kilowatts measure the engine power and kilowatt days at sea. It measures how often this engine power is used for fishing. It also captures some of the technological change, since larger engines are usually an indicator of new and larger fishing gear, higher top speeds for vessels (for cruising to and from the fishing grounds) and other technological changes which require more engine power.

Man-kw-days-at-sea

By combining kilowatt days and man days at sea one has a good indicator for changes in the use of labor and capital for a given fishery. This measure should capture most of the effort changes, where effort is measured as use of inputs for production of the product in question, i.e. landed fish.

Capital value

Capital value simply measures the total capital used in a fishery for harvesting and on-board processing.

8.11.2. Overall development of effort

Having established the measures of effort we first look at the overall development of effort for the entire fishing fleet, from 1980 through 2000. Unfortunately newer data is not readily available.

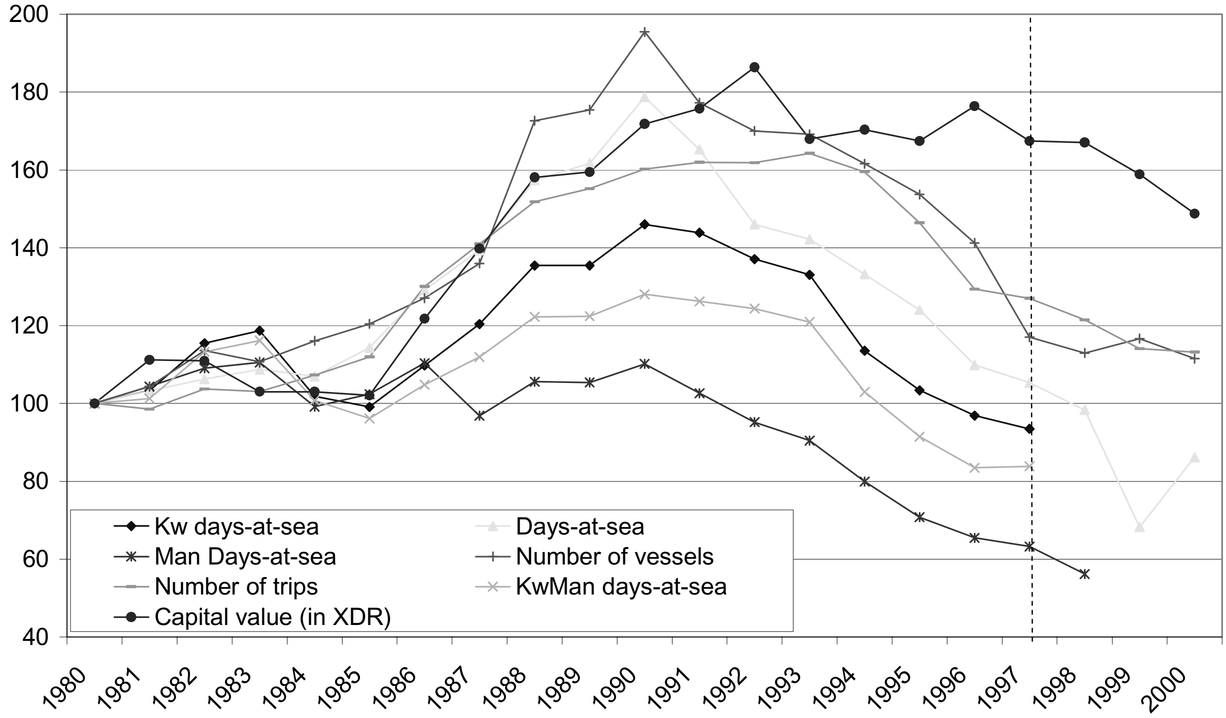


Figure 8.10: Development of fishing effort as measured by seven different effort definitions

Figure 8.10 shows the development of effort as an index change with 1980 equal to 100 for all vessels for each of the seven definitions. In all cases the effort is increasing from 1980 through 1983 when it drops considerably. In 1984 and 1985, the first years of the IQ system, there is a decrease in effort as measured by man Days-at-Sea, number of trips, Days-at-sea and Kw Days-at-sea. However in 1986 effort starts to increase considerably, and continuous to increase until 1991 and 1992. This effort increase coincides with the period of the management system when both effort control and quantity control were used to regulate groundfish fisheries, in all vessel categories. This might be seen as an indicator for increased effort due to the days-at-sea system and the build in race to fish for those operating under that system. It is also noticeable that soon after the new fisheries management law came into effect on January 1st 1991 there is a reduction in fishing effort as measured by each one of the seven different definitions. Hence, regulations obviously have direct and immediate impact on the economic behavior of fishermen. The data sources change in 1998 and some of the effort definitions could not be constructed for the period from 1998 through 2000.

There story becomes even more interesting when looking at individual vessel categories. Figure 8.11 shows the development of effort by gear type from 1980 through 2000 measured as number of vessels.

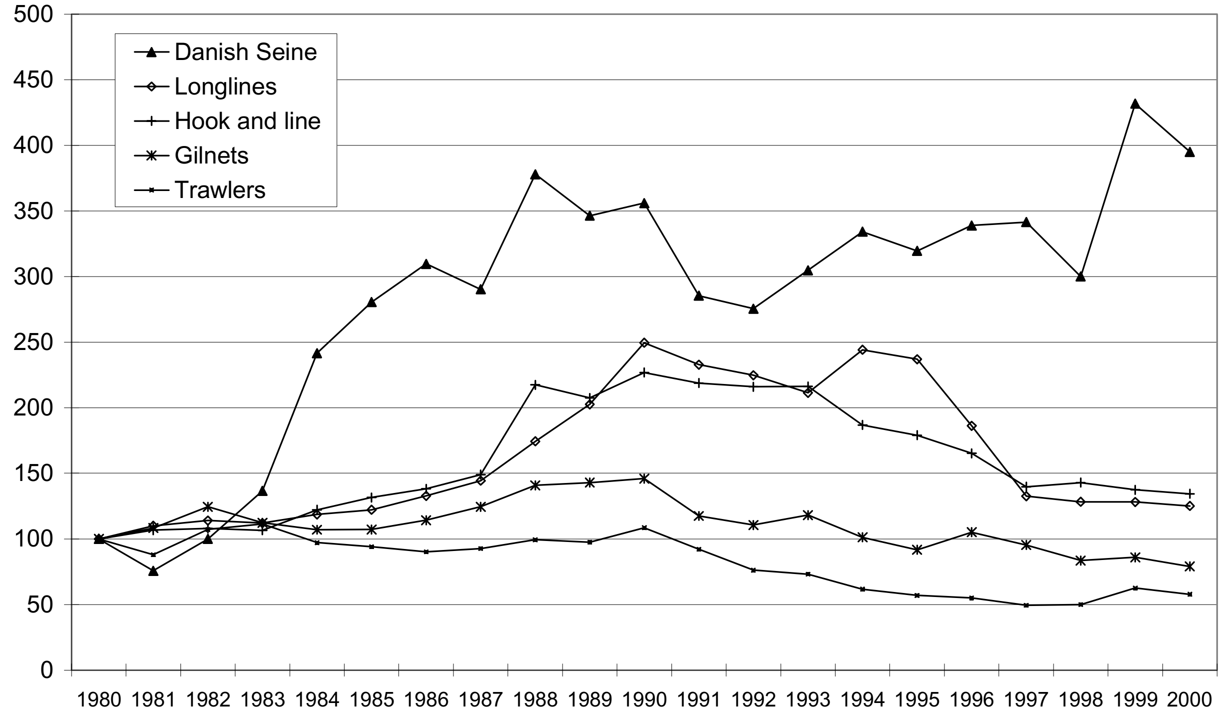


Figure 8.11: Development of effort (number of vessels) by gear type between 1980 and 2000

Most notable is the increase in effort (as measured as number of vessel) using the Danish seine and the reduction of effort in the trawler category. Danish seines are used to harvest flatfish species, but it is a multi-species fishery with cod and other groundfish as bycatch. Most of the flatfish species were not under the quota system between 1984 and 1990. Therefore vessels using gillnets changed to Danish seines and targeted non-quota species, but their overall share in the catch was relatively low. Longliners had also favorable treatment prior to 1991. Only half of the catch was measured towards the quota if caught by longline. Hence vessels using longlines increased until 1991 but started to reduce again after this was abounded by the new fisheries management law in 1991.

The trawler category has been under the most stable part of the system during this period. In 1988 the effort system was abounded for trawlers and all trawlers were under a de facto transferable quota system. This was reinforced by the new legislation in the early 90s. The trawlers also caught relatively high portion of the entire groundfish catch as can be seen from Figure 8.12.

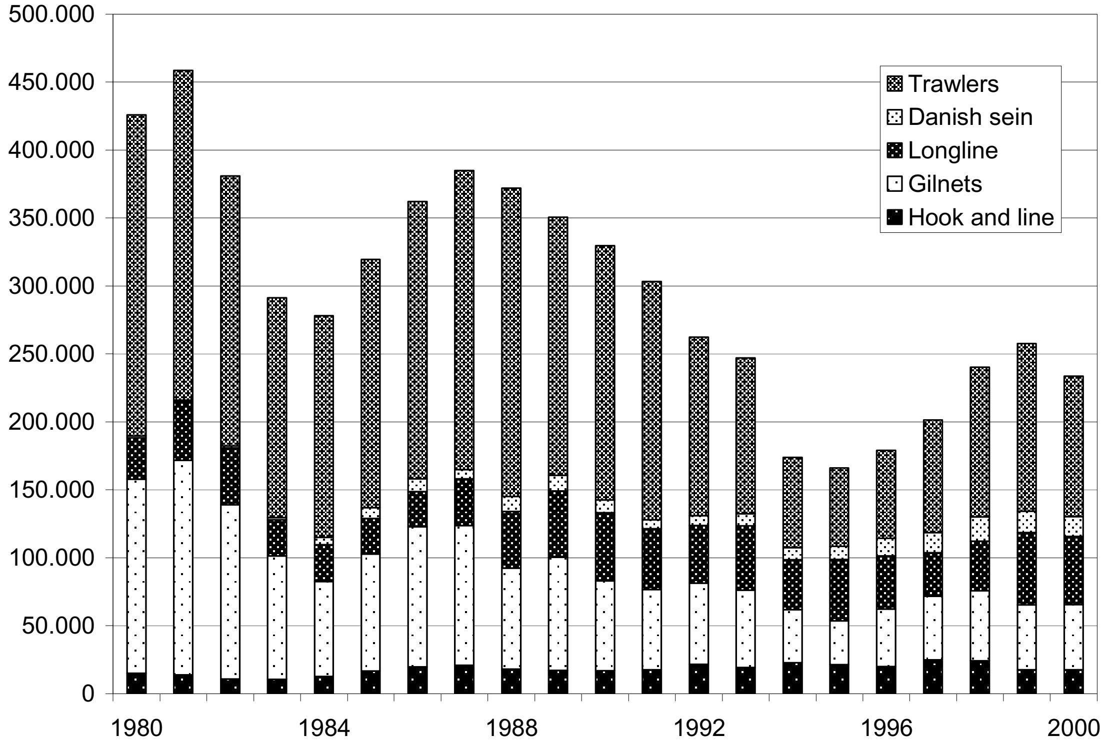
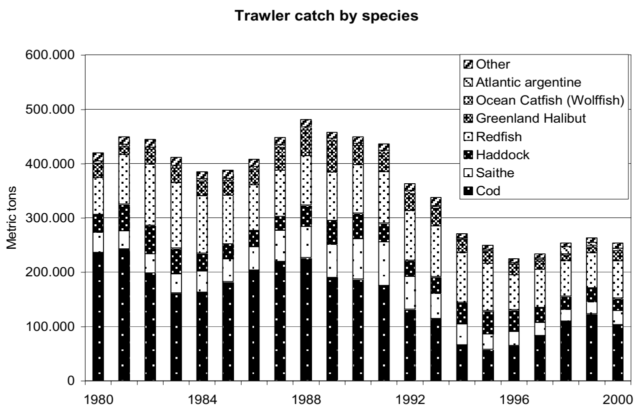


Figure 8.12: Cod catch from 1980 through 2000 by gear type

The figure above shows that trawlers have had about 50% of the cod catch annually between 1980 and 2000. It also shows the decrease in cod landings over the time period. However, some types of fishing gear have actually increased their share, and even their actual landings. Danish seines harvested almost no cod in 1980 but harvested close to 10 thousand metric tons in 2000. Longliners increased their catch as well but gillnets received a smaller share, and smaller tonnage in 2000 than in 1980. Smaller boats using hook and line have increased their share of the catch considerably, or from 5% in 1980 to more than 10% in 2000. The smaller boats have been under a mixed system of output control (quota) and effort control (Days-at-sea) over the entire period.

If we examine the catch composition of the trawler fleet and compare it to the Danish seine fleet some interesting facts emerge. Figure 8.13 shows the composition of the catch for each gear type.



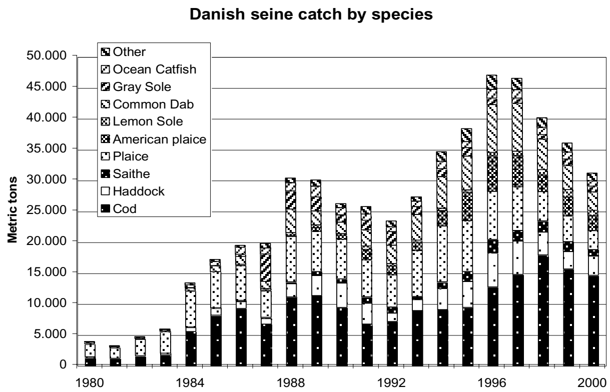


Figure 8.13 Catch composition for trawlers and Danish Seine

Source: Marine Resource

For the trawler fleet the species composition has been relatively unchanged though the catch has declined by more than 40% of the period. Cod still accounts for little less than 50% of the overall catch, with redfish being the second most important species for the trawlers. For the Danish seines other species account for more than 50% of the overall catch, with several flatfish species accounting for the remaining catch.

Vessels using Danish Seines obviously target other species than the trawlers, and their catch is increasing quite dramatically. The Danish Seines are utilizing the system to target non-quota species, with quota species as bycatch. Again, a direct result from the fisheries management system in place.

Table **8.3** shows the results of the effort analysis for all gear types and all seven definitions of effort.

Table 8.3: Changes in effort by effort definition and gear type

Effort definition	Hook and line	Gilnet	Longline	Danish Seine	Bottom trawl	Overall
No. of vessels	+	÷	+	+	÷	+

Number of trips	+	÷	÷	+	÷	+
Days-at-sea	÷	÷	+	+	÷	÷
Man-days-at-sea	÷	÷	÷	+	÷	÷
Kw-days-at-sea	+	÷	+	+	÷	÷
ManKw-days-at-sea	÷	÷	÷	+	÷	÷
Capital value	N/A	N/A	N/A	N/A	N/A	+
Catch	+	÷	+	+	÷	÷

Several interesting facts emerge from this table. First of all only Gillnets and Bottom trawls decrease their effort between 1980 and 2000 as measured by all seven effort definitions. Hook and line increase their effort by the measure of number of vessels, number of trips and kw Days-at-sea, but decrease their effort measured as days-at-sea, man days-at-sea and hence manKw days-at-sea.. Overall effort decreases measured in days at sea but increases in number of vessels and number of trips, as well as in terms of capital value.

The results from the effort analysis are inconclusive but show clearly how different management regulations have direct impact on the effort level used. Given that bottom trawlers harvest about half of the groundfish catch and that the results of the effort analysis seem to show that there is an decrease in effort in the trawler fishery further analysis is based on the trawler fleet.

8.12. Measures of Efficiency in the Icelandic Trawler Fishery

8.12.1. Data

The data used in this research is from four different government agencies. The data is on catch, effort, vessel characteristics and cost of fishing operations.
Data on annual catch and number of fishing days for vessels with reported cod catch by bottom trawling was obtained from the Marine Research Institute in Iceland. This resulted in 490 observations for the time period in question with 108 different vessels.

The number of vessels that landed cod annually declined steadily from 1995 through 2000. In 1995 there were 93 vessels; down to 69 vessels in 2000 or a 26% reduction in the number of vessels. At the same time the average catch almost doubles. There can of course be any of number of reasons for this increase in the average catch. Chapter 0 reviews several plausible explanation for changes in the cod stock itself and changes in technology, but none of this hypothesis has been proven yet. As pointed out in the chapter there are possibly more than one reason for these change, but we can focus on two of them. First of all the average size of the remaining vessels is increasing and from 1997 through 2000 catchability for demersal species increased, probably due to changes in environmental factors. This increase in catchability led to an overestimation of the cod stock, and thus higher quotas than optimal. Fisheries scientists did not realize this until the year of 2000 and recommended a decline in catch levels and fishing effort in 2001 and 2002. Total catch increased from 119 thousand metric tons to 163 thousand metric tons. However, when the MRI data was compared with data from the Fisheries Directorate there were indications that the 1995 data from MRI showed less catch than estimated by the FD. Data for other years showed similar level of catch within the MRI and FD datasets. Data on vessels characteristics were obtained from the Icelandic Maritime Administration (IMA). Costs and earnings data were acquired from Statistics Iceland. Statistic Iceland collects data from annual reports and through survey work. However, the institute only collects data on companies, but not individual vessels. When companies operate both fishing vessels and on shore processing plants the company is asked for cost and earnings data for their fishing fleet separately from the processing operation. The cost and earnings data was then matched with the catch and vessel characteristic data to build the final data set used in the empirical analysis, as described in the next section.

Since many companies operate more than one vessel, and only about 80% of each fishing company is surveyed annually, the total number of observations decreases. After combining the data from the four different sources the final dataset has 157 observations. The descriptive data for the final dataset is shown in table 8.4.

Table 8.4: Descriptive statistics for company data (monetary units in millions of krona)

Year	1995	1996	1997	1998	1999	2000
Number of vessels	2.2	2.2	2.2	2.7	2.7	2.7
Days at fishing	365.1	341.5	349.0	408.0	479.7	521.8
Annual catch (MT)	3,098.6	3,446.7	4,304.0	5,389.1	6,075.9	6,609.5
Total Revenues	565,822.7	550,599.8	676,617.3	858,100.0	1,004,684.7	1,161,285.2
Total costs	518,057.4	527,375.4	650,802.1	805,303.6	909,047.7	1,042,434.2
Fuel	48,769.9	55,475.0	67,695.9	56,781.0	58,497.1	124,734.1
Maintainance	42,811.5	46,255.1	49,688.8	63,536.2	69,178.5	82,832.4
Crew share	198,136.7	204,091.8	254,835.6	329,134.4	374,222.0	452,398.2
Depreciation	68,566.2	74,547.9	86,424.5	125,677.0	141,495.2	163,405.1
Other costs	159,773.0	147,005.5	192,157.4	230,175.0	265,654.9	219,064.4
Per vessel						
Crew (average)	19.2	19.1	19.5	19.0	18.9	19.2
Registered length (meters)	49.9	49.3	50.3	50.0	50.6	50.5
GT	996.6	978.7	1,011.8	990.5	1,016.7	1,017.9
Engine Power (Kw)	1,817.8	1,775.7	1,834.7	1,800.1	1,821.5	1,851.5

The average company had 2,2 vessels, with maximum of 8 vessels for one company and minimum of one vessel per company. The use of these vessels is increasing since the average days at fishing increased from 365.1 per company to 521.8 per company in 2000 (an increase from 163 days per vessel to 197 days per vessel in 2000). The average annual catch increased from 3,100 metric tons in 1995 to 6,600 metric tons in 2000. This is an increase from 8.5 metric tons per day to 12.7 metric tons per day and per vessel. The increase in catch per company is probably due to two factors. First, the increase in catchability as described before and secondly because of consolidation of fishing rights and cooperation between companies.

8.12.2. Econometric results

A dual approach is used to find the optimal use of capacity within the given time period. It is important to note that that this research focuses on a static estimation of the cost function, not dynamic one. Since we are not looking for the optimal path it is not necessary to take into account the stock dynamics and we can focus on the question of operational efficiency, given the current technology and catchability. A translog functional form is used to estimate the total cost curve for the trawler fleet.

A graphical representation of the estimated cost functions is shown in Figure 8.14.

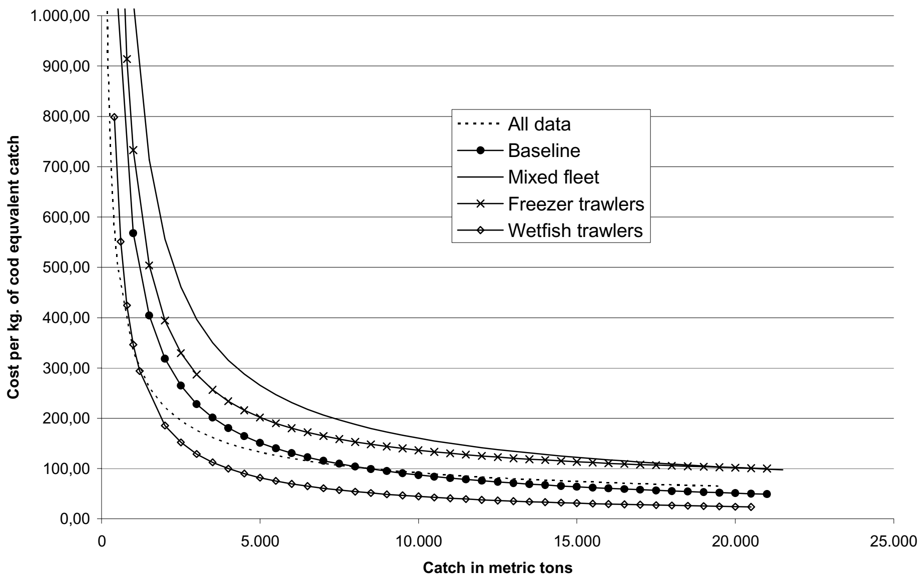


Figure 8.14: Estimated total cost functions for the Icelandic trawler fisheries

The initial dataset estimated used all 157 observations. The estimation had relatively good fit, or a R-square of 0.93. The econometric results are shown in Table 8.5 below.

Table 8.5: Estimation results - parameters

Estimation Results - All data				
	Coefficient	**Std. Error**	**t-Stat.**	**Prob.**
α_0	0.22	0.04	4.88	0.00
D96	-0.11	0.05	-2.23	0.03
D97	-0.19	0.06	-3.18	0.00
D98	-0.21	0.06	-3.31	0.00
D99	-0.10	0.07	-1.39	0.16
D00	-0.12	0.07	-1.71	0.09
α_c	0.13	0.06	2.22	0.03
α_l	0.41	0.05	8.04	0.00
α_f	0.01	0.05	0.19	0.85
α_{cc}	0.08	0.00	23.65	0.00
α_{cl}	-0.01	0.00	-2.39	0.02
α_{cf}	-0.05	0.00	-28.97	0.00
α_{ll}	0.14	0.00	42.28	0.00
α_{lf}	0.00	0.00	-3.07	0.00
α_{ff}	0.07	0.00	49.30	0.00
α_{oo}	0.23	0.05	4.36	0.00
α_q	0.77	0.03	29.78	0.00
α_{qq}	0.08	0.04	1.98	0.05
α_{cq}	0.00	0.00	-1.55	0.12
α_{lq}	0.00	0.00	2.21	0.03
α_{fq}	0.00	0.00	-1.39	0.17
α_{oq}	0.10	0.04	2.76	0.01
α_{sq}	0.09	0.06	1.51	0.13
α_{sl}	-0.07	0.05	-1.41	0.16
α_{sf}	0.08	0.05	1.58	0.12
R-squared	0.93			
Adjusted R-squared	0.92			
S.E. of regression	0.24			
Durbin-Watson stat	2.20			

The regression has relatively high R-squared with 19 out of 27 parameters statistically significant at the 95% level. The most important parameters are α_q and α_{qq}, since they are used in calculating the returns to scale and are used to calculate the optimal firm size. Those parameters are both statistically significant. Table 8.6: Elasticities shows the own price and cross price elasticities for each of the four input factors. The own price elasticities are all negative and statistically significant at the 95% level. All the cross price elasticities indicate that each input factor is a substitute for the other, and all but two are statistically significant at the 95% level.

Table 8.6: Elasticities

	Elasticities*			
	Capital	*Labour*	*Fuel*	*Other*
Capital	**-0.61 (0.03)**	**0.9 (0.05)**	**0.72 (0.13)**	**0.68 (0.06)**
Labour	**0.90 (0.04)**	**-0.36 (0.04)**	**0.41 (0.08)**	0.09 (0.10)
Fuel	**0.72 (0.13)**	**0.41 (0.08)**	**-0.24 (0.01)**	**0.20 (0.07)**
Other	**0.67 (0.05)**	0.20 (0.07)	**0.20 (0.07)**	**-0.21 (0.04)**

** Bold numbers are statistically significant at the 95% level*

The regression output and the elasticities show that the model performs reasonable well. An interesting observation is that capital is relatively price elastic compared to the other input factors.

Returns to scale were calculated at 1.3 which is relatively low since an optimal cost minimization would result in returns to scale of 1. The optimal firm size would be about 26 times larger than the average firm size, or harvest about 120 thousand metric tons. Maximum annual harvest per large sized trawler (over 800 GT) is about 8000 metric tons. This number can of course change due to environmental factors, labor laws and labor contracts, etc. but managers within the largest companies agreed that 8000 metric tons would be close to the maximum average catch. Given that optimal firm size is 120.000 metric tons and that the average annual catch by the trawler fleet is about 225.000 metric tons of groundfish species there would only be room for two companies operating mixed fleet of freezer and wetfish vessels.

These numbers are rather extreme though they conform with theory that there should only be one company given exclusive rights to fishing. The fact that the data mixes together wetfish trawlers and freezer trawlers, as well as one boat operations with multi vessel companies, might have adverse effect on the estimation. In order to avoid that problem the data set was split into four different subsets. The first subset is called BASELINE and contained data that had cost per kilogram of landed fish lower than 300 Iskr. The second subset looked at companies with MIXED operations. The third subset looked at companies that operated only FREEZER trawlers and the fourth subset examined companies which operated only WETFISH trawlers. The results from the estimation and calculations of the optimal fleet size are shown in the table below.

Table 8.7: RTS and optimal firm size for each subset of data

	RTS	R^2	Average firm size (tons cod equivalent catch)	Number of companies	Number of vessels per company
All data	**1.30**	**0.94**	**120,000**	**2**	15
Baseline	**5.11**	**0.94**	**133,000**	**<2**	17
Mixed fleet	**3.26**	**0.97**	**66,000**	**<4**	8
Freezer trawlers	**3.99**	**0.94**	**10.500**	**<22**	<2
Wetfish trawlers	**9.45**	**0.91**	**23.000**	**<10**	3

There is a stark contrast in the estimation of the different datasets. This difference in average firm size is obviously related to each sub-sample. But the results conform in at least one way; there is still room for increasing efficiency within the Icelandic trawler fleet. Due to the nature of the translog function, and the fact that all optimal values are outside of each individual sample the accuracy of the forecasted optimal size might be low. However, the optimal firm size is obviously beyond the current limit on quota ownership. Hence, the Icelandic fisheries would become more efficient if the restrictions on quota shares were lifted. Given that the average catch of each vessel is 8000 metric tons then the trawler fleet could have been reduced from the 69 vessels used down to about 30 or 40 vessels, or up to 50% reduction.

8.13. Resource Rent in the Icelandic trawler fishery

Resource rents are defined as the difference between total revenue and total cost, where costs are defined as the opportunity cost of capital, labor and other inputs used in the fishery. In a properly managed fishery the resource owners/harvesters can earn sustainable economic rent from their harvesting practices. Resource rents are therefore a measure of efficiency in the fishery, where higher resource rent mean higher level of efficiency.

It is difficult to measure resource rents, especially in a fishery where the fleet is heterogeneous and perhaps harvesting multiple species at the same time. Opportunity costs are also a concept that is difficult to obtain information on. What is the opportunity cost of a fisherman that has no other alternative of employment than fishing? Hence, fisherman fishing the same fish stock, from different ports might actually have different opportunity costs. Opportunity costs are difficult to measure except at very aggregate levels.

In this study we have estimated the actual costs of capital, labor, fuel and other inputs. Prices for capital and fuel were based on market prices, and assuming that the markets are efficient, should give us the opportunity cost for those inputs. The labor and other input cost are measured as user costs. Fishermen get a share of the catch value and hence reap part of the resource rent directly. The difference between the fisherman wages and the wages he could earn in other professions is his share in the resource rent. In Iceland fishermen bear a certain respect in society because they earn a high level of income, often triple or quadruple compared to what they could earn in other professions. Heterogeneity in the fishing fleet also helps some captains to earn some intra-marginal rents through better harvesting techniques. All of this makes it difficult to estimate the true resource rents for the Icelandic groundfish fishery.

Using the estimated model from previous section and the average landing value from 1995 through 2000 one can calculate the potential and realized rents. Table 8.8 shows the results from those calculations.

Table 8.8: Potential and Realized Resource Rents in the Icelandic groundfish fisheries

Average Resource Rents	Actual	%
Average revenue per kilo	166 kr/kg.	-
Average cost	154 kr/kg.	-
Margin	12 kr/kg.	7%
Resource rent of crew share	23 kr/kg.	14%
Total realized resource rents	36 kr/kg.	21%

Potential Resource Rent	Overall	%
Average revenue per kilo	166 kr/kg.	-
Minimum cost at optimal firm size	82 kr/kg.	-
Resource Rent	84 kr/kg.	51%
Resource rent of crew share	23 kr/kg.	14%
Total potential resource rent	107 kr/kg.	65%

The results from the calculation show that the potential resource rent for the Icelandic groundfish fishery is between 50% and 65%, depending on if we use the actual labor cost or the opportunity cost of labor. Calculating the resource rent by using average values for costs and earnings and using the opportunity cost of labor as 65% of the crew share the realized resource rent is between 7% and 21% of total revenues.

The 7% margin on the average is higher than the economic performance as calculated by the National Economic Institute for the same time period. This is due to different treatment of capital costs in this research compared to the NEI study.

In theory a fisherman should be willing to pay all his resource rents for an additional unit of lease quota. If the quota market is efficient prices should reflect marginal prices and hence one could calculate the resource rents by simply dividing the lease price by the ex-vessel landings value. Using the annual lease prices for cod collected from brokers and from the Icelandic quota exchange (which now has been closed) and the annual landing prices for cod from 1997 through 2000 showed that at the margin quota buyers were willing to pay up to 75% of the landing value for an annual lease of quota. The result from that calculation is shown in the table below.

Table 8.9. Margin in quota trades

Year	Lease price (Iskr, nominal prices)	Landing value at auction markets (Iskr. Nominal prices)	Margin
1997	81,71	91,00	0,75
1998	86,52	113,32	0,64
1999	104,74	139,30	0,63
2000	110,3	145,21	0,64

Other studies have found that resource rents in fisheries can be up to 60% to 70% of the landing value and hence these values seem to be reasonable. However, one must take into account that there has been a shortage of cod quota over the past two decades and there are high fines for landing fish without quota. Hence the lease quota price might include the cost of landing fish without quota, as well as the resource rent. That is the captain is willing to pay more than the resource rent to obtain one more kilogram of quota, in order to avoid suspension of his fishing license and to avoid fines. To support that theory one can look at the lease prices of haddock.. Haddock used to be sold at the same price as cod at the domestic auction markets. Starting in 2001 the quotas for haddock were increased annually because of

increased stocks, due to favorable natural conditions. In 2001 haddock and cod annual lease quotas were sold at about 110 to 120 Iskr per kg. By the end of 2003 the price of haddock quota had dropped to Iskr. 28. As a share of auction prices the annual lease price for haddock increased from 33% in 1998/1999 to 68% in 2001/2002 and then dropped again to 35% by the end of 2003 (Útvegshúsið 2004). This strongly reflects the increase in the TAC for haddock and the subsequent collapse in quota prices due to excessive supply of quota.
Based on the discussion above it is possible to state that resource rents in the Icelandic groundfish fisheries are somewhere between 30% and 60% of the landing value depending on the species and market conditions at any given time. It seems therefore that some of the resource rent was being realized for the trawler fleet between 1995 and 2000. However, this was relatively low compared to the potential resource rents.

The ministry of fisheries recently issued the calculation of the new fishing fee to be 1.99 Iskr. per cod equivalent kilo, increasing to ca. 2.50 Iskr. per cod equivalent kilo in 2007. At the current auction prices this is less than 2% of the landing value.

8.14. Discussion and conclusions

This paper has focused on explaining economic behaviour of Icelandic fishing companies operating wetfish and freezer trawlers. The results of the paper show that there is considerable difference in the development of effort depending on the regulatory framework for the fishery in question. It has also shown that operators of fishing companies respond to the incentives of the individual transferable quota system. Further analysis showed also that only small parts of the potential resource rents have actually been realized within the ITQ system. There is more room for efficiency gains by increasing the size of companies and utilizing returns to scale to minimize operating cost of each vessel, and that the year 2000 trawler fleet could have been reduced up to 50%.

This study covers the period from 1995 through 2000. Since then some considerable changes have occurred in the Icelandic groundfish fisheries. Large fishing companies have been merged and sold into smaller pieces again and several trawlers have been decommissioned. In 2003 and 2004 thirty two fishing vessels (trawlers, gilnetters and longliners) were taken out of the Icelandic fisheries (either sold abroad or scrapped) but three new vessels were bought instead. The 32 vessel were registered close to 18.000 GT and the new vessels are registered as 6.000 GT. This is a net reduction of 12.000 metric tons in just two year (Fiskifréttir 2004). All of these changes indicate that the Icelandic trawler fleet is rapidly adjusting to the current regulatory regime by decreasing the number of vessels used to harvest the current share of TAC allocated to the trawler fleet.

This is maybe best seen in an example of the development of a particular fishing company. In 1990 three fishing companies owned 10 vessels measuring a total of 6,850 GRT. The three companies held quota of about 20.000 metric tons in cod equivalent values or 5.6% of the overall TAC measured in cod equivalent values. By 2004 these three companies had merged into one. The new company controlled about 20.000 metric tons of cod equivalent value (5% of the overall TAC) but it now used only five vessels to harvest this quota. These five vessels measured as 3,850 GRT. Three new vessels were bought instead of the eight vessels that the company either sold domestically or abroad or scrapped.
All evidence point in the same direction: The efficiency of the Icelandic trawler fishery is increasing though the process has now taken twenty years, and there is still room for further increase in efficiency.

9. The Swedish Case

The Baltic Sea cod stock[61] was for a long period among the most productive in the world and during 1980-85 landings were more than 300 000 tonnes annually, which at that time constituted more than 10% of global cod landings. After this period with severely high fishing mortality levels, the stock started to decline drastically and from 1993 landings have been around or below 100 000 tonnes (see fig 9.1 and 9.2).

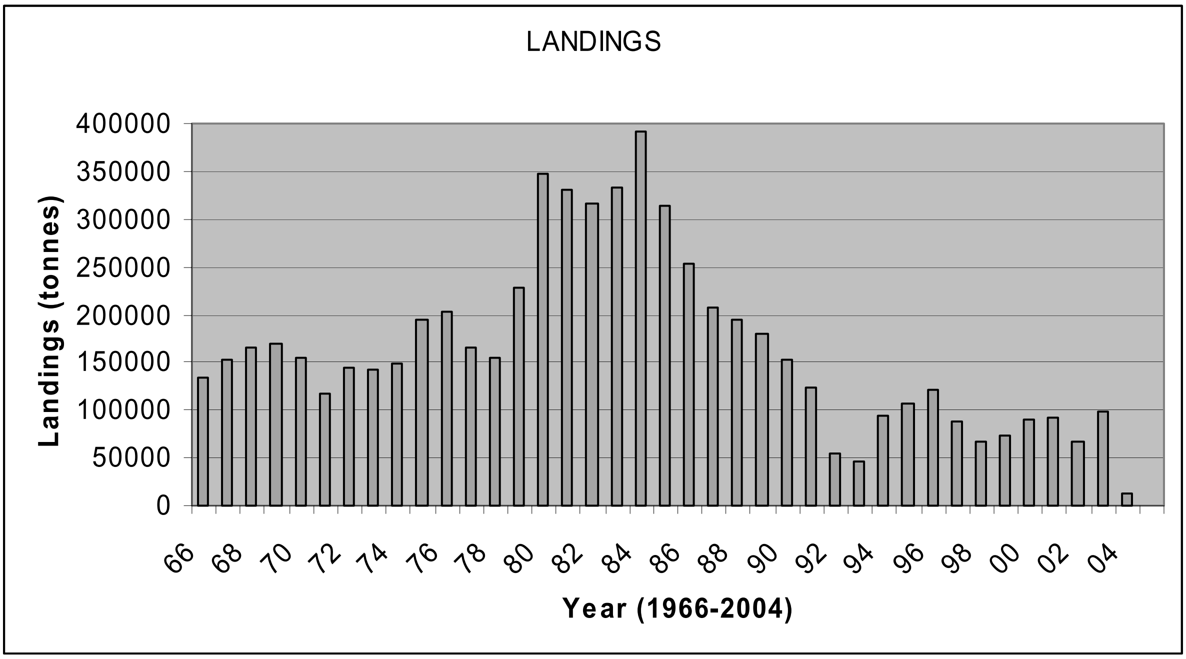


Figure 9.1. Annual landings of cod in the Baltic Sea, 1996-2004

Figures for 2003-04 are predicted values, given that the recovery plan is actually carried out.

Today, the spawning stock biomass is judged to be outside safe limits and a four month moratorium was imposed during 2003 in order to restore the stock (Anon, 2003). The Baltic Sea fisheries are managed by The International Baltic Sea Fishery Commission (IBSFC), which was established in 1973. The IBSFC started to set TACs for the cod fishery in 1974, but due to disagreement on jurisdiction of the Baltic Sea there was no functioning TAC during the period 1982-88.

[61] Biologists usually refer to two stocks in the Baltic, one west of the Bornholm Island and the other east. During the highly productive years, 1978-1986, the total stock was completely dominated by the eastern stock. For simplicity, we refer to these two stocks as one stock through out this paper.

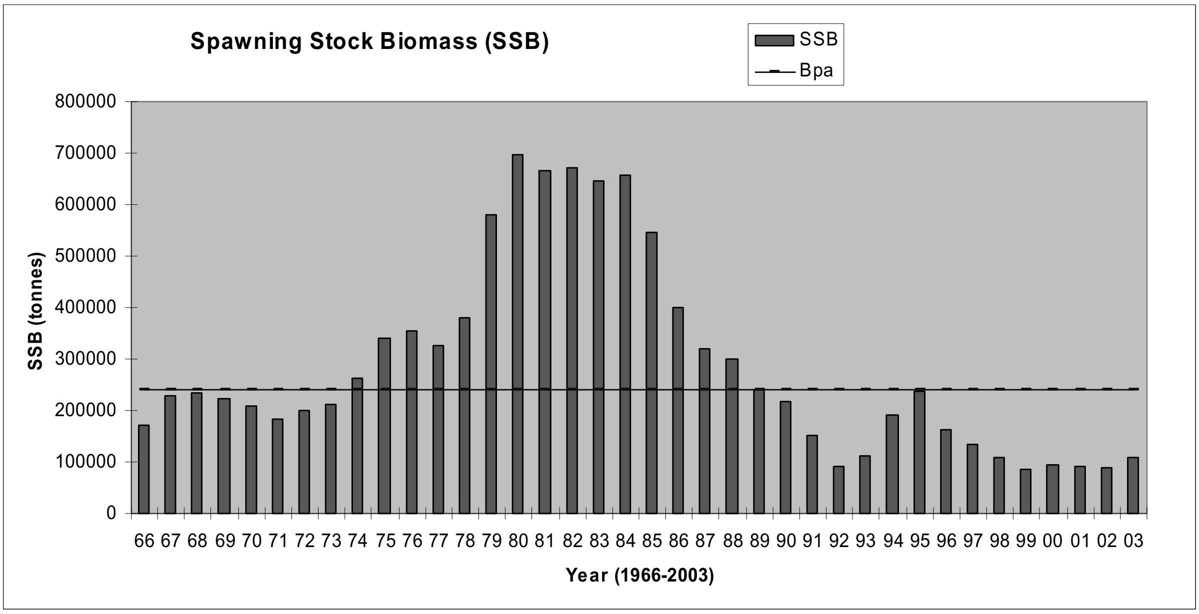


Figure 9.2. Spawning Stock Biomass of cod, Baltic Sea, 1966-2003.

The cod fishery has been subject to various measures and in the early 1990ies, when the spawning stock biomass (SSB) was estimated to be below safe limits, i.e. 240 000 tonnes, a temporary moratorium was imposed. The Swedish cod fishery in the Baltic Sea is carried out with fixed gear, i.e. mostly gill net, and with moving gear, i.e. mostly trawl. Landings with fixed gears amount to roughly 70%, while the remaining 30% is caught with moving gear. In 1995 a regulation was introduced for the Swedish cod fishery in the Baltic Sea, which resembles an IVQ system. All vessels are granted a weekly quantity of cod, which is increasing in vessel length. This system has been in place ever since, but the authorities have both increased and reduced the original rations during 1995-2003. In table 9.1, we report the weekly rations for the Swedish vessels during 2001 where vessels below 9 meters length were allowed to catch 6.4 tonnes, vessels above 9 meters but below 21 gross registered tonnes (GRT) could catch 9.6 tonnes and so on.

Table 9.1. Swedish weekly rations of cod in the Baltic Sea, 2001.

Vessel length (GRT)	9 meters	>9 m & < 21 GRT	21-40	40-55	55-80	80-106	106-131	131-161	>161
Weekly ration (tonnes guttered cod)	6.4	9.6	12.8	16.0	19.2	22.4	25.6	28.8	32.0

During 2002 fisheries biologists raised warnings about the poor state of the Baltic cod stock. In Sweden these ideas was pushed forward by the Green party and Sweden planned for a unilateral one-year moratorium. This was not in accordance with the CFP and the Swedish government got signals indicating that if the Swedish part of the Baltic TAC was not landed, other countries could in fact land that share. The moratorium was not carried out, but 3-4 months stops have been used. The total cod TAC for all countries fishing the Baltic Sea was down to 60 000 tonnes in 2004, but for 2005 there is a discussion about raising the total cod landings to 75 000 tonnes.

9.1.Data

The Swedish National Board of Fisheries collected the data used in this study. The log book database identifies vessel, including various vessel characteristics, fishing effort, gear type and landing date on a per trip basis. Economic data comes from a sample of vessels' tax reports for the year 2001, which include gross revenues, expenditure data on fuel, maintenance, insurance, labor costs, crew size, ice and product fees. The merged data set from these two data sets provides information of annual fishing effort, gross revenues and total costs. The total sample of observations was 37 vessels but due various missing items, the final analysis was carried out on 30 observations.[62] We report mean values for the sample vessels in Table 9.2 with corresponding figures for all 37 vessels in brackets and note that the sample is representative for the population.

Table 9.2. Key characteristics of the Baltic Sea cod trawlers, mean values.

	No of obs	Vessel size (GRT)	Crew	Vessel value (SEK 10^6)[63]	Revenue (SEK 10^6)	Costs (SEK 10^6)
Swedish Baltic Sea cod trawlers	30 (37)	113 (114)	3.2 (3.2)	4.5 (4.6)	2.4 (2.4)	2.4 (2.4)

Total costs are divided into three components, capital costs, fuel and other operating costs, and labor costs. Capital cost is defined as the sum of depreciation costs and opportunity cost. Several vessels in the sample are old and there is a general tendency among fishers to invest

[62] All costs, output, and revenue data are confidential at the level of the individual firm.
€ 1 = SEK 9.1, November, 2004.

surpluses from successful years in equipment, e.g. reducing mortgages on the vessel. The result is that recorded depreciation and interest costs are low, the annual average is 6% of the total capital value, and would lead to downward biased estimates of the capital cost. We add a social user cost of capital changing the average price of capital to 12% of the total capital, which is more in line with previous studies (e.g. Squires, 1987a). The price of capital (w_1) is defined as the capital cost divided by total capital, where total capital is measured by the insurance value. The composite price of fuel and other inputs (w_2) is calculated using monthly prices on fuel from IEA and monthly prices on materials and services from Statistics Sweden. We calculate the average annual fuel price for each vessel by using the number of trips per month as weights in the Divisia index. The price of labour (w_3) is defined as recorded labor costs divided by crew size. Output (y) is measured by harvest in kilos.

9.2. Empirical Results

The estimated parameters are provided in table 9.3. The R-square statistics for the cost function is 0.999, while the corresponding figures for the two share equations, capital and running costs, were 0.855 and 0.962 indicating a good fit of the data.

Table 9.3 Translog SURE Cost Function Estimates

Variables	Coef.	Prob.val.
Const.	17.036	0.00
αy	-1.023	0.21
$\alpha y2$	0.138	0.08
$\alpha 1$	0.885	0.00
$\alpha 2$	0.306	0.14
$\alpha 3$	-0.191	0.31
$\alpha 11$	0.031	0.46
$\alpha 12$	-0.027	0.51
$\alpha 13$	-0.004	0.52
$\alpha 22$	0.055	0.17
$\alpha 23$	-0.028	0.00
$\alpha 33$	0.032	0.00
$\alpha y1$	-0.047	0.01
$\alpha y2$	0.043	0.01
$\alpha y3$	0.004	0.82

The parameters of flexible functions are difficult to interpret. We provide the own price elasticities, which are significant at the 1% level, in table 9.4. All the elasticities have the expected negative sign and we see for instance that the $\varepsilon_{capital}$ = - 0.63. All else equal, this indicates that a 1% increase in capital costs will lead to a capital reduction of 0.63%. Returns to scale is derived at the mean prices and output level and found to be 1.43, which indicates substantial economies to scale.

Table 9.4. Estimated Elasticities

	Mean	St.error	T-value
ε_y	1.425	0.173	8.22
$\varepsilon_{Capital}$	-0.632	0.179	-3.54
ε_{Fuel}	-0.330	0.072	-4.61
ε_{Labor}	-0.640	0.029	-21.92

* $\varepsilon_i = (\alpha_{ii} + S_i^2 - S_i)/S_i$ where i = Capital, Fuel, Labor, $\varepsilon_y = 1/(\partial \ln C/\partial \ln y)$

In figure 9.4, we plot the estimated marginal and average cost curves. The optimal catch, given the prevailing regulation, was 880 tons during 2001. We note the large reductions in unit costs for annual landings up to around 400 tons, while landings above that level do not enjoy scale economies to any larger extent and as noted above, scale diseconomies occur for landings above 880 tonnes.

The optimal annual catch of 880 tons is based on estimates where we have added a 6% user cost of capital to adjust for the low mortgage loans. In table 9.5 we report the optimal catch levels depending on the assumed additional user cost.

Table 9.5. The optimal annual catch depending on additional user cost of capital.

Additional user cost of capital	0%	3%	6%	9%	12%
Optimal catch (tons)	6000	1700	880	670	570

The optimal catch when the additional user cost is excluded and only the actual capital figures are used is way above the highest catch recorded. This is likely a reflection of the regulated open-access regime (Homans and Wilen, 1997) of all Swedish fisheries before 1995. All vessels in the sample are constructed before 1992, with one exception of a mid size vessel built in 1999.

The overall picture is that this industry has the often found L-shaped average cost curve (e.g. Robidoux and J. Lester, 1992) with large returns to scale in the lower interval and then a flat AC curve. The flat AC curve is the reason for the sensitivity of the optimal catch level. We also note that the suggested optimal levels are above the actual landing figures, where the maximum was about 400 tons. As a consequence and to get a conservative estimate, we assume that the optimal landing level is in the range 300-400 tons. If the sampled vessels were replaced by vessels landing 300-400 tons the cost reduction would be almost 40% and about ten vessels of the larger size from the sample instead of 30 could have harvested the same amount of fish, which corresponds to a reduction in GRT of about 25%. Further, assuming that our sample was representative of the Swedish cod trawler fleet in the Baltic Sea at that time and that the trawlers have an equal or better performance than the vessels using fixed gear, the optimal size vessels could have replaced the gill net fishers and landed all of the Swedish quota of cod, which in 2001 was almost 18 000 tons. The gains from landing at a unit cost of SEK 12.50 instead of SEK 20 would lead to a total profit of about SEK 140 millions, which corresponds to almost 40% of the total landing value in 2001, SEK 370 millions.

9.3.Conclusions

In this paper we model an IVQ fishery by assuming that fishers aim at minimizing cost, and apply the model to the Swedish cod fishery in the Baltic Sea. The results indicate an L-shaped average cost curve with considerable scale economies at low levels of output but exhausted economies of scale at output levels of the larger vessels in the fleet. We find that there are substantial gains to be made from adjusting the fleet to enjoy scale economies. It is interesting to note that the larger vessels on average are more profitable despite the prevailing regulation where the weekly allocation system is designed in favor of the smaller vessels. The estimated optimal landing level is sensitive to the chosen additional user cost of capital, but the initial cost reductions from increasing landings from the lower landing intervals are robust. However, the additional user cost is not perceived by individual fishers and the estimates then confirm how regulated open access leads to overcapacity, which has not yet been reduced in the Swedish fishery. Our study indicates cost savings of SEK 140 millions and capacity reductions of about 25% for the given stock level. Recalling the current poor state of the Baltic Sea cod stock it is plausible that the potential rent from a cost minimizing industry exploiting a recovered cod stock are substantially larger. A recovery to what biologists recommend, i.e. 240000 tons, implies an increase of roughly three times the 2001 level. Doubling the stock level for a uniformly distributed species like cod implies a doubling of landings from the same amount of effort. However, a substantial stock recovery should rather be accompanied with further effort reduction, i.e., fleet reduction. The EU has aimed at structural adjustment for more than 20 years through the multiannual guidance programmes, but overcapacity is still a major problem for European fisheries. According to recent estimates there is more than 40 per cent overcapacity in the total EU fleet (DG Fish, 2000). The estimated 25% reduction is for the given stock level, but a recovered stock implies further fleet reduction. In terms of rent, such stock improvements may lead to increased landings and some price reductions, but a moderate assessment of the potential rent for the Swedish part of the cod fishery in the Baltic Sea is in the range SEK 300-400 millions and the corresponding figure for the total cod fishery in the Baltic Sea is then SEK 1000-2000 millions.

An additional feature of a regulated open access, which applies for most Swedish fisheries, is the general uncertainty of a seasonal closure. Most Swedish fishers tend to be risk averse (Eggert and Tveterås, 2004) and the more risk averse they are the more they support the introduction of IVQs (Eggert and Martinsson, 2004). Swedish taxation is asymmetric in the sense that profits are taxed while investments are deductible. The overall outcome of these conditions is that the stochastic nature of fisheries with some very profitable years leads to fishers reinvesting heavily, which often means reducing mortgages, instead of consuming profits. An article in a daily Swedish paper sheds some light on this issue:

> *"The two brothers bought the vessel in 1997 and paid half of the total 14 millions cash. They got an interest free loan of 3 millions from the EU, which is depreciated by 10% annually, and the remaining 4 millions from the bank are completely repaid today. The Sorensson brothers do not have any interest to worry about"* (Göteborgs Posten, 2004)

Given our conservative estimate of the optimal landing size a 25% fleet reduction is desirable and the potential rent from such reduction could be 40% of the total landing value in 2001. These figures may seem high to fisheries managers, but are low or in line with the few similar studies of this area. Dupont (1990, 1991) estimates the potential rent to 42% for the British Columbia salmon fishery and hold that the fleet should be reduced by 50%. Weninger (1998) estimates the optimal fleet reduction to 80% for the Mid-Atlantic surf clam and ocean quahog fishery, but does not provide a measure of potential rent. Asche et al (2003) estimate the potential rent to 60-70% of the landing values given that the fleet is reduced by 70%. Weninger and Waters (2003) study the reef fishery of the Northern Gulf of Mexico and hold that an optimal fleet reduction should exceed 80%. Given the regulated open access nature of Swedish fisheries we note that fishers whenever they find it suitable can target other fisheries elsewhere than the Baltic Sea cod fishery. We could also identify such behavior to some extent in our data sample, on average 20% of the trips had destinations outside the Baltic Sea, which also reflects the over capacity. The structural adjustment programs have at best reduced overcapacity with less than 10%, but mostly served as an income transfer to the remaining vessel owners (Weninger and McConnell, 2000). This study clearly indicates that fleet reduction has to be substantially larger than what has been done within these programs.

Our results indicate that the rent for the Swedish part implies SEK 100-200 millions. The potential gains are of course larger, firstly a build up of the cod stock to three times of the 2001 level would lead to substantial increases. Secondly, the Swedish system uses weekly rations, which means that fishers cannot optimally allocate their trips but are forced to make at least a trip per week to enjoy all possible catch. This is a drawback of this system, which may have other benefits. One potential benefit, not explored in this paper, is a higher level of compliance. Monitoring and enforcement activities in this system induce higher risk of detection, compared to an annual IVQ system, for those who try to exceed their quota allocation. Overall, our assessment is that the Swedish weekly rationing system has mitigated the depletion of the Baltic cod stock, but has not been successful in generating rent. A first step towards such a development would be to explicitly allocate IVQs in all Swedish fisheries and eliminate the incentive to first catch your IVQ and then target non-IVQ species, which is possible behavior today. The greatest merit of the prevailing regulation is probably that it paves the way for necessary changes in Swedish fishery regulation. These changes include a more complete use of IVQs and the introduction of ITQs for some segments of the fishery to facilitate some of the necessary capacity reduction.

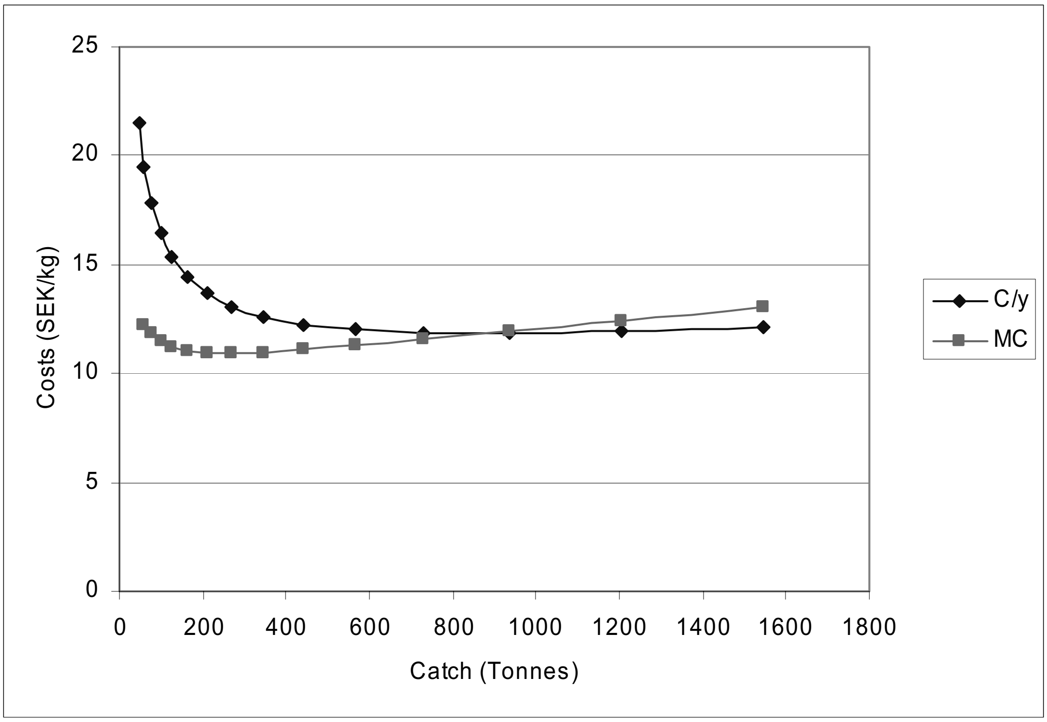


Figure 9.3. Predicted Cost Function for Sample Average Vessel

Optimal catch = 880 tons

10. The Danish Case Empirical

The Danish fisheries are administered by a combination of output-, effort- and capacity-restrictions, as well as technical measures. Access to the fishery is granted to (Danish) citizens who comply with certain criteria regarding experience and income gained through fishery. Fishermen are divided into occupational or partly occupational fishermen determined by the ratio the income obtained by fishery constitutes of the total personal income.

Capacity regulation is connected to the given vessel, which must be registered as an occupational fishing vessel in the Danish vessel register. Each vessel in the register has an exclusive license to fish, given certain capacity specifications in relation to tonnage and engine. Changes in capacity are limited by a set of rules regarding capacity, given the Danish development programme for capacity limits in the Danish fishing fleet derived from EU regulations. Until 2003 effort regulation administered by regulation of days at sea was not applied, but this type of regulation has now been introduced as part of the recovery plan for cod. Days at sea are granted conditional on vessel gear on a monthly basis, and can be transferred between vessels given certain conditions on gear and vessel capacity, measured in engine power.

The output-regulation is a combination of different quota systems. Fishery for quota species in EU waters requires in addition to the vessel license a permit specifying the conditions in terms of species, fishing ground, fishing gear and fishing time. Fishery carried out outside EU fishery territory must generally have a license too. Until 2003 the Danish fishery has most commonly been managed through quotas based on the TAC's for Denmark in a given year. The permits granted to the fishermen to fish the quotas are divided between yearly individual allocations and rations. The yearly allocations are granted to the vessels conditional on vessel size and the historical landings of the vessels. The rations are granted on a monthly, two-weekly or weekly basis and vary with vessel size, gear and target species. Furthermore a new law passed though the Parliament in 2001 offers all Danish fishermen with vessels below 15 m the option to choose individual yearly quotas for all quota species in their catch composition (the same system has been operating for cod in the Baltic Sea since 1994), and the herring fishery is offered ITQ's according to historical rights. For the more important species the management systems are summarized in tables 10.1 and 10.2. The species that are subject to individual vessel allocations are shown in Table 10.1.

The Danish Trawler fleet below 50 GT/GRT, operating in all Danish fishing grounds, in the period 1995-2000 was considered in the Danish study. Data is aggregated on a yearly level for each vessel included in the dataset. Vessels that catch industry species, herring and shrimp have been removed from the dataset. In the remaining fleet the main catch species are cod, flatfish and lobster, although other species are also caught in small amounts. To gain a homogeneous dataset only vessels for which the catch weight of cod, flatfish and lobster constitute more than 2/3 of the total catch weight have been included in the analyses. Moreover a number of much specialised vessels are removed from the dataset, i.e. vessels that primarily target cod, flatfish or lobster. This leaves 176 observations, distributed over 77 individual vessels.

Table 10.1. Species subject to individual vessel allocations in the Danish output-regulation system.

Quota system	Species	Operating area	Vessel type	Notes
Ration	Cod	All	All	
Yearly allocation	Cod	The Baltic sea	All	
Yearly allocation	Cod, sole, plaice	North Sea, Skagerrak and Kattegat	< 15 m	Inshore fishery system
Until 2003 IVQs From 2003 ITQs	Herring	North Sea, Skagerrak and Kattegat	All with historical rights	Running for 5 years from 2003. Possible extension for 3 additional years.
Ration	Herring	The Baltic sea and the belts	License, but allowed for all	
Yearly allocation	Mackerel	North Sea and Skagerrak	All with historical rights	Change to ITQ under consideration.
Ration	Cod fish and flat fish	North Sea, Skagerrak and Kattegat	All	
General quota	Industry species, plaice and certain cod fish	North Sea, Skagerrak and Kattegat	All	Until 50% or 70% of the quota has been caught, then rations.

As mentioned above the most important species, regarding catch weight, for the selected fleet are cod, flatfish and lobster. The average catch revenues and catch weights of these species are shown in table 10.2. It is seen that cod was the most important species in terms of catch weight in all years, and was the most important species in terms of revenue in 1995, 1997 and 1998, while lobster had the highest average catch revenue in the remaining years.

Table 10.2. Average yearly catch revenue (1000 DKK) and weight (tones) per vessel for the sample fleet of Danish trawlers below 50 GRT.

Year	1995	1996	1997	1998	1999	2000	All Years
Revenue:							
Total	1032 (±560)	1136 (±560)	1276 (±679)	1292 (±698)	1411 (±605)	1409 (±787)	1287 (±677)
Cod	350 (±303)	342 (±361)	517 (±452)	663 (±526)	540 (±500)	510 (±453)	503 (±456)
Lobster	308 (±402)	443 (±432)	403 (±469)	348 (±482)	553 (±552)	589 (±602)	457 (±513)
Flatfish	323 (±288)	318 (±277)	311 (±235)	246 (±188)	280 (±192)	275 (±202)	288 (±225)
Other	51 (±46)	34 (±32)	46 (±45)	34 (±43)	38 (±42)	35 (±44)	39 (±42)
Weight:							
Total	75 (±43)	77 (±47)	93 (±54)	94 (±54)	76 (±45)	72 (±45)	81 (±48)
Cod	43 (±37)	46 (±47)	59 (±49)	62 (±50)	46 (±46)	41 (±40)	49 (±45)
Lobster	7 (±9)	10 (±9)	7 (±9)	6 (±9)	8 (±8)	9 (±9)	8 (±9)
Flatfish	20 (±15)	17 (±12)	22 (±15)	23 (±14)	19 (±13)	19 (±13)	20 (±14)
Other	5 (±4)	4 (±4)	5 (±5)	3 (±4)	3 (±3)	3 (±3)	4 (±4)

Note: Numbers in the parentheses are the standard deviations.

Extensive data are available on the expenses of the sample fleet in question, comprising disaggregated information on maintenance, sales costs, running costs, depreciation etc. In applications it is optimal only to employ some of the expenses, and to add some of the expenses into aggregated cost-variables. Three aggregated cost variables were therefore constructed: wage per crew member, overall running costs per days at sea and capital costs per gross tonnage. Table 10.3 shows the averages and standard deviations for these three cost variables and the total short run costs for the selected fleet. Moreover the average number of crew members, the average number of days at sea, and the average vessel tonnage are shown.

Table 10.3 Descriptive statistics for Danish trawlers below 50 GRT targeting cod, lobster and flatfish in the period 1995-2000.

	Short Run total Costs	**Wage per crew member**	**Crew members**	**Running costs per days at sea**	**Days at sea**	**Capital costs per tonnage**	**Tonnage**
1995	1044 (±502)	250 (±107)	2 (±1)	2 (±1)	151 (±45)	8 (±4)	20 (±7)
1996	1191 (±517)	264 (±79)	2 (±1)	3 (±2)	161 (±36)	8 (±4)	21 (±9)
1997	1301 (±610)	284 (±84)	2 (±1)	3 (±1)	168 (±41)	9 (±7)	20 (±8)
1998	1306 (±612)	292 (±68)	2 (±1)	3 (±2)	171 (±35)	8 (±3)	21 (±8)
1999	1443 (±534)	323 (±81)	2 (±1)	3 (±2)	166 (±30)	8 (±3)	22 (±8)
2000	1560 (±746)	334 (±91)	2 (±1)	4 (±1)	168 (±36)	10 (±6)	22 (±10)
All Years	1342 (±623)	297 (±89)	2 (±1)	3 (±2)	165 (±37)	9 (±5)	21 (±12)

Note: Numbers in the parentheses are standard deviations. All costs are in 1000 DKK.

10.1. Empirical Specification

In this study it is estimated a multioutput Generalized Leontief cost function. Following the Kumbhakar (1994) and Larsson (2003), this has the form:

$$
\begin{aligned}
&VC_L^M(y_1,...,y_M,w_1,...,w_N,k,t)=\\
&\quad\left(\sum_{r=1}^{M}\delta_r y_r\right)\left[\sum_{i=1}^{N}\sum_{j=i}^{N}b_{ij}w_i^{1/2}w_j^{1/2}+t\sum_{i=1}^{N}b_{it}w_i+t^2\sum_{i=1}^{N}b_{itt}w_i+k\sum b_{ik}w_i+k^2\sum_{i=1}^{N}b_{ikk}w_i\right]+\\
&\quad\sum_{i=1}^{N}a_i w_i+t\sum_{i=1}^{N}a_{it}w_i+k\sum_{i=1}^{N}a_{ik}w_i+\sum_{i=1}^{N}\sum_{r=1}^{M}\sum_{s=r}^{M}\beta_{irs}w_i y_r y_s
\end{aligned}
$$

(10.1)

A fixed factor is added in standard fashion.

10.2. Estimation results

The variable short run generalised Leontief Cost function (10.1) has been fitted to data with the *N=2* variable input prices given in table 10.1 (wages and running costs), the *M=4* output groups given in table 10.2 (cod, lobster, flatfish, other species) and a fixed capital input *k*, i.e. tonnage. The time parameter *t* is running from *t=1* (1995) to *t=6* (2000). The variable cost function (10.1) is estimated together with the two input demand equations for days at sea and average number of crew members. I.e. the days at sea are equal to the derivative of (10.1) with respect to the running costs, and the average number of crewmembers is equal to the derivative of (10.1) with respect to wages. The three equations are estimated using seeming unrelated regression (SUR). To estimate all three functions together instead of only the cost function increases the accuracy of the estimated function parameters. In the estimation the restrictions that (i) $\beta_{irr} > 0$ and (ii) $\sum_{i,r,s} \beta_{irs} > 0$ (notation as in equation 10.1) have been included for *i=1,2*, and *r=1,…,4*, to ensure that the cost function is increasing as a function of each of the output variables, as well as along any ray vector $n(y_1^0,...,y_4^0)$. The model has been estimated for normalised values of the short run variable costs, the outputs and the capital input, i.e. all values have been divided by their average value over all years.

The cost function estimation was run in two steps. The first included all the parameters given in equation (10.1). Inspection of the standard deviations of these parameters indicated that the time variable did not have any significant influence on the model, and that the cross terms between the capital input (tonnage) and the running cost per days at sea did likewise not influence significantly on the model. To reduce the multicollinarity of the model, and hereby increase the accuracy of the significant model parameters, a second model was estimated in which all time dependence and cross terms between capital and running costs were set equal to zero. The SUR results for this variable short run Leontief cost function, estimated for the dataset described above, are shown in table 10.4. The model seems well specified. The R^2 and adjusted R^2 values are in the neighbourhood of 0.5 indicating some scatter in the explanatory power of the chosen model. This is due to the fact that the model has been observed to overestimate the true variable cost to some degree.

Table 10.5 shows the own and cross price elasticities for the variable inputs. The elasticities are calculated for average (over all years) input prices, output values and capital. It is seen that all elasticities have the expected signs.

Table 10.4. Parameters of the restricted generalised Leontief variable cost function.

Estimated for the full sample of data for the fleet of Danish trawlers below 50 GRT targeting cod, lobster and flatfish in the period 1995-2000. Notation is as in equation (15).

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
δ_2	1.4842***	b_{1k}	-0.2649***	β_{111}	0.0062	β_{211}	0.0231***
δ_3	1.8169***	b_{2k}	0	β_{112}	0.0188	β_{212}	0.0001
δ_4	0.4972**	b_{1kk}	0.0557***	β_{113}	0.0542**	β_{213}	-0.0348**
b_{11}	-0.0051	b_{2kk}	0	β_{114}	0.0464***	β_{214}	-0.0098
b_{12}	0.2637***	a_1	0.1419	β_{122}	0.0206**	β_{222}	0
b_{22}	-0.0690***	a_2	0.3636***	β_{123}	0.0901***	β_{223}	-0.0050
b_{1t}	0	a_{1t}	0	β_{124}	0.0093	β_{224}	-0.0139*
b_{2t}	0	a_{2t}	0	β_{133}	0	β_{233}	0
b_{1tt}	0	a_{1k}	0.6630***	β_{134}	-0.0068	β_{234}	-0.0056
b_{2tt}	0	a_{2k}	0	β_{144}	0	β_{244}	0
R^2		0.52		Adjusted R^2		0.49	

Note: '***', '**' , '*' indicates that the parameters are significantly different from zero at the 1%, the 5% and the 10% level
The subscripts for inputs are '1'=wages, '2'=running costs. The subscripts for outputs are '1'=cod, '2'=lobster, '3'=flatfish, '4'=other species.

Table 10.5 Own and cross price elasticities for the generalised Leontief variable cost function (10.1).

Parameters given in table 10.7.

	Wage expenses	Running costs
Labour	-0.49	0.49
Days at sea	0.50	-0.50

Table 10.6 shows the product specific returns to scale (PSRTS) for each of the four outputs, together with the overall returns to scale and the economies of scope, all evaluated at average (over all years) input prices, capital and output values. It is seen that the product specific returns to scale are less than unity for cod and lobster, indicating that the average cost increases when the catch of these two species increases separately. Contrary to this the PSRTS for flatfish and other species are both equal to unity. The overall returns to scale is 4.60, indicating strong overall economies of scale for the fleet. I.e. the average (per unit output) cost decreases fast when the outputs are increased along a ray through the vector of

average outputs. Finally it is seen that the economies of scope is 3.67, indicating that the cost of targeting the four output groups simultaneously is 3.7 times lower than the cost of targeting each output group separately. This is to be expected, as it is difficult and thus costly for trawlers to target one specific species.

Table 10.6 Product specific returns to scale (PSRTS) for each of the four outputs, overall returns to scale (ORTS) and economies of scope (ESCP), for the fleet of Danish trawlers below 50 GRT targeting cod, lobster and flatfish in the period 1995-2000.

ORTS	$PSRTS_1$	$PSRTS_2$	$PSRTS_3$	$PSRTS_4$	ESCP
4.60	0.72	0.83	1	1	3.67

Note: The subscripts for outputs are ‘1’=cod, ‘2’=lobster, ‘3’=flatfish, ‘4’=other species.

The total short run cost function is the sum of the variable cost function estimated above and the capital cost times the capital input (tonnage). As the variable cost function has been estimated for normalised values of outputs, input prices and short run variable costs, it has been scaled up with the average of the observed variable costs when constructing the total short run cost function.

In order to find the long run (LR) equilibrium output, i.e. the optimal quota size in the long run (cf. the discussion presented above), the marginal cost equation has been solved under the assumption that the yearly individual vessel quota $(y_1^0,...,y_4^0)$ for the selected fleet is equal to the vector of average catch weights over the total period, and that the vessels will only catch the four species along a ray through this vector. Moreover average (over the total period) values of variable input prices, capital input and capital cost have been used in the estimations.

If the yearly individual vessel quota is increased by the factor *r* the number of vessels in the fleet must be decreased by a factor *1/r* such that the total catch of the fleet does not exceed the total allowable catch (TAC). Thus when the individual vessel quota is increased by the LR expansion factor *r* noted above, the number of vessels in the fleet must therefore on the average be reduced by *1/r=1/1.11=0.90.* I.e. 90% of the fleet should be maintained after LR readjustment of the individual quotas.

The second economic equilibrium discussed in connection with assessing the capacity of the fleet is the constant returns to scale (CRS) equilibrium presented above. In this case the aim is to identify the output vector for which the average cost (per unit output) is minimised, or correspondingly the output vector for which the overall returns to scale (ORTS) is equal to unity. As in the LR case it is assumed that the individual vessel quota $(y_1^0,...,y_4^0)$ of the four species is equal to the vector of average catches over the total period (cf. table 10.5), and that the average vessel will only catch the four species along a ray through this vector, i.e. will only catch $s \cdot (y_1^0,...,y_4^0)$ for some positive factor *s*. When ORTS is set equal to unity under this assumption, using average values of the variable input prices and the capital, it is found that the average catch vector must be multiplied with the factor *s=2.56* for the average vessel to reach minimum average cost. This corresponds to a reduction of the fleet by a factor *1/2.56=0.39.*

Finally in order to find by which amount the average catch vector must be increased to reach maximum profit (MP), one maximise long run profits with respect to output expansion factor *p*, again using the vector of average catch weights $p \cdot (y_1^0,...,y_4^0)$ over the total period as individual vessel quota vector, average input prices, capital and tonnage and furthermore average output prices over the total period for the four species in question. These are p_1=10.63 DKK per kilo Cod, p_2=57.59 DKK per kilo Lobster, p_3=15.68 DKK per kilo Flatfish and p_4=10.72 DKK per kilo other species. The resulting maximum profit expansion factor is *p=3.06*, corresponding to a fleet reduction factor of *1/3.06=0.33.*

The above results are summarised in table 10.7.

Table 10.7 Optimal individual vessel quota expansion factors for the fleet of Danish trawlers below 50 GRT targeting cod, lobster and flatfish in the period 1995-2000.

	LR	**CRS**	**MP**
Quota expansion factor	1.11	2.56	3.06
Fleet reduction factor	0.90	0.39	0.33

Note: ‘LR’=Long Run, ‘CRS’=Constant Returns to Scale, MP=Maximum Profit

When the individual quota of a vessel is increased the yearly revenue of the vessel will clearly increase. The yearly cost of the vessel will also increase as the cost is an increasing function of the catch, but the average (per output weight) cost will decrease, and the vessel is thus, as discussed above, moving towards increasing yearly profit. Table 10.8 shows the observed average (per vessel) yearly revenues, costs and profits of the vessels in the sample, together with the long run (LR), constant returns to scale (CRS) and maximum profit (MP) optimal yearly revenues, costs and profits. These are evaluated when the yearly quotas of the vessels have been increased by the LR, the CRS and the MP expansion factors given in table 10.10.

Table 10.8 Observed average (per vessel) yearly revenues, costs and profits, together with long run (LR), constant returns to scale (CRS) and maximum profit (MP) optimal values of these for the fleet of Danish trawlers below 50 GRT targeting cod, lobster and flatfish in the period 1995-2000.

	Observed	LR	CRS	MP
Average revenue	1287	1429	3295	3938
Average costs	1342	1712	2810	3419
Average profit	-55	-283	485	509

Note: Average costs, profits and revenues are averaged per vessel. All measures are in 1000 DKK.

Table 10.8 firstly shows that the observed average vessel profits are close to zero for the fleet in question, i.e. that the profit of the fleet is dissipated. This is believed to be caused by the high overcapacity for the fleet, which has been indicated by the above estimations. The table further shows that the average vessel should be able to land a maximum profit of ~500.000 DKK a year, if the individual vessel quota is adjusted to the MP optimal amount. This is not an unrealistic measure of the profit, as the highest observed profit in the fleet is ~640.000 DKK. However, if the individual vessel quotas are increased to reach the maximum profit equilibrium, the fleet should be reduced to ~33% of its present size. Such a reduction does even at the present, seeing that decommissioning has been a vital part of capacity adjustment measures, seem quit severe. It must however be remembered that the MP quota expansion factor, and thus the MP fleet reduction factor, are both evaluated from the assumption that the individual vessel quota is equal to the vector of average catches for the fleet. It is clear that the individual quotas vary, depending on the individual vessel characteristics. The individual vessel quota expansion factors will therefore also vary, and the fleet reduction factor should therefore be seen as an upper limit of fleet reduction following a possible increase in individual vessel quotas, more than a direct recommendation for fleet reduction.

10.3. Conclusion

This paper presents an analysis of the economic capacity (potential profit) of the fleet of Danish trawlers below 50 GRT targeting cod, lobster and flatfish in the period 1995-2000. The fleet is regulated through individual quotas and the revenue of the vessels in the fleet is consequently fixed. As it can therefore be assumed that the fishermen in this fleet are cost minimises rather than profit maximisers, the fleet capacity has been analysed through a dual cost function approach, using the generalised Leontief cost function. As the catch of the fleet is multi species an extended version of the Leontief cost function, including multiple outputs, has been applied.

The cost function for the fleet has been estimated using cod, lobster, flatfish and other species as outputs. Variable input costs included in the estimation are wages per crewmember and running costs per days at sea. The capital input, represented through the tonnage, is assumed to be quasi fixed, and a restricted form of the generalised Leontief cost function has therefore been applied.

Three measures of economic capacity have been calculated for the fleet. The first evaluates how much the observed individual vessel quotas must be increased for the average vessel to operate at long run (LR) equilibrium cost. The second measure evaluates how much the quotas must be increased for the average vessel to have minimum average cost, or correspondingly constant returns to scale (CRS). And finally the third measure evaluates how much the individual quotas must be increased for the average vessel to have maximum profit (MP). In all three cases it has been assumed that the average vessel in the fleet will catch the four species (cod, lobster, flatfish, other species) in fixed proportions, i.e. that the optimal quota vector is some optimal expansion factor times the observed quota vector. Corresponding to this it is evaluated how much physical overcapacity there is in the fleet in each of the three cases, i.e. how much the number of vessels in the fleet must be reduced when the individual vessel quotas are increased, in order not to exceed the total allowable catch (TAC) for the fleet.

It has been shown that the average individual vessel quota vector must be multiplied with a factor ~1.1 to reach long run equilibrium, with a factor ~2.6 to reach CRS and with at factor ~3.1 to obtain maximum profit. In the latter case the average vessel should be able to land a potential maximum profit of ~500.000 DKK. When the individual vessel quotas are increased to the maximum profit level, the fleet should correspondingly be reduced to 33% of its present size. This is quit a severe reduction, and should thus more be seen as an upper limit of fleet reduction than an actual recommendation.

Generally the results of the analysis indicate that the fleet at present is operating at severe economic overcapacity, leading to profit dissipation in the fleet. The analysis has however shown that positive profit can be generated if the vessel quotas are increased, followed by a reduction in the number of vessels in the fleet in order not to exceed the total allowable catch of the fleet.

11. The UK Case

11.1. Background on the fisheries examined

As with the other fleets operating in EU waters, the UK fleet is currently regulated through a series of input and output controls. In addition, a series of technical measures (e.g. mesh size restriction) are in place. In this section, a brief review of the key management instruments employed in the UK to limit fishing capacity is presented. Technical measures are not discussed, as these are not directly related to capacity.

The capacity-related input controls are largely based on licence limitations, which restrict entry to the fishery, and a unitisation system that restricts boat replacement and is used as the basis for decommissioning programmes. The unitisation system is based on Vessel Capacity Units (VCU's) that are a combination of engine power and vessels size. The number of VCUs requried to be held by a vessel is given by: VCU = length*breadth (in metres) + 0.45*engine power (in kW). In order to replace a vessel in the fleet, an appropriate number of VCUs (determined by the size of the new vessel) need to be purchased from other unit holders, thereby ensuring that the physical 'capacity; of the fleet is contained. Further, forfeiture of an additional certain percentage of units is also required to offset the potential gains in efficiency through introducing a new vessel to the fleet. Vessel decommissioning schemes in the UK – of which there have been several under the series of multi-annual guidance programme (MAGPs) – have been based on purchasing VCUs rather than vessels *per se*. More recently, restrictions on the number of days-at-sea have been implemented in certain fleet segments as part of the EU's cod recovery strategy.

Output controls are also imposed on the fleet for key fish species and Nephrops. Aggregate total allowable catches are set at the European level for each stock of the key species and distributed to the individual Member States in relatively fixed proportion. In the UK, these are further distributed to individual vessels greater than 10m in length in the form of fixed quota allocations (FQA). The under 10m fleet are not subject to individual quota controls, but are generally subject to catch limits that vary month to month. The under 10m fleet segment dominate the industry in terms of vessel numbers (74 per cent in 2002 (DEFRA 2003)), but contribute less than 10 per cent of the value of the catch.

Although the UK does not formally have an ITQ system, the management system has many similarities. Firstly, there exists a generally accepted system of quota allocation at the individual vessel level, at least for the offshore (over 10m) sector which accounts for the great majority of landings. Secondly, the fishing industry has succeeded in developing ways of trading quota under the current quota management arrangements. Briefly, although each over 10m vessel has a FQA, those vessels belonging to a producer organisation (PO) – which includes most vessels targeting quota stocks – are able effectively to lease quota to other vessels either in the same or a different PO. Quota trades between vessels in different POs are accomplished via long-standing arrangements with the Government for quota swaps between POs. Not all POs, though, are involved in quota trading to the same extent. Some POs operate internal ITQ systems for some or all stocks, while others still pool members' FQAs and allocate flat-rate monthly catch limits, although members may be able to "top up" their monthly allowances by leasing in quota. Although individual vessels each have a notional FQA, the basis of the quota management system in the UK remains the allocation of quota to POs, not individual vessels.

Quota trading is also possible as a result of licence aggregation, or removing vessels from the fishery, either through decommissioning or voluntary withdrawal. Trade in this way is restricted, as the whole FQA package must remain intact when transferred to the new vessel. However, the new FQA owner may lease out unwanted 'surplus' quota.

The key fleet segments examined in this study was the UK demersal fleet. These fleets primarily catch species that are subject to quota controls, but also catch a number of non-quota species. The UK demersal trawl fleet consists of three main activities – otter trawling, danish seining and Nephrops trawl. Otter trawlers and danish seiners both target similar whitefish species, but using different types of trawl gear, while Nephrops trawlers target primarily Nephrops (also known as scampi, langoustine and Dublin Bay prawns). In 2002, there were 929 demersal trawlers over 10 metres in length (DEFRA 2003), of which around 230 were Nephrops trawlers. Between 1999 and 2002, the over 10m demersal trawl fleet decreased by almost 25 per cent as a result of decommissioning programmes and voluntary retirement as a result of the adverse economic conditions facing the industry.

The whitefish trawlers (otter trawlers and seiners) operate primarily in the North Sea, English Channel, Celtic Sea and Irish Sea targeting cod and other whitefish species. The catch composition varies in the different areas, with the English Channel trawlers being characterised by a relatively high proportion of non-quota species in the catch. In contrast, catch in the North Sea is dominated (i.e. in excess of 90 per cent) by quota species. The Nephrops trawlers are predominantly based in Scotland, and operate in the North Sea as well as off the west coast of Scotland. Nephrops are also caught in the Irish Sea, a high proportion of which is caught by vessels moving down from the west coast of Scotland on a seasonal basis.

11.2. Data

Data on costs, revenues and physical characteristics for 67 UK demersal whitefish trawlers relating to the 2001 financial year were available, representing roughly 9 per cent of the total whitefish trawl fleet. These vessels were all above 10m in length. A summary of the key characteristics of the data set is presented in Table 11.1 Data on a small number of vessels under 10m were also available. As these vessels are not subject to the same individual quota regulations as the larger vessels these data were not used. The data were collected through personal interview by the Seafish Industry Authority for the North Sea and Irish Sea, and by CEMARE for the English Channel.

Table 11.1. Key characteristics of the sample, 2001

Fleet segment	No of obs.	Average length (m)	Average engine power (kW)	Average crew number	Average revenue (£)	Average total costs (£)
Irish Sea trawlers	4	20.0	242	2.0	140005	90596
North Sea trawlers	42	23.6	439	5.4	436255	271849
English Channel trawlers	8	14.0	224	2.0	115504	61207
Seiners (NS and EC)	13	25.4	411	5.0	399941	257121
Total	67	22.6	396	4.7	373224	311015

The individual cost items were aggregated into four cost categories: crew costs, running costs, capital costs and 'other' costs. Crew costs were the payments to crew. Running costs consisted of fuel costs, ice, box charges and food. Information on the capital value of the vessel was not provided by most skippers. However, where information on capital values was provided, this was generally based on the insurance value of the vessel. The insurance cost was therefore used as a proxy measure for capital costs. All other costs were included in the 'other' cost category.

Data on input prices were not available, but proxy measures of input prices were derived from the survey data. The crew price was derived from total crew payments divided by the number of crew. This is a potentially misleading measure, as crew are paid a share of the net revenue (i.e. revenue less running costs). As a result, a relatively high crew price may indicate a relatively high labour productivity, but may also be a consequence of 'luck' (i.e. higher than expected catches). Running costs are a function of both the amount of time fished and the size of the vessel. Information on fishing effort (e.g. days fished) was not available for most of the vessels. The input price associated with running costs was assumed to be the running cost of the vessel if it was operating at full capacity divided by the number of vessel capacity unit (VCUs). An assumption was made that running costs were proportional to the level of capacity utilisation.[64] Hence the running cost if fully utilised was given by the observed running cost divided by the capacity utilisation rate.[65] The prices of capital and other inputs were also derived from the costs information and the physical boat characteristics. Various combinations of measures were tried. The physical measures that resulted in the lowest variance in input prices were length for 'other costs' and the VCUs for capital costs. Input prices for other costs and capital costs were therefore taken as other costs per unit length and insurance cost per VCU.

The costs and revenue values were normalised (after appropriate adjustments to account for capacity utilisation and efficiency) such that the mean values of the normalised data were 1.

[64] Capacity utilisation was estimated using Data Envelopment Analysis (DEA).

[65] This essentially assumes constant returns to fishing effort. Previous studies of revenue functions for the North Sea and English Channel demersal whitefish trawl fleet have found the production elasticity associated with days fished is around 1 (one) (see Pascoe, Tingley and Mardle 2003), suggesting that such an assumption is realistic.

11.3. UK Emprical results

The UK analysis used a combination of DEA and the cost function approach described in Chapter 11.2. The DEA approach was used to estimate a primal measure of capacity, and also used to modify the data in order to estimate the long run cost function.

11.3.1. DEA: Capacity utilisation, efficiency and returns to scale

The DEA model was run with revenue as the output measure and length and engine power as the fixed inputs. Fuel costs, which were assumed to be proportional to days fished, were included as the variable input for the purposes of estimating technical efficiency and the 'unbiased' estimate of capacity utilisation. Estimates of capacity utilisation were also obtained for the case of both constant returns to scale and variable returns to scale. The ratio of these measures provides a measure of the scale efficiency.

A summary of the DEA results is presented in Table 11.2. On average, the vessels were operating at around 87 per cent capacity and at around 69 per cent efficiency. If the vessels operated at both full capacity and efficiency, average output could potentially increase by 67 per cent (i.e. 1/0.6). In contrast, if the vessels were fully utilised but remained at their current (in)efficiency levels, potential output could increase by around 15 per cent on average.

Scale efficiency was estimated relative to both capacity utilisation and technical efficiency. The seiners and North Sea otter trawlers were, on average, closer to the 'optimal' scale. The optimal scale in this case is defined where constant returns to scale exist. Both these boat groups were larger, on average, than the other two in terms of length and engine power as well as in terms of output.

Table 11.2. Average capacity utilisation and technical efficiency

	Otter Trawlers			Seiners	All boats
	Irish Sea	North Sea	Channel		
Fully efficient CU ($1/\theta_1$)	0.53	0.61	0.68	0.54	0.60
Technical efficiency ($1/\theta_2$)	0.59	0.68	0.79	0.67	0.69
Capacity utilisation (CU*) (θ_2/θ_1)	0.88	0.89	0.86	0.82	0.87
Scale efficiency: CU ($\theta_{1,VRS}/\theta_{1,CRS}$)	0.71	0.88	0.46	0.94	0.83
Scale efficiency: TE ($\theta_{2,VRS}/\theta_{2,CRS}$)	0.83	0.92	0.70	0.96	0.90

A measure of returns to scale can be derived from the sum of the weights from the CRS technical efficiency model. Only four boats were found to be operating at the optimal scale, with three boats operating at above the optimal scale (and therefore subject to decreasing returns to scale). The remaining vessels were all found to be operating with increasing returns to scale. Of the four boats operating at the optimal scale, only 2 were both fully efficient and operating at full capacity. These vessels where 26m and 30m in length with respective engine powers of 750kW and 500kW, and respective revenues of £1.16 and £0.97m (an average revenue of £1.06m). While they were at the top end of the vessels in the fleet (in terms of size), they were not the largest vessels.

11.3.2. Cost function

The cost function was estimated excluding the capital share equation in order to avoid singularity. Three variants of the model were run using different manipulations of the data. The first run was assuming the industry was in a long-run equilibrium. The second run took into account capacity under-utilisation and the revenue, crew and running costs were re-estimated. The third run took into account the existence of inefficiency as well as capacity under-utilisation. In this run, revenues and crew costs were increased to take into account both of these factors while running costs were increased to take into account the increased utilisation only.

The parameter estimates from the three model runs are presented in Table 11.3. In all three models, most parameters were significant at the 1 per cent level. The adjusted R^2 values were also reasonably high for the cost function itself, but less so for the share equations. While the adjusted R^2 values varied for the different models, these cannot be compared as the values of the dependent variable also differed in each model run.

Table 11.3. Results from econometric analysis

	Base Run		Full capacity utilisation		Technically efficient full CU	
	Coeff	St. Err.	Coeff	St. Err.	Coeff	St. Err.
Constant	-0.023	0.020	-0.018	0.028	-0.029	0.030
Crew	0.343	0.009 ***	0.357	0.011 ***	0.429	0.014 ***
Running	0.240	0.006 ***	0.243	0.004 ***	0.196	0.005 ***
Other	0.349	0.006 ***	0.327	0.006 ***	0.278	0.005 ***
Capital	0.068	0.006 ***	0.073	0.006 ***	0.097	0.014 ***
Revenue	0.549	0.030 ***	0.630	0.050 ***	0.754	0.064 ***
Crew^2	0.003	0.013	0.024	0.010 **	0.051	0.009 ***
Running^2	0.065	0.013 ***	0.101	0.008 ***	0.096	0.008 ***
Other^2	0.100	0.014 ***	0.046	0.009 ***	0.039	0.011 ***
Capital^2	0.017	0.010 *	0.016	0.009 *	-0.003	0.019
Revenue^2	0.023	0.017	0.069	0.023 ***	0.120	0.021 ***
Crew*running	-0.019	0.022	-0.056	0.010 ***	-0.085	0.007 ***
Crew*other	-0.061	0.019 ***	-0.057	0.012 ***	-0.082	0.007 ***
Crew*capital	0.074	0.017 ***	0.066	0.010 ***	0.065	0.018 ***
Crew*revenue	0.014	0.016	0.019	0.017	0.031	0.020
Running*other	-0.070	0.018 ***	-0.042	0.012 ***	-0.021	0.014
Running*capital	-0.040	0.017 **	-0.104	0.013 ***	-0.085	0.020 ***
Running*revenue	0.053	0.013 ***	-0.002	0.010	0.001	0.011
Other*capital	-0.069	0.020 ***	0.007	0.016	0.026	0.025
Other*revenue	-0.100	0.016 ***	-0.041	0.013 ***	-0.030	0.014 **
Capital*revenue	0.033	0.013 **	0.024	0.013 *	-0.002	0.025
Irish	-0.008	0.062	-0.001	0.093	-0.092	0.087
Channel	-0.206	0.053 ***	-0.162	0.080 **	-0.079	0.077
Seine	0.042	0.034	0.001	0.050	-0.016	0.049
Adjusted R^2						
Total costs		0.969		0.934		0.901
Running share		0.573		0.723		0.505
Other share		0.380		0.562		0.561
Crew share		0.150		0.245		0.189

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

From the base run in Table 11.3, the production structure was non-homothetic as the coefficients β_{iy} where generally significantly different from zero. In contrast, when the output and input prices were adjusted to reflect full capacity utilisation (both efficient and inefficient), homothetic production was generally observed, the exception being the ‘other’ costs.

The estimated partial own and cross price elasticity for the demand for factor *i* are presented in Table 11.4. As would be expected, the own price elasticity was negative for each input and the cross price elasticities were generally positive indicating the potential for substitution. The exception to this was capital and running costs, which were found to have a complementarity relationship. As running costs are a function of both the level of capital and its utilisation, an increase in capital prices would lead to lower levels of capital and, consequently, also lower running costs.

Table 11.4. Own and cross price elasticities for demand for the factor inputs

	Crew		Running		Other		Capital	
Base run								
Crew	-0.650	***	0.177	***	0.177	***	0.288	***
Running	0.260	***	-0.489	***	0.054		-0.104	
Other	0.170	***	0.035		-0.364	***	-0.123	**
Capital	1.401	***	-0.343		-0.621	**	-0.683	***
Full CU								
Crew	-0.569	***	0.094	***	0.168	***	0.243	***
Running	0.139	***	-0.344	***	0.156	***	-0.359	***
Other	0.190	***	0.119	***	-0.535	***	0.084	*
Capital	1.414	***	-1.410	***	0.434	*	-0.678	***
Full TE CU								
Crew	-0.425	***	0.024		0.098	***	0.192	***
Running	0.055		-0.330	***	0.171	**	-0.359	***
Other	0.166	***	0.128	**	-0.583	***	0.146	
Capital	1.687	***	-1.400	***	0.761		-0.997	***

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

The returns to scale derived at the mean prices and output levels for each model is given in Table 11.5. In all three models, increasing returns were found at the mean. In the base model, the optimal vessel is 17,020 times greater than the current average sized vessel, suggesting an optimal vessel length or around 254km – approximately half the southern UK coastline. Despite this magnitude, the scale factor is not significantly different to zero. In contrast, if considering fully efficient and fully utilised vessels, the optimal scale is about 2.8 times the current average sized vessel, with the value being statistically significant.

Table 11.5. Estimated returns to scale, UK fleet

	Base Run		Full capacity utilisation		Technically efficient full CU	
	Coeff	St. Err.	Coeff	St. Err.	Coeff	St. Err.
Returns to scale	1.822	0.099 ***	1.588	0.126 ***	1.327	0.111 ***
Scale factor	17020	125869	14.599	16.321	2.793	1.178 **

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

From the DEA analysis, the average of the 'optimum' level of output was £1.04m. The vessels from which this average was obtained were both fully efficient and operating at full capacity. From the cost function analysis, the optimal vessel size (if fully efficient and fully utilised) was 2.793 times larger than the current average vessel. Given that the current average vessel if full efficient and fully utilised would produce revenue of £0.625m, the optimal vessel size would produce an output of around £1.74m.

Although the cost function estimate of optimal yield is 67 per cent greater than the DEA estimate, the lower DEA estimate of optimal output is within the 95 per cent confidence interval of the corresponding cost function estimate. Hence, the two estimates are not statistically significantly different. The DEA estimate of optimal production, by the nature of its calculation, is restricted to be within the range of the available data. Also, the DEA estimate is based on a primal output oriented function with output maximisation the implicit objective. In contrast, the cost function derived estimate of optimal production is not restricted to fall within the range of observed output levels, and the dual function has the objective of minimising costs as well as maximising output in order to maximise profits. However, extending beyond the range of the data creates problems for obtaining reliable and robust estimates. The translog function underlying the cost function is lest robust the further the variable values deviate from 1.

These difficulties in obtaining reliable estimates not withstanding, estimates of the profits associated with the "optimal" scale vessels are presented in Table 11.6. These are not true rents, as the non-cash capital costs (i.e. economic depreciation and opportunity cost of capital) have not been taken into account in the estimation of total costs. However, they provide an indication as to the potential increase in vessel profits that may occur through restructuring.

From Table 11.6, if the vessels tend over time to move to the optimal scale identified by the DEA, then the fleet would need to reduce by nearly two thirds in order to enable the vessels to operate at full capacity (assuming also full efficiency). In contrast, if the vessels tend to increase in size over time to the optimal scale identified by the cost function, the fleet size would need to reduce by almost 80 per cent.

Table 11.6. Estimated revenues, costs and profits

	Current "average" vessel	DEA "optimal" vessel	Cost function "optimal" vessel
Revenue (£m)	0.373	1.065	1.747
Costs (£m)	0.311	0.633	1.182
Profits (£m)	0.062	0.431	0.565
Profits as proportion of revenue (%)	16.6	40.5	32.4
Potential fleet reduction (%)	-	65	79

12. Multi-Output Industry with Output Restrictions

Many of the worlds' fisheries have been regulated with quota restrictions based on concerns for negative stock effects from over harvesting and reduced economic efficiency under alternative regulatory schemes.[66] However, in most cases quotas are set only for the most valuable species and on a species-by-species basis within a multi-species fishery. Hence, one can question the efficiency of regulations given that the multi-species nature of the fishery is not taken into account. An additional issue in fisheries is that quota restricted vessels with idle capacity are likely to target unrestricted species. This increased fishing pressure on unrestricted species can have substantial negative environmental effects.

In this chapter we provide an empirical analysis of a fishery were some but not all species are regulated with quotas. The fishery to be investigated is a group from the Norwegian purse seine fleet, a fleet that harvests a number of different fish species and where the harvest levels of some species are regulated with vessel quotas.

The choice of functional form to be used in estimating a constrained profit function is important because profits can be positive or negative in such a restricted setting. Fulginiti and Perrin (1993) avoid this problem by restricting 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 on one input factor. However, Diewert and Wales (1987) and Kohli (1993) show that the estimated results for this functional form depend on the normalisation. These authors suggest a symmetric normalized quadratic functional form to avoid this problem and we use this empirical equation in our work.[67]

[66] The multi-output nature of this industry has received considerable attention with Squires (1987; 1988), Squires and Kirkley (1991; 1996) and Weninger (1998) as some examples. See, Jensen (2002) for a survey of the production economics in the fishery,

[67] The symmetric normalized quadratic profit function is similar in structure to the symmetric normalized cost function of Diewert and Wales (1987).

12.1. The Industry and Data Summary

The Norwegian purse seine fleet consists of relatively large vessels, with a gross tonnage of 644 tons on average. Individual vessel quotas (IVQ) are used to regulate harvest of the pelagic species mackerel, North Sea herring, spring spawning herring and capelin. However, the vessels also target several unregulated species such as Atlantic horse mackerel, sandeel, and sprat. There are also minor by-catches of cod and haddock. The IVQ are allocated gratis on an annual basis species-by-species to purse seine vessels. Quotas are not transferable between vessels, but if the total allowable annual catch for the fishery is not reached, individual vessels can apply for additional quota. However, to reduce capacity, vessel owners have been allowed, in some years, to transfer the quota to another vessel(s), if the vessel the quota is removed from is permanently taken out of the fishery. Bjørndal and Gordon (2000) provide a more detailed discussion of the regulatory system. Some capacity adjustment for this fleet took place in the 1980s when buyback programs were in operation. During this period the importance of mackerel and spring spawning herring was minor after stock collapses (in fact, there was a harvest moratorium for spring spawning herring in place between 1973 and 1988). When the stocks rebounded in the late 1980s and early 1990s, there was already an IVQ system in place that prevented the capacity increase that would have otherwise occurred. Accordingly, the stock increases allowed existing vessels to harvest at reasonably high capacity levels.

The Norwegian Directorate of Fisheries provided annual data on financial accounts and landings for individual vessels in the purse seine fleet for the period 1992-1999, giving a total of 170 observations. The data are survey data and accordingly have the form of an unbalanced panel. However, as there are a number of vessels with only one or two observations we cannot specify firm specific effects. The unregulated output variable is constructed using a Fisher index. Initial econometric work revealed a singularity problem in the regressor matrix.

Correlation coefficients[68] 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 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, again using a Fisher index for the aggregation. Two input factors are specified, one variable, operation costs and one fixed, vessel size. Operation cost includes cost for fuel, wages, insurance and other crew costs, and the price is expressed as operating cost per fishing day. For ease of empirical interpretation each variable is centred on its mean value in 1996. Vessel size is measured by length of vessel.

12.2. Empirical model

Our approach to modeling the purse seine fleet is to assume cost minimization over quota restricted harvest and profit maximization over the unrestricted harvest. The Symmetric Normalized Quadratic (SNQ) functional form introduced by Diewert and Wales (1987) in the form of a cost function, and extended to a profit function by Kohli (1993) is used to represent the restricted profit function. In a multi-output variable profit setting, this functional form has the advantage of allowing for both positive and negative short-run profits. In addition, the regularity condition for normalization is not dependent on any one particular price but is imposed with an index of all variable prices (Diewert and Wales (1987)). Furthermore, the curvature conditions apply globally, and are easily checked from the second order parameters.

Profit (π) is defined as the landing value of the unrestricted outputs minus the cost of variable inputs. The restricted quadratic profit function defined over one variable output, one variable input, three quota restricted outputs and one fixed input factor is written as;

68 Spearman's correlation coefficients between IVQ quantities

	SS-herring	NS-herring	Mackerel	Capelin
SS-herring	1	-	-	-
NS-herring	-0.435*	1	-	-
Mackerel	-0.504*	0.845*	1	-
Capelin	-0.315*	-0.351*	0.424*	1

* Correlation is significant at the 1% level (2-tailed).

$$\pi = \Sigma_i^2 \alpha_i P_i + ½ \Sigma_i^2 \Sigma_j^2 \alpha_{ij} P_i P_j / \Sigma_i^2 (\theta_i P_i) \quad (12.1)$$

$$+ ½ \Sigma_k^3 \Sigma_j^3 \rho_{kj} Y_k Y_j (\Sigma_i^2 \theta_i P_i) + ½ \beta_i ZZ (\Sigma_i^2 \theta_i P_i)$$

$$+ \Sigma_i^2 \Sigma_k^3 \gamma_{ik} P_i Y_k + \Sigma_i^2 \nu_i P_i Z + \Sigma_k^3 \phi_{ik} Y_k Z (\Sigma_i^2 \theta_i P_i),$$

where

P_i is the i^{th} variable price, i = u, o, where u is unrestricted output and o is operation costs, $\Sigma_i^2 \theta_i P_i$ is the normalizing price index that impose homogeneity, θ_i is the weight of the i^{th} variable price in the index, $Y_{k,j}$ is the quantity of restricted outputs (k, j = h, c, and m, where h is spring spawning herring, c is capelin and m is mackerel and North Sea herring), and Z is the level of the vessel size.

Output supply and input demand equations are defined in the usual way by applying Hotelling's lemma,

$$d\pi/dp_i = q_i = \alpha_i + \Sigma_i^2 \alpha_{ij} P_i/(\Sigma_i^2 \theta_i P_i) - ½ \Sigma_i^2 \Sigma_j^2 \alpha_{ij} \theta_i P_i P_j/(\Sigma_i^2 \theta_i P_i) \quad (12.2)$$

$$+ ½ \Sigma_k^3 \Sigma_j^3 \rho_{kj} (\theta_i) Y_k Y_j + ½ \beta_i (\theta_i) Z Z$$

$$+ \Sigma_k^3 \gamma_{kj} Y_k + \nu_i Z + \Sigma_k^3 \phi_{ik} (\theta_i) Y_k Z$$

where q_i is positive for unrestricted output values and negative for the variable demand values, operation costs.

In contrast to the translog functional form, it is possible to recover all parameters of the profit function by estimating the system of equations defined by (12.2). Symmetry is imposed by requiring that $\alpha_{ij} = \alpha_{ji}$ and $\rho_{jk} = \rho_{kj}$.

The marginal cost of producing one additional unit of the restricted output is found by differentiating (11.1) with respect to the restricted output (Y_k),

$$d\pi/dY_k = (\Sigma_i^2 \theta_i P_i)(\Sigma_k^3 \rho_{kj} Y_k + \phi_i Z) + \Sigma_i^2 \gamma_{ik} P_i . \quad (12.3)$$

The quota rent to the firm for a given regulated output is the difference between the landing price and the production cost of the marginal unit of the regulated output. This can be interpreted as the marginal value of the quota and in long-run equilibrium it will equal the unit quota value.

12.3. Estimation and empirical results

The parameters of the restricted profit function are recovered from the supply and demand equations. An iterative SUR procedure is used in estimation. The parameter estimates and corresponding t-statistics are reported in Table 12.1. The unrestricted output equation had a measured R^2 of 84% and the variable input equation reported 35%. The own- and cross-price elasticities are reported in Table 12.2. The own-price elasticity for the unregulated species is very small at 0.01 and statistical unimportant. This is also true of the cross-price elasticities. On the other hand, the variable input demand elasticity is measured at -0.12 and statistically significant. Purse seiners are responsive to input price changes but not to changes in the price of the unrestricted output. This would be consistent with a vessel strategy where the primary production is harvesting the quota regulated species (high value) and the unrestricted output (low value) is harvested based on available excess capacity and time (fishing season) considerations.

Table 12.1 Parameter estimates for purse seine vessels

Parameter	Estimate	St. Error	Parameter	Estimate	St. Error
α_o	2.762588*	0.316	$\gamma_{\mu o}$	-0.749*	-4.038
α_ϕ	-0.527*	0.104	$\gamma_{\chi o}$	-0.074	-0.823
α_{oo}	-0.022	0.026	ν_o	0.146	0.350
$\alpha_{\phi\phi}$	-0.172*	0.033	$\phi_{\eta o}$	0.272	1.133
$\alpha_{\phi o}$	-0.387*	0.119	$\phi_{\mu o}$	-0.039	-0.327
$\rho_{\eta\eta}$	0.170	0.215	$\phi_{\chi o}$	-0.021	-0.336
$\rho_{\mu\eta}$	-0.029	0.093	κ_o	-1.067*	-3.477
$\rho_{\chi\eta}$	-0.065	0.051	κ_ϕ	0.330*	4.406
$\rho_{\mu\mu}$	0.190*	0.066	$\gamma_{\eta\phi}$	-0.410*	-2.975
$\rho_{\chi\mu}$	0.002	0.030	$\gamma_{\mu\phi}$	-0.323*	-4.037
$\rho_{\chi\chi}$	0.048	0.047	$\gamma_{\chi\phi}$	-0.062	-1.761
β_1	0.066	0.324	ν_ϕ	-0.188	-0.970
$\gamma_{\eta o}$	-0.649*	0.287			

* indicates statistically significant at a 5% level

Table 12.2 Own, cross price elasticity

	Quantity	
Prices	Unrestricted catch	Operation Costs
Unrestricted catch	0.008	-0.020
	(0.015)	(0.026)
Operation Costs	-0.008	-0.120*
	(0.017)	(0.029)

* indicates statistically significant at a 5% level

Table 12.3 Elasticity of intensity between restricted outputs and variable output/input

	Variable Output	Variable Input
Spring Spawning herring	-0.383*	0.110
	(0.176)	(0.215)
Capelin	-0.065	0.077
	(0.076)	(0.126)
Mackerel and North sea herring	-0.875*	0.159
	(0.218)	(0.305)

* indicates statistically significant at a 5% level

Table 12.3 provides estimates of the elasticity of intensity, or in words, how changes in each of the regulated harvests will impact the supply of the unrestricted harvest and the aggregate index measuring variable inputs. The first column gives changes in the unregulated harvest, while the second column gives the changes in operation costs. For unrestricted harvest all estimates are negative although the capelin estimate is statistically insignificant. This implies that a change in quota levels causes a decline in the harvest of the unregulated species, or probably more importantly, that reduced quotas will increase fishing pressure on unregulated species. This is reasonable as quota species (particularly spring spawning herring and mackerel and North Sea herring) are of a higher value than the unregulated species. Specifically, a 1% change in either spring spawning herring or mackerel and North Sea herring cause a decline in unregulated harvest of 0.4% and 0.9%, respectively. These results are consistent with a strategy of targeting the unrestricted species to exploit spare capacity mainly because of low quota levels on mackerel and the herring species rather than due to market prices for the unregulated species. The second column estimates are positive indicating an increase in input use with respect to changes in quota but the standard errors are too large for significant effects.

We start the investigation of the multioutput cost structure by testing different hypotheses with respect to nonjointness. The test results are presented in Table 12.4. The first test is a test of nonjointness in inputs, i.e. a null hypothesis that each species has a separate production function. This hypothesis is clearly rejected. We then proceed by testing whether the regulated outputs can be characterized by separate production functions. This hypothesis cannot be rejected. This indicates that there are no spillover effects amongst the quota fisheries. Hence, the current practice of setting the quota for these species on a species-by-species basis is reasonable, if one disregards the potential effect on the unregulated species. The final row provides a test of the hypothesis that there is a separate production function for the unregulated species. This hypothesis is clearly rejected as expected given the elasticities of intensity. Hence, the quotas for the regulated species will influence the harvest of the unregulated species.

Table 12.4 Nonjointness and separability tests

Null hypothesis	Test statistics Chi-square	Critical value ($\alpha \leq 0.05$)	Degrees of Freedom	Decision
Non-jointness restricted & unrestricted. outputs	21.38	12.59	6	Reject null (jointness)
Non-jointness restricted outputs	1.64	7.82	3	Accept null (nonjointness)
No interaction between the restricted and the variable outputs.	17.03	7.82	3	Reject null (jointness)
Input-output separability	106.16	15.51	8	Reject null
Separability between all output and the variable input	50.75	9.49	4	Reject null
Separability between restricted and unrestricted outputs	11.369	5.99	2	Reject null

The last three rows of Table 12.4 report results for three separability tests. The first is a test for input/output separability i.e. whether the fishery can be modeled using a single aggregate output index and a single aggregate input index. The second is a test for separability between the outputs and the variable input, which can be interpreted as a measure of short-run input/output separability. The last is a test of whether the restricted species can be treated as a separate group. All hypotheses are rejected. This implies that the fishery cannot be regulated efficiently using highly aggregate measures.

We now turn to investigate cost complementarity in the production structure i.e. measuring for cost advantages in producing multi outputs. Since only the qualitative information is available for the unrestricted output, we define three categories of complementarity; cost complementarities (CC), no cost complementarities (NCC) and anti-cost complementarities (ACC). The results are reported in Table 12.5. The results show no cost complementarities in the production of the regulated outputs. This is consistent with results reported for nonjointness found earlier, and again confirms that the regulated species represent separate production processes. For the restricted outputs we find evidence of anti-cost complimentarity and indicate that higher costs are associated with the joint production of restricted and unrestricted outputs. This indicates that in years of high quota levels for the regulated species (except capelin), fishing vessels will experience lower costs, and if the quotas of the regulated species where high enough, the unregulated species would not be harvested.

We define three broad categories of product specific returns to scale (constant returns (CRTS), increasing returns (IRTS) and decreasing returns (DRTS)) for the four output groups and report the results in column four of Table 12.5. Constant returns to scale is measured for the capelin and spring spawning herring fisheries, as well as for the unrestricted output.[69] Decreasing returns to scale is found in the mackerel and North Sea herring fisheries. These results are interesting and indicate that for the spring spawning herring and capelin fisheries the quota levels allow vessels to operate at optimum scale. On the other hand, for mackerel and North Sea herring the results show excessive quota levels for the capacity of the fishery. That we observe constant returns to scale in two of our groups can be regarded as an indication that the fleet is operating at a level consistent with reasonable capacity utilization. However, given that purse seiners are harvesting stocks that are fairly insensitive to stock levels (Bjørndal, 1988), it can also be interpreted as an indication that the race to fish has been stopped. The fact that the stocks have rebounded is an indication that at least part of the story is that the quota levels have increased to a level that allows scale effects to be captured. For the mackerel and North Sea herring fishery these results suggest that the quota levels are in

[69] Bjørndal and Gordon (2000) also found evidence for CRTS in the fishery for spring spawning herring.

fact too high for the capacity of the existing fleet as we measure product specific decreasing returns to scale. Moreover, these vessels would have been selling quota if allowed to do so.

Table 12.5 Cost complementarity and Product specific returns to scale

	Cost Complementary			Product Specific Returns to Scale
	Capelin	Mackerel & North Sea Herring	Unrestricted Output	
Spring Spawning Herring	NCC	NCC	ACC	CRTS
Capelin		NCC	NCC	CRTS
Mackerel & North Sea Herring			ACC	DRTS
Unrestricted Output				CRTS

Finally, Table 12.6 presents estimates of the marginal cost of producing an additional unit of the restricted output, the average landing price and the associated rent value for the fishermen willingness to pay for additional quotas. The marginal costs indicate significant values for spring spawning herring and mackerel, but not for capelin. The largest potential is seen in the harvesting of mackerel and NS herring, where potential rent 1.85 Norwegian kroner per kilo. For this species there is substantial resource rent collected that makes up almost 30% of the total value for the product. Spring spawning herring is also measured to have a positive rent value for additional quota. Somewhat surprisingly, not only is the estimate of marginal cost not significantly different from zero, but on average the quota rent for capelin is negative.

Capelin is a low value fish compared to the other regulated species with only a minor share (2% on average) of the total regulated revenue generated. The negative rent for this species can be due to a large volatility in stock and quota levels with substantial price shocks, in a fishery that traditionally was important. Because of the remote fishing location north of Norway and highly variable quota levels, vessels may make only one or two trips and price is realized after delivery.

Table 12.6 Marginal cost, and shadow value on restricted outputs per kilo (Norwegian Kroner)

	Marginal Cost	Average landing price	Shadow Value
Spring spawning herring	1.598* (0.720)	1.91	0.31
Capelin	0.490 (0.342)	0.32	-0.17
Mackerel and NS herring	4.651* (1.170)	6.50	1.85

Standard error in parentheses.

* indicates statistically significant at a 5% level

12.4. Concluding Remarks

In this paper we investigate firm behavior when some but not all outputs are regulated by a quota using a constrained profit function. This is a setting that is observed in polluting industries, natural resource industries, agriculture and other industries where governments restricts firm behavior. To evaluate the regulatory measures it is then important to investigate the effect of the regulations including changes in the quotas. Single output measures like elasticities of intensity and product specific economies of scale as well as multiouput measures like cost joitntness in production, cost complementarities and different forms of separability provides important information when assessing the effect of the regulations and to avoid unnecessary costs due to the regulations. In natural resource industries quota rents are also of particular interest, since these should be positive in a well managed industry.

An empirical application is provided for a group of Norwegian purse seines regulated by quotas for the most important species, but also targeting unregulated species. The results indicate that the production process is joint between restricted and unrestricted outputs, implying that changes in the regulations will also influence production of unregulated species. As restricted and unrestricted outputs are substitutes, a reduction in the quotas induces the firms to increase the production of unrestricted outputs. As such, this fishery provides a case where quota systems do have negative effects on unregulated stocks. The fact that there is a cost anticomplementarity between the main regulated species and the unregulated species is an indication that the unregulated species would not be targeted without the regulations. Furthermore, it indicates that the regulations are not well designed and accordingly induce unnecessarily high harvesting costs. For two of the regulated species there is a substantial positive quota rent, at almost 30% of the landed value for the most valuable species. This indicates that the management system has been somewhat successful in allowing some resource rents to be collected.

13. Discussion

13.1. Validation of the results

The reported results from the case studies may appear dramatic or even unrealistic to a fisheries manager. More than half of the vessels are redundant and more then a third of the revenues are potential rents in the fisheries in Denmark, Iceland, Norway and the UK. Still, these results are to a large extent confirmed by the Icelandic results. A further validation is to study the empirical evidence from the Icelandic quota market. In an ITQ fishery, we expect the annual rental price of a quota unit to equal the rent per unit of fish that the quota entitles the holder to land. In Table 13.1 we report the average ex-vessel prices and annual quota rental prices from the Icelandic cod fisheries. Apart from the ITQ regulation, the Icelandic cod fisheries share many similar characteristics with the Norwegian fisheries. The ratio between rental price and ex-vessel price is close to one and varies between 73% and 84%, which is substantially higher than the estimated 50-70% for the Norwegian cod trawlers. There are several signs that the Icelandic quota market has not reached long-run equilibrium (Asche, 2001), and the willingness to pay for an additional unit of quota is determined by short run considerations, i.e., higher than the long-run, as fixed costs are disregarded (See Danielsson, 2001). However, even if the quota rental price is higher than the rent, the Icelandic quota lease market indicates that the share of rents in total revenue is substantial, and it may well be higher than our estimates for the Norwegian cod trawlers. In fact, as the Norwegian regulatory system discriminates against larger vessels, our estimate of the optimal quota is if anything likely to be low. If this is the case, the potential rents can be even higher if the vessels are allowed to operate at full efficiency levels.

Table13.1. Ex-vessel price and quota price, Iceland, Icelandic kroner

Year	**Quota price**	**Ex-vessel price**	**% quota price of price pr/kg**
1997	82	98.3	83.4
1998	88	119.6	73.5
1999	100	137.4	72.7

Source: The Icelandic Fresh Fish Price Directorate

Few studies have empirically investigated the potential for rent or efficiency gains in a fishery, with Dupont (1991), Weninger (1998) as two exceptions. Although their results are not strictly comparable, it is of interest to mention some of their results that shed light on some of the issues we consider here. In particular, Dupont (1991) finds that in the Canadian Pacific salmon fishery, potential rents are about 42% of total revenue. Weninger (1998), for the US surf clam and quahog fisheries, finds that a fleet of 128 vessels can be reduced to between 21 and 25, i.e., a reduction of about four-fifths of the number of vessels, when individual vessel quotas were introduced. Hence, it seems clear from these studies that both the potential rent and overcapacity in traditionally regulated fisheries are substantial, even though one must be careful when generalizing. Jim Wilen has, in a number of venues, argued that potential rents are around 50% of harvest value. The results presented in this report give some support for Wilen's rule of thumb' although there are substantial variations.

It is also of interest to note that the prices obtained for the total catch varied substantially between the two years under investigation. As a consequence, optimal fleet size also varied. A constant optimal fleet size relies on the notion of a steady state for fish stocks. However, natural variations are likely to make stock size variable, even in a well managed fishery.[70] The question of optimal capacity and potential resource rent generation over time in a fishery, with natural fluctuations in stock size are not considered here, but represent an interesting avenue for future research.

13.2. A Comparison

There are a number of striking results coming out of these studies. First, it is surprising that it is only in Iceland that there seems to be generated any substantial rents. Not even the limited transferability in the Norwegian and UK systems seems to make any difference. This implies two main conclusions with respect to the present state for the regulatory systems in the five countries:

3. There was substantial overcapacity when the individual quotas were introduced, and the cost associated with the race to fish were primarily related to this overcapacity, so

[70] For instance, recruitment and mortality will be dependent on a number of variables including water temperature, abundance of food and predators etc.

that it has not been possible to reduce harvesting cost to such an extent that rents are generated.

4. There are no alternative markets where value could be added to the landings because of better control with the harvest.

The first conclusion is probably the most surprising and its cause is probably related to the fact that although all the incentives to build capacity are present in European fisheries, the derby was never as strong as it was in many North American fisheries. There are few if any examples of European fisheries where the fishing season are down to a few days or weeks, and that is certainly not the case for any of the fisheries in question. Hence, the race to fish is not literally a derby like many of the cases one has observed in North America. The costs are therefore primarily related to the capacity, and are not variable costs associated with the derby that disappears when the derby is taken away. There are accordingly no easy cost savings associated with the regulatory structure one has in the cases studied. It seems to be only capacity reduction that allows rents to be generated, and as the capacity reduction has to be substantial, even the Norwegian case does not allow rents to be generated.

In the Icelandic case there are substantial resource rents generated, but this is associated with a substantial capacity reduction. Furthermore, the capacity reduction did not start in earnest until the changes that was introduced to the system in 1990 with a high degree of transferability.

That there does not seems to be any rent generation associated with revenue increasing measures are less surprising. Since the harvesting season for whitefish in Europe spans more or less the full year, there is a fresh market that has been supplied for decades. Although the estimates are imprecise there is little doubt that there is consumed more than 100 000 tonnes of fresh cod in Europe, and the quantity of other whitefish species like haddock, saithe, redfish and hake is most likely also a six digit number of tonnes. Hence, there really are no high paying markets that the regulatory system has prevented the fishermen from serving. Certainly, the Icelandic exports of fresh cod have increased after the regulatory system allowed better control with the harvest, but the price increase at the ex. vessel level is orders of magnitude less than what was experienced in the Pacific halibut fishery.

The next conclusions are related to the rent potential in these fisheries given the present TACs and the capacity reduction required to reach this. In Table 13.2 we show the percent of landing value that is the potential rent and the percent of the current fleet that is required to land this fish. As one can see, with the exception of Denmark the numbers are substantial, as potential rents is between 30 and 60% of total landing value, and the fleets has to be reduced to between a half and a third of the current fleets sizes if the rents are to be realised. Also, even at Iceland where one has seen a substantial reduction in capacity, there is still a long way to go if all the rents are to be realised. In the Danish case it is noticeable that the economic rent in proportion to the landing value is relative small and stable compared to the large reduction in capacity. This indicates relative 'flat' average revenue and cost curves.

Table 13.2. Potential rents and overcapacity

Country	Potential rents as % of landing value	% reduction in the fleet
Norway	61%	65%
Iceland	51%	50%
Sweden	40%	75%
Denmark	13-15%	67%
UK	30-40%	50-70%

There are tendencies that buy-back programs and similar capacity reducing measures target fairly limited reductions in the fleet. The limited transferability in the Norwegian program, where almost 20% of the fleet is removed also seems to be in this category. As it is the least efficient vessels that is removed first, these numbers from the case studies suggest that it is not surprising that such structural programs has little effect and that such programs do not have any effect on the rents realised. For capacity reduction to have a real effect, it seems like a substantial part of the fleet needs to be removed.

An open access fishery is close to being the regulatory scheme that generates the highest employment in a fishery. This is also natural since it is associated with the highest effort level in a traditional bioeconomic model. Wilen and Homans (1997) results suggest that one may generate even higher effort levels and the presumably employment levels in a regulated open access fishery. These results are natural since in a fishery where there is a race to fish the resource rent is dissipated by the additional harvesting cost associated with the overcapacity.

In most fisheries there is little variation in the crew size on a given vessel over time. There is then a close relationship between the number of vessels removed from a fishery and the reduction in the number of fishers. It then follows that the more efficient one make a fishery, the more the employment in the fishery is reduced. For policies that are concerned with living societies along remote coastlines, a more efficient regulatory system then will have the effect that employment is substantially reduced. There are accordingly a real trade-off between employment in a fishery and efficiency. And the magnitudes suggest that it is an important trade-off since a regulatory system that makes the fisheries as efficient as possible will have the side effect that several fishery dependent communities will disappear.

These results also clearly illustrates the fact that the resource rent are allowed to be used to build overcapacity is a real subsidy to coastal communities. Moreover, since the labour and capital used to create the over-capacity do not contribute anything to the value added in society, the size of the subsidy is not only the resource rent that is not generated, but also the loss of value added that this effort would have created if it were put to use in other sectors of society. This cost will only disappear if there are no other sectors that these factors can be used in, that is the fishermen becomes unemployed and the capital is sunk.

14. Conclusion

The seminal paper of Gordon (1954) shows that because fish stocks in an unregulated state is a common pool resource, the tragedy of the commons will unfold. One main insight about fishermen behaviour comes out of this analysis. Under good management a fish stock give rise to a resource rent, that is, the return on capital invested in a fishing vessel provides a return that exceeds what one would obtain in alternative use of the capital in a traditional industry. The resource rent act as pure profits for the fishermen, and the fishery will therefore attract excess capacity until this resource rent is fully dissipated due to the competition between the fishermen. In addition, in an unregulated or open access fishery the fish stocks will be at a lower level than what is both biologically and economically optimal.

In this report we investigate over-capacity and potential rent in a fishery regulated with individual vessel quotas. The quotas are taken as given, as they in most regulatory regimes are set based on biological recommendations. That means that the over-capacity and potential rent investigated is the numbers that can be obtained with more efficient management of how the fishery is conducted. If one is able to manage the stock optimally from a biological point of view, the rents can be further increased.

Since the quotas limit the quantity of fish each vessel can harvest, modelling the outputs as fixed is the most appropriate approach when investigating fishermen's behaviour under IVQs. In most cases a cost function is then the natural specification. For each vessel optimal output can then be estimated. This will give the optimal quota for the vessel and allow us to derive the potential rent for the vessel and the fishery, as well as optimal fleet size. With this information, one can also estimate the overcapacity in a fishery.

There are at least two causes for rent generation when the race to fish is eliminated by introducing an IVQ system. The most obvious is that harvesting costs are reduced as the race to fish is stopped. The second is that revenues are increased since fishers with better control of their harvests can target different markets. However, while the introduction of individual quotas holds the potential to generate rent, it is not a sure outcome. To ensure rent generation due to lower costs, capacity in the fishery cannot be too high. This is a problem as there tends to be substantial overcapacity in fisheries when individual vessel quotas are introduced. There has been a few examples of species where individual quotas has allowed a substantial revenue potential to be harvested, with the Pacific halibut fishery as the best known example.[71] However, it is not obvious that all fisheries have this potential. Halibut is a high valued species with a substantial fresh market that was not really serviced when the halibut fishery was a derby fishery. Moreover, the derby was extreme as the season was down to 48 hours of fishing. Less valuable species like e.g. herring with little potential in the fresh market and a relatively long harvesting season even when there is competition for the quota may not hold the same potential as they have not incurred the same variable cost in association with the derby. In such cases, capacity reduction seems to be the only way to harvest rents.

In this project, five case studies of the cod fisheries where provided for fishery management systems using some sort of IVQ in Denmark, Iceland, Norway, Sweden and the UK. At Iceland, a relatively high degree of transferability is allowed, in Norway and the UK a limited degree of transferability is allowed and in Denmark and Sweden no transferability is allowed. The results indicate that there do not seem to be any easy cost savings or revenue effects associated with the introduction of IVQs in these fisheries, as with the exception of Iceland, there are no rents generated in any of the cases. Moreover, the rents generated at Iceland seem to be associated with a substantial capacity reduction.

We are not able to estimate potential rents for Denmark, but in the four other cases the estimated potential rents ranges between 30 and 61%. These numbers are high, but it is reassuring that they are of a similar magnitude in all cases, and also confirms with Wilen's rile of thumb that potential resource rent is about 50% of the ex. vessel value of the landings. It is also reassuring since the estimates in general is outside the observed data point, and as such must be regarded with some care.

The capacity reduction required to realise these rents are substantial at around two thirds of the fleet, with UK as an exception in that only about a third of the fleet must be removed. This is large numbers, but are to some extent confirmed by the substantial capacity reduction that has taken place on Iceland. It does highlight at least two important points. The targeted

[71] Casey et al (1993) provide a review of the Pacific halibut fishery.

capacity reduction in most buyback programs are in most cases so small that the effect is negliable and probability not very cost effective. Moreover, as there is a close link between number of vessels and employment in the fishing industry, the employment effect of pursuing economically efficient regulations is substantial.

15. Exploitation and and dissemination of results

The results from this project were planned to be exploited and disseminated in various ways.

1) The deliverables from the project include several publicly available reports. These will contain all results of the project, although their detail will probably make the reports of interest only to highly specialized readers.

2) A representative for Swedish fisheries management authorities is directly involved in the project through UG, and also the other partners will have meetings with representatives from their respective countries fisheries managers discussing the results of the project.

3) The project is addressing several new theoretical, methodological and empirical issues. We think there will be at least three papers containing significant methodological and theoretical contributions. We will target at least two of the papers to either the *American Journal of Agricultural Economics, Land Economics* or *Journal of Environmental Economics and Management* which are the leading resource economics journals. We will also target one paper either at a general journal with an interest in resource economics like *Canadian Journal of Economics* or a regulatory economics journal like *Journal of Regulatory Economics*. The empirical results from each of the country studies will also be that basis for scientific papers.

Results from the project are available in a number of academic papers and reports. So far only two papers have been published in scientific journals, and one of them in *American Journal of Agricultural Economics*. Several are in review including a resubmit to *Land Economics* and two papers that are submitted to *Journal of Environmental Economics and Management* and *Journal of Regulatory Economics*, or are to be submitted in the near future, so this number is expected to increase substantially. Results have also been disseminated at several conferences and meetings with industry and government officials and in articles and interviews in trade magazines. In Norway results from the project has also been used in the work of an expert comitee that is to propose a revised law for the management of marine resources where Dr. Asche is a member. The comitee is to submit its report in june 2005.

As the present project is rooted only in social sciences, there are no patent applications etc.

With the exception of interviews, the dissimination is as follows:

Asche, F. (2002) Norsk fiskerinæring – Med en næringsstruktur for fremtiden?, (In Norwegian, The Norwegian Fishing Industry – With a structure for the future?) *Kystmagasinet*, nr. 6.

Asche, F., T. Bjørndal, H. Eggert, H. Frost, D. V. Gordon, E. Gudmundsson, A. Hoff, C. Lynge Jensen, S. Pascoe (2003) Modelling Fishermen Behaviour under new Reulatory Regimes: Methodological Report, SNF Report 4/03. *Deliverable no. 1.*

Asche, F., T. Bjørndal, H. Eggert, H. Frost, D. V. Gordon, E. Gudmundsson, A. Hoff, C. Lynge Jensen, S. Pascoe, R. Tveteras (2004) Modelling Fishermen Behaviour under new Regulatory Regimes – Overcapacity and rents, five case studies. Deliverable no. 5.

Asche, F., T. Bjørndal, H. Eggert, H. Frost, D. V. Gordon, E. Gudmundsson, A. Hoff, C. Lynge Jensen, S. Pascoe, Sigurdsson, E. H. Sissener, R. Tveteras, Valtysson (2004) Modelling Fishermen Behaviour under new Regulatory Regimes – Overcapacity and rents, Final report, Deliverable no. 6.

Asche, F., T. Bjørndal and D. V. Gordon (2004) Overcapacity and Scale Effects in the Fishery: Methodology and Empirical Results. In Advances in the Economics of the Fishery: Papers in Honour of Professor Gordon Munro, R. Arnarson, T. Bjørndal and D. V. Gordon (ed.). Forthcomming, Blackwell, Oxford.

Asche, F., T. Bjørndal and D. V. Gordon (2004) Fishermen Behaviour with Individual Vessel Quotas – Over-capacity and Potential Rent. Resubmitted to *Land Economics*.

Asche, F., H. Eggert, E. Gudmundsson, A. Hoff, CS. Pascoe (2004) Modelling Fishermen Behaviour under new Regulatory Regimes, to be submitted to *Marine Policy*.

Asche, F., D. V. Gordon and C. Lynge Jensen (2004) Measuring Performance in a Multi-Output Industry with Output Restrictions. To be submitted to the *Journal of Environmental Economics and Management*.

Asche, F. and A. G. Guttormsen (2004) Råfiskloven og lønnsomheten i norsk fiskeindustri (In Norwegain: The marine fish act and the profitability in the Norwegian Fishing Industry). *Norsk Fiskerinæring*, no. 10.

Jensen, C. L. (2002) Applications of Duality Theory in Fisheries: A Survey, *Marine Resource Economics*, 4, 309-334.

Eggert, H. and R. Tveterås. (2004) 'Stochastic Production and Heterogeneous Risk Preferences: Commercial Fishers' Gear Choices', *American Journal of Agricultural Economics* **86**(1): 199-212.

Eggert, H. and R. Tveterås (2004). Potential Rent and Overcapacity in the Swedish Baltic Sea Trawl Fishery. Submitted to *Environmental and Resource Economics*.

Hoff, A. and Frost H. (2004). *Assessing Optimal Economic Behaviour for Danish Trawlers below 50 GRT: A Dual Approach.* In preparation for a peer-review journal.

Gudmundsson, E and A. Bjarki Bergsson (2004) "Development of fleet capacity in the Icelandic trawler fishery from 1995 through 2003.", Paper in preparation for publication in a peer reviewed journal.

Gudmundsson, E, Thorir Sigurdsson and A. Bjarki Bergsson (2004) "Cost minimization and realization of resource rents: The case of the Icelandic trawler fishery." Paper in preparation for publication in a peer reviewed journal.

Pascoe, S. Excess capacity and potential rent in UK demersal whitefish trawl fisheries: a cost function approach. Paper submitted to the *Journal of Agricultural Economics*.

Pascoe, S. Quota trading and profitability in UK trawl fisheries. Paper in preparation, to be submitted to *Environmental and Resource Economics*.

Asche, F., D. V. Gordon and C. Lynge Jensen (2004) Measuring Performance in a Multi-Output Industry with Output Restrictions. Paper presented at Conference on Fisheries Economics and Management in Honour of Professor Gordon R. Munro, 5. aug, 2004, in Vanouver, Canada.

Asche, F., D. V. Gordon and C. Lynge Jensen (2004) Measuring Performance in a Multi-Output Industry with Output Restrictions. Paper presented at EAFE 2004 in Rome

Asche, F. (2004). Profitability and rents in Norwegian Fisheries. Speech at internal workshop in the Ministry of Fisheries.

Asche, F. (2005). Rents and capacity in Norwegian Fisheries. Speech at internal workshop in the Ministry of Fisheries.

Asche, F. (2004) Modelling Fishermen Behavior under New Regulatory Regimes -How are individual quota schemes different from traditional schemes and how does this influence fishermen behavior? Presentation at the DG – Fish seminar for delivering the results from FP5 – FP6 research project to DG Fish, Brussels, September 16th, 2004.

Asche, F. (2004) Profitability in the whithefish sector. Speech given at the “Whitefish conference”, an industry forum with about 200 participants. Tromsø, November 15.

Asche, F., T. Bjørndal and D. V. Gordon (2002) Fishermen Behaviour with Individual Vessel Quotas – Over-capacity and Potential Rent. Paper presented at IIFET 2002.

Asche, F., T. Bjørndal and D. V. Gordon (2002) Fishermen Behaviour with Individual Vessel Quotas – Over-capacity and Potential Rent. Paper presented at EAFE 2003.

Eggert, H. and R. Tveterås (2004). Potential Rent and Overcapacity in the Swedish Baltic Sea Trawl Fishery. Paper presented at EAFE 2004 in Rome.

Gudmundsson, E. (2004) A discussion was organized with the Icelandic Ministry of Fisheries on two different occasions. The first meeting was in March of 2004, where the project was reviewed and some initial findings were presented. The second meeting was in October when final results of the paper were presented to representatives of the ministry of fisheries along with representatives from all institutions which provided data for this study.

Gudmundsson, E. (2004) "Development of effort and fishing fleet capacity in the Icelandic cod fishery." Paper presented at the bi-annual meeting of IIFET, Tokyo, July 21 – 30, 2004.

Gudmundsson, E (2004) "Capacity reduction in the Icelandic trawler fishery." Paper presented at the XVIth annual EAFE meeting, Rome, April 5th – 7th, 2004.

Gudmundsson, E (2004) "Development of fishing effort and fleet capacity in the Icelandic trawler fishery." Seminar at the Faculty of Business Administration, University of Akureyri, Akureyri, November 12th, 2004.

Gudmundsson, E (2004) "Modelling fishermen´s behaviour under new regulatory regimes: Five case studies." Presentation at the DG – Fish seminar for delivering the results from FP5 – FP6 research project to DG Fish, Brussels, September 16th, 2004.

Hoff, A. and H. Frost (2004) Cost and Profit Structure for the Fleet of Danish trawlers below 50 GRT, presented at the XVIth Annual EAFE conference in Rome April 2004.

Pascoe, S. Economies of scale, excess capacity and potential rent in UK demersal whitefish trawl fisheries. Paper presented at the 12th Biennial Conference of the International Institute of Fisheries Economics and Trade, Tokyo University of Marine Science and Technology, 26-29 July 2004

16. Policy related benefits

Since the review of the Common Fisheries Policy in 1991, two of the four objectives have been explicitly stated (European Commission, 1991) as: a) to achieve sustainable fishing and b) to avoid undesirable side effects on fishing communities heavily dependent on fishing. This projects focus is related to these two issues as fishing capacity have substantial impacts on harvesting, and on employment in communities heavily dependent on fishing

The Common Fisheries Policy TAC and quota system has to a large extent failed to conserve stocks. During the last decades several innovations have taken place in fisheries management, which have the potential of correcting this failure. Of particular interest here is the introduction of individual vessel quotas (IVQ), which may be transferable or not. These measures are additions to the TACs in fisheries management. While these measures have been pioneered at Iceland and in Oceania, EU-member countries have only started to use them in a few fisheries. However, varieties are becoming increasingly common particularly in northern Europe. Several of the British producer organisations operate something which is very close to *de facto* Individual Transferable Quota (ITQ) systems, in the Netherlands one has been operating ITQ systems for some time, and in Denmark and Norway one has a system with nontransferable IVQ. One type of traditional fisheries is also of interest in this context, as for species with little migration, where fishers often have a right to an area. In this project we investigate the effect of IVQ systems in Denmark, Iceland, Norway, Sweden and the UK, where only the system at Iceland allows for a high degree of transferability.

When fishers are allowed to maximise profits for a given quota, theory indicates that the fishery tend to become more profitable, lasting for a longer period, but employing fewer fishers and vessels. IVQ have the potential of fulfilling the objective of conserving the stocks, but leading to employment of fewer fishers and vessels. The latter have in some cases been referred to as a potential draw back of IVQ and sometimes seen as contradictive to the CFP objective of avoiding undesirable side effects on fishing communities heavily dependent on fishing. As for any multi-objective policy, contradictive policies may exist within the CFP. If the resource rent harvested, the maximal resource rent, the optimal vessel size and the optimal fleet size are estimated for different fisheries, these figures will provide valuable information to managers, and help them to balance the trade off between different objectives within the CFP. This project shows that the tradeoff is substantial, as the reduction in the fleet capacity necessary to harvest a large part of the resource rent are more then 50%, and the employment will have to be reduced along the same lines. Moreover, policies that aims at a fairly limited reduction in capacity is not likely to have much effect.

Management systems with individual quotas change the fisher's incentives from maximising their share of the catch to maximising the profits from their share of the catch. Hence, these new management systems cause a fundamental change in how the fishers operate. The result is that the traditional profit function approach to model fisher's behaviour is not appropriate for IVQ systems. Rather the restricted behaviour can be modelled using a cost function. A cost function can be shown to be a special form of a restricted profit function, where the outputs are the restricted factors. This can be used to estimate relevant policy information as the actual resource rent harvested, the maximal resource rent, the optimal vessel size, and the optimal fleet size under IVQ.

Appropriate modelling of fishers' behaviour is a necessary requirement to estimate the relevant policy information in order to compare the outcome of different management systems. This project aims to show that a cost function can be a special form of a restricted profit function, where the outputs are the restricted factors. Improvement of this methodology will be a convenient tool for fisheries economists, who carry out empirical studies on different EU fisheries. The project will also carry out empirical studies of three types of fisheries management. In Iceland, where ITQ systems have been in operation for a decade; in Norway, where individual nontransferable quotas has been in operation for some fisheries for most of the 1990s, and in Sweden and Denmark where the regulation is of the traditional type with TACs.

There are a number of striking results coming out of these case studies. First, it is only in Iceland, where the quotas are transferable, that there seems to be generated any rents. Not even the limited transferability in the Norwegian and UK systems seems to make any difference. This implies two main conclusions with respect to the present state for the regulatory systems in the five countries:

1. There was substantial overcapacity when the individual quotas were introduced, and the cost associated with the race to fish were primarily related to this overcapacity, so that it has not been possible to reduce harvesting cost to such an extent that rents are generated.
2. There are no alternative markets where value could be added to the landings because of better control with the harvest.

The first conclusion is the most surprising and its cause is probably related to the fact that although all the incentives to build capacity are present in European fisheries, the derby was never as strong as it was in many North American fisheries. There are few examples of European fisheries where the fishing season are down to a few days or weeks, and that are certainly not the case for any of the fisheries in question. Hence, the race to fish is not literally a derby like many of the cases one has observed in North America. The costs are therefore primarily related to the capacity, and are not variable costs associated with the derby that disappears when the derby is taken away. There are accordingly no easy cost savings associated with the regulatory structure one has in the cases studied. It seems to be only capacity reduction that allows rents to be generated, and as the capacity reduction has to be substantial. Even the Norwegian and UK cases where some transferability are allowed, do not allow rents to be generated. In the Icelandic case there are resource rents generated, but this is associated with a substantial capacity reduction. Furthermore, the capacity reduction did not start in earnest until the changes that was introduced to the system in 1990 with a high degree of transferability.

That there does not seems to be any rent generation associated with revenue increasing measures are less surprising. Since the harvesting season for whitefish in Europe spans more or less the full year, there is a fresh market that has been supplied for decades. Although the estimates are imprecise there is little doubt that there is consumed more than 100 000 tonnes of fresh cod in Europe, and the quantity of other whitefish species like haddock, saithe, redfish and hake is also a six digit number of tonnes. Hence, there really are no high paying markets that the regulatory system has prevented the fishermen from serving. Certainly, the Icelandic exports of fresh cod have increased after the regulatory system allowed better control with the harvest, but the price increase at the ex. vessel level is orders of magnitude less than what was experienced in the Pacific halibut fishery.

The next conclusions are related to the rent potential in these fisheries given the present TACs and the capacity reduction required to reach this. The numbers are substantial, as potential rents is between 30 and 60% of total landing value (with Denmark as an exception with about 15%), and the fleets has to be reduced to between a half and a third of the current fleets sizes if the rents are to be realised. Also, even at Iceland where one has seen a substantial reduction in capacity, there is still a long way to go if all the rents are to be realised. There is a tendency that buy back programs and similar capacity reducing measures target fairly limited reductions in the fleet. As it is the least efficient vessels that is removed first, these numbers from the case studies suggest that it is not surprising that such structural programs has little effect and that such programs do not have any effect on the rents realised. For capacity reduction to have a real effect, it seems like a substantial part, between a half and two thirds of the fleet needs to be removed.

In most fisheries there is little variation in the crew size on a given vessel over time. There is then a close relationship between the number of vessels removed from a fishery and the reduction in the number of fishers. It then follows that the more efficient one make a fishery, the more the employment in the fishery is reduced. For policies that are concerned with living societies along remote coastlines, a more efficient regulatory system then will have the effect that employment is substantially reduced. There is accordingly a real trade-off between employment in a fishery and efficiency. And the magnitudes suggest that it is an important trade-off since a regulatory system that makes the fisheries as efficient as possible will have the side effect that several fishery dependent communities will disappear.

These results also clearly illustrates the fact that the resource rent are allowed to be used to build overcapacity is a real subsidy to coastal communities. Moreover, since the labour and capital used to create the over-capacity do not contribute anything to the value added in society, the size of the subsidy is not only the resource rent that is not generated, but also the loss of value added that this effort would have created if it were put to use in other sectors of society. This cost will only disappear if there are no other sectors that these factors can be used in, that is the fishermen becomes unemployed and the capital is sunk.

References

Alam M. F., H. O. Ishak and D. Squires (1996): Sustainable Resource Use, Economic Development, and Public Regulation: The Multiproduct Gill Net Fishery of Peninsular Malaysia. *Environmental and Resource Economics* 7: 117-132.

Alam M. F., H. O. Ishak and D. Squires (2002): Sustainable Fisheries Development in the Tropics: Trawlers and License Limitation in Malaysia. *Applied Economics* 34: 325-337.

Anderson, L.A. (1994): Highgrading in ITQ fisheries. *Marine Resource Economics* 9: 209-226.

Anon (2003): Report of the Baltic Fisheries Assessment Working Group. ICES CM 2003/ACFM:21.

Anon (2004a): Environmental conditions in Icelandic waters 2003. Fjölrit Hafrannsóknastofnunarinnar 101: 43.

Anon (2004b): State of marine stocks in Icelandic waters 2003/2004 - Prospects for the quota year 2004/2005. Fjölrit Hafrannsóknastofnunarinnar 102: 175.

Arnason, R. (1994): On catch discarding in fisheries. *Marine Resource Economics* 9: 189-208.

Arnason, R. (1990): Minimum Information Management in Fisheries, *Canadian Journal of Economics*, 23: 630-653.

Arnason, R and B. Valsson, (1999): Productivity in Icelandic fisheries (in Icelandic). Report published by the Ministry of Fisheries, Iceland.

Arnason, R. (2003): On Productivity and Productivity growth in the Icelandic Fisheries. Gudmundsson, E. and H. T. Valtysson (eds.) *Competitiveness within the global fisheries.* University of Akureyri, Iceland.

Arnason, R. (1995): *The Icelandic Fisheries: Evolution and Management of a Fishing Industry.* Fishing News Books, Oxford

Arnason, Ragnar (1980): Dynamic Fishery Economics and the Optimal Utilization of the Icelandic Cod Stock (in Icelandic), *Fjármálatíðindi 1*.

Arnason, Ragnar, LK Sandal, SI Steinsham and N Vestergaard, (2004): Optimal feedback controls: Comparative evaluation of the cod fisheries in Denmark, Iceland and Norway. *American Journal of Agricultural Economics,* 86(2): 531-542.

Asche, F., T. Bjørndal, H. Eggert, H. Frost, D. V. Gordon, E. Gudmundsson, A. Hoff, C. Lynge Jensen, S. Pascoe (2003): Modelling Fishermen Behaviour under new Regulatory Regimes: Methodological Report, SNF Report 4/03.

Asche, F., T. Bjørndal, and D.V. Gordon (2003): Fishermen behaviour with individual vessel quotas – over-capacity and potential rent. Country report.

Asche, F., D. V. Gordon and C. Lynge Jensen (2004): Measuring Performance in a Multi-Output Industry with Output Restrictions. Mimeo, SNF.

Asche, F., and S. Tveterås. 2004. On the Relationship between Aquaculture and Reduction Fisheries. *Journal of Agricultural Economics* 55: 245-265.

Baldursson, F.M. (1993): Um neyslu og tekjur á Íslandi (On Consumption and Income in Iceland). *Fjármálatíðindi* 40(3).

Baldursson, F. M., A. Danielsson, and G. Stefansson. (1996): On the Rational Utilization of the Icelandic Cod Stock. *ICES Journal of Marine Science* 53(1):643-58.

Barten, A. P. (1969): Maximum Likelihood Estimation of a Complete System of Demand Equations, *European Economic Review 1*: 7-73.

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

Begg, G., A.and Marteinsdottir, G. (2002): Environmental and stock effects on spawning origins and recruitment of cod *Gadus morhua*. *Marine Ecology Progress Series* 229: 263-277.

Binswager, H. P. (1974): A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution. *American Journal of Agricultural Economics* 56: 377-386.

Bjørndal, T. (1987): Production Economics and Optimal Stock Size in a North Atlantic Fishery. *Scandinavian Journal of Economics* 89: 145-164.

Bjørndal, T. and D.V. Gordon (1993): The Opportunity Cost of Capital and Optimal Vessel Size in the Norwegian Fishing Fleet. *Land Economics* 69: 98-107.

Bjørndal, T. and D.V. Gordon. (2000): The Economic Structure of Harvesting for Three Vessel Types in the Norwegian Spring-Spawning Herring Fishery. *Marine Resource Economics* 15: 281-292.

Brander K. (2000): Effects of environmental variability on growth and recruitment in cod (Gadus morhua) using a comparative approach. *Oceanologica Acta* 23 (4): 485-496.

Brown, R. S., and L. R. Christensen (1981): Estimating Elasticities of Substitution in Model of Partial Static Equilibrium: An Application to U.S. Agriculture, 1947 to 1974. Berndt, E. R and B.C. Field (eds.) *Modeling and Measuring Natural Resource Substitution*. The MIT Press, Cambridge.

Campbell, H. F. (1991): Estimating the Elasticity of Substitution between Restricted and Unrestricted Inputs in a Regulated Fishery: A Probit Approach. *Journal of Environmental Economics and Management* 20: 262-274.

Campbell, H. F. and R. K. Lindner (1990): The Production Of Fishing Effort and The Economic Performance Of Licence Limitation Programs. *Land Economics*. 66(1): 56-66

Campbell, H.F. and R.B. Nicholl (1994): Can Purse Seines Target Yellowfin Tuna? *Land Economics* 70: 345-53.

Campbell, H. F. and R. B. Nicholl (1995): Allocating Yellowfin Tuna between the Multispecies Purse and Longline Fleets. *Marine Resource Economics* 10: 35-58.

Casey, K. E., C. M. Dewees, B. R. Turris, and J. E. Wilen (1995): The Effect of Individual Vessel Quotas in the British Columbia Halibut Fishery. *Marine Resource Economics* 10: 211-230.

Chambers, R. G. (1994): Applied Production Analysis: A Dual Approach. Cambridge University Press, Cambridge

Christensen, L. R. and W. H. Greene (1976): Economies of Scale in U.S. Electric Power Generation. *Journal of Political Economy*, 84: 655-76.

Coelli, T., D. S. P. Rao and G. E. Battese (1998): *An introduction to efficiency and productivity analysis.* Kluwer Academic Publishers, USA.

Conrad, K. and R. Unger (1987): Ex Post Tests for Short- and Long-Run Optimization. *Journal of Econometrics* 36: 339-358.

DG Fish. 2000. MAGP IV not effective enough in dealing with overcapacity. EU press release 01.10.2000. [http://www.europa.eu.int/comm/fisheries/pcp/faq2_en.htm]

Danielsson, A. (1993): Elasticity of Demand for Icelandic Cod. Working Paper. National Economic Institute.

Danielsson, A. (2001): Quota prices and the cost of rationalization in ITQ fisheries. Proceedings of the 13th annual conference of the European Association of Fisheries Economists, Salerno, April 18-20, 2001.

Danielsson, A., G. Stefansson, F. Mar Baldursson and K. Thorarinsson (1997): Utilization of the Icelandic Cod Stock in a Multispecies Context. *Marine resource Economics*, 12(4): 329-344

DEFRA 2003 UK Sea Fisheries Statistics 2002, DEFRA

Diewert, W. (1974): Functional Forms for Revenue and Factor Requirement Functions. *International Economic Review* 15: 119-130.

Diewert, W. E. and T. J. Wales (1987): Flexible functional forms and global curvature conditions. *Econometrica*. 55: 43-68.

Diop, H. and R. F. Kazmierczak (1996): Technology and Management in Mauritanian Cephalopod Fisheries. *Marine Resource Economic* 11: 71-84.

Dupont, D. P. (1990): Rent Dissipation in Restricted Access Fisheries. *Journal of Environmental Economics and Management* 19: 26-44.

Dupont, D. P. (1991): Testing for Input Substitution in a Regulated Fishery. *American Journal of Agricultural Economics* 73: 155-164.

Dupont, D.P., R.Q. Grafton, J. Kirkley and D. Squires (2002): Capacity utilization measures and excess capacity in multi-product privatized fisheries. *Resource and Energy Economics* 24(3): 193-210.

Durrenberger, E. P., and G. Palsson (1987): The Grass Roots and the State: Resource Management in Icelandic Fishing. McCay, B. J and J. M. Acheson (eds.) *The Question of the Commons: The Culture and Ecology of Communal Resources*. The University of Arizona press, Tucson.

European Commission. 1991. Report 1991 from the Commission to the Council and the European Parliament on the Common Fisheries Policy. SEC (91) 2288, EC, Brussels.

Eggert, H. and R. Tveterås (2004): Stochastic Production and Heterogeneous Risk Preferences: Commercial Fishers' Gear Choices. *American Journal of Agricultural Economics***,** 86(1): 199-212.

Eggert, H. and R. Tveterås (2004): Potential Rent and Overcapacity in the Swedish Baltic Sea Trawl Fishery. Country report.

Eggert, H. and P. Martinsson (2004): Are Commercial Fishers Risk Lovers? Forthcoming in *Land Economics* 86(4).

Eythorsson, E. (2000): A decade of ITQ-management in Icelandic fisheries; consolidation without consensus. *Marine Policy* 24(6): 483 – 492.

Färe, R., S. Grosskopf and S.K. Li (1992): Linear programming models for firm and industry performance. *Scandinavian Journal of Economics*, 94(4): 599-608.

Färe, R., S. Grosskopf and C.A.K. Lovell (1994): *Production Frontiers*. Cambridge University Press, Cambridge.

Felthoven, R.G (2002): Effects of the American Fisheries Act on capacity, utilisation and technical efficiency. *Marine Resource Economics* 17: 181-206.

Fiskifréttir (2004): 22(20), p. 4, May 28th. Framtíðarsýn, Reykjavík, Iceland.

Fogarty, M. J., R. A. Myers and K. G. Bowen (2001): Recruitment of cod and haddock in the North Atlantic: a comparative analysis. *ICES Journal of Marine Science* 58: 952-961

Flaaten, O., K. Heen, and K. G. Salvanes (1995): The Invisible Resource Rent in Limited Entry and Quota Managed Fisheries: The Case of Norwegian Purse Seine Fisheries. *Marine Resource Economics* 10: 341-356.

Fox, G. and L. Kivanda (1994): Popper or Production? *Journal of Agricultural Economics* 42: 1-13.

Fulginiti, L., and R. Perrin. (1993): The Theory and Measurement of Producer Response under Quotas. *Review of Economics and Statistics* 75: 97-106.

Gordon, H. S. (1954): The Economic theory of a common property resource: the fishery. *Journal of Political Economy*. 62:124-142.

Grafton, Q, D. Squires and K. J. Fox (2000): Private property and economic efficiency: a study of a common pool resource. *The Journal of Law and Economics* 43: 671-714.

Gudmundsson, E. (2004): Capacity reduction in the Icelandic trawler fishery. Country report.

Göteborgs Posten (2004): Med havet som arbetsplats (The Sea as Working Place), February 7.

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

Hannesson, R. (1983): Bioeconomic Production Function in Fisheries: Theoretical and Empirical Analysis. *Canadian Journal of Fisheries and Aquatic Science* 40: 968-982.

Hannesson, R. (1996): *Fisheries Mismanagement*. Fishing News Book, Oxford

Hausmann, J. (1978): Specification Tests in Econometrics. *Econometrica* 46: 1251-1271.

Helgason, A. (1995): The Lords of the sea and morality of exchange: The social context of ITQ management in Iceland. MA thesis, University of Iceland

Herrero, I. and S. Pascoe (2003): Value versus volume in the catch of the Spanish south-Atlantic, trawl fishery. *Journal of Agricultural Economics*. 54 (2): 325 - 341

Hoch, I. (1958): Simultaneous Equation Bias in the Context of the Cobb-Douglas Production Function. *Econometrica* 26: 566-578.

Hoff, A. and H. Frost (2004): Cost and Profit Structure for the Fleet of Danish trawlers below 50 GRT. Country report.

Holland, D. S. and J. G. Sutinen (2000): Location choice in New England trawl fisheries: Old habits die hard. *Land Economics* 76(1): 133-150.

Homans, F. R., and J. E. Wilen (1997): A Model of Regulated Open Access Resource Use. *Journal of Environmental Economics and Management*, 32, 1-21.

Homans, F. R., and J. E. Wilen (2004): Markets and Rent Dissipation in Regulated Open Access Fisheries. Forthcoming in *Journal of Environmental Economy and Management.*

Jakobsson, J. and G. Stefánsson (1998): Rational harvesting of the cod-capelin-shrimp complex in the Icelandic marine ecosystem. *Fisheries Research* 37: 7-21.

Jensen, C. L. (1998): Investment Behaviour and Tax Policy. *Marine Resource Economics* 13: 185-196.

Jensen, C. L. (2002): Applications of the Dual Theory in Fisheries: A Survey. *Marine Resource Economics.* 17(4), pp.309-334.

Jonsson, S. (1981): The Development of the Icelandic Fishing Industry 1900 - 1940 and its Regional Implications. Economic Development Institute, Reykjavík.

Jonsson, S. (1984): Sjávarútvegur Íslendinga á tuttugustu öld. Hið íslenska bókmenntafélag, Reykjavík.

Kim, H. Y. (1987): Economies of Scale in Multi-product Firms: An Empirical Analysis. *Economica* 54: 185-206.

Kirkley, J. E. and I. E. Strand. (1988): The Technology and Management of Multi-Species Fisheries. *Applied Economics* 20: 1279-1292.

Kirkley, J. E., D. Squires, and I.E. Strand (1985): Assessing technical efficiency in commercial fisheries: The Mid-Atlantic Sea Scallop Fishery. *American Journal of Agricultural Economics*, 77(3), 686-97.

Kirkley, J. E., D. Squires, and I.E. Strand (1998): Characterizing managerial skill and technical efficiency in a fishery. *Journal of Productivity Analysis*, 9:145-160.

Kirkley, J. and D. Squires (1999): Measuring Capacity and Capacity Utilization in Fisheries. Gréboval, D. (ed.) *Managing fishing capacity: selected papers on underlying concepts and issues*. *FAO Fisheries Technical Paper*. No. 386, Rome.

Kirkley, J. E., D. Squires, M. F. Alam, and H. O Ishak (2003): Excess capacity and asymmetric information in developing country fisheries: the Malaysian purse seine fishery. *American Journal of Agricultural Economics* 85(3): 647-662.

Kulatilaka, N. (1985): Tests on the Validity of Static Equilibrium Models. *Journal of Econometrics* 28: 253-268.

Kumbhakar, S. C. (2001): Estimation of Profit Functions When Profit is Not Maximum, *American Journal of Agricultural Economics*, 83(1): 1-19.

Kumbhakar, S. C. (1994): A Multiproduct Symmetric Generalized McFadden Cost Function. *Journal of Productivity Analysis*, Vol 5: 349-357.

Larsson, J. (2003): Testing the Multiproduct Hypothesis on Norwegian Aluminium Industry Plants. Discussion Paper No. 350, Statistics Norway, Research Department.

Lau, L (1976): A Characterization of the Normalized Restricted Profit Function. *Journal of Economic Theory* 12: 131-163.

Lipton, D. W. and I.E. Strand (1989): The Effect of Common Property on the Optimal Structure of the Fishing Industry. *Journal of Environmental Economics and Management*, Vol. 16: 45-51.

Lipton, D. W. and I. E. Strand (1992): Effect of Stock Size and Regulations of Fishing Industry Cost and Structure: The Surf Clam Industry. *American Journal of Agricultural Economics* 74: 197-28.

Lopez, R. E. (1982): Applications of Dual Theory to Agriculture. *Western Journal of Agricultural Economics* 7: 353-366.

Lopez, R. E. (1984): Estimating Substitution and Expansion Effects Using a Profit Function Framework. *American Journal of Agricultural Economics* 66: 358-367.

Lucas, R. E. J. (1987): *Models of Business Cycles*. Basil Blackwell, Oxford.

Malmberg, S.-A. and Valdimarsson, H. (2003): Hydrographic conditions in Icelandic waters, 1990-1999. ICES Marine Science Symposia 219: 50-60.

Matthiasson, T. (1997): Consequences of Local Government Involvement in the Icelandic ITQ market. *Marine Resource Economics* 12(2):107-26.

McFadden, D. (1978): Cost, Revenue and Profit functions. Fuss, M. and D. McFadden (eds.) *Production Economics: A Dual Approach to Theory and Applications*, Vol. I, North Holland, Amsterdam.

Morrison, C. (1985): Primal and Dual Capacity Utilization: An Application to Productivity Measures in the U.S. Automobile Industry. *Journal of Business and Economic Statistics* 53: 312-332.

Munro, G. R. and A. D. Scott (1985): The Economics of Fisheries Management. *Handbook of Natural Resource and Energy Economics*, ed. by A. V. Kneese, and J. L. Sweeny. North Holland, Amsterdam.

Matulich, S. C. and M. Sever (1999): Reconsidering the Initial Allocation of ITQs: The Search for a Pareto-Safe Allocation between Fishing and Processing Sectors. *Land Economics*, 75: 203-19

Neary, J. and K. Roberts (1980): The Theory of House Behaviour under Rationing. *European Economic Review* 13: 24-42.

Ostrom, E. (1990): *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press, New York.

Palsson, G. (1999): Individual transferable quotas: Unconstitutional regimes? *Journal of the Fisheries Research Board of Canada* 36: 859-866.

Pascoe, S., J. L. Andersen, and J. W. de Wilde (2001): The impact of management regulation on the technical efficiency of vessels in the Dutch beam trawl fishery. *European Review of Agricultural Economics* 28(2): 187-206.

Pascoe, S., L. Coglan, and S. Mardle (2001): Physical versus harvest based measures of capacity: the case of the UK vessel capacity unit system. *ICES Journal of Marine Science* 58(6): 1243-1252.

Pascoe, S. and L. Coglan, (2002): Contribution of unmeasurable factors to the efficiency of fishing vessels: an analysis of technical efficiency of fishing vessels in the English Channel. *American Journal of Agricultural Economics* 84(3) 45-57

Pascoe, S. and I. Herrero (2001): Estimation of a composite fish stock index using DEA. Paper presented at the XIIIth Annual conference of the European Association of Fisheries Economists, Salerno, Italy, 18-20 April 2001.

Pascoe, S., D. Tingley and S. Mardle (eds) (2003): *Technical efficiency in EU fisheries: implications for monitoring and management through effort controls: Final Report*, CEMARE, University of Portsmouth, UK

Pascoe, S. and C. Robinson (1998): Input Substitution and Profit Maximisation in the English Channel Beam Trawl Fishery. *Journal of Agricultural Economics* 49: 16-33.

Pascoe, S (2003): Excess capacity and potential rent in UK demersal whitefish trawl fisheries: a cost function approach. Country report.

Pearse, P. H. and J. E. Wilen (1979): Impact of Canada's Pacific Salmon Fleet Control Program. *Journal of the Fisheries Research Board of Canada* 36: 764-769.

Planque, B.and T. Frédou (1999): Temperature and the recruitment of Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Science* 56: 2069-2077.

Pope, R. D. (1982): To Dual or Not to Dual? *Western Journal of Agricultural Economics* 7: 337-352.

Pope, J. G. (2000): An overview of additional studies made on Icelandic cod: Summer 2000. Manuscript.

Reid, C., D. Squires, Y. Jeon, L. Rodwell and R. Clarke (2003): An analysis of fishing capacity in the western and central Pacific Ocean tuna fishery and management implications, *Marine Policy*, 27(6): 449-469.

Robidoux, B. and J. Lester (1992): Econometric Estimates of Scale Economies in Canadian Manufacturing. *Applied Economics,* 24: 113-22.

Runolfsson, B. T., A. Ragnar (1996): Evaluation and Performance of the Icelandic ITQ system. Icelandic Economic Papers. Economic Institute, University of Iceland.

Runolfsson, B. T. (1999): Icelandic Fisheries: Development, current situation and future outlook (in Icelandic). Ministry of Fisheries, Iceland.

Sakai, Y. (1974): Substitution and Expansion Effects in Production Theory: The Case of Joint Production. *Journal of Economic Theory* 9: 255-274.

Salvanes, K. G. and D. Squires (1995): Transferable Quotas, Enforcement Costs and Typical Firms: An Empirical Application to the Norwegian Trawler Fleet. *Environmental and Resource Economics* 6: 1-21.

Sampson, D. (2002): Fishing strategies and fishing success: An empirical analysis based on trawl logbooks. Proceedings of the 10th Biennial Conference of the International Institute of Fisheries Economics and Trade, Oregon State University, Corvallis, 10-14 July 2000, Oregon State University (CD-Rom).

Segerson, K. and D. Squires (1990): On the Measurement of Economic Capacity Utilization for Multi-Product Industries. *Journal of Econometrics* 44: 347-361.

Segerson, K. and D. Squires (1993): Capacity Utilization under Regulatory Constraints. *Review of Economics and Statistics* 75: 76-85.

Segerson, K. and D. Squires (1995): Measurement of Capacity Utilization for Revenue-Maximizing Firms. *Bulletin of Economic Research* 47: 77-84.

Sharma, K. R and P. Leung (1999): Technical Efficiency of the Longline Fishery in Hawaii: An application of a Stochastic Production Frontier. *Marine Resource Economics*, 13: 259-274.

Shumway, C. R. (1995): Recent Duality Contribution in Production Economics. *Journal of Agricultural and Resource Economics* 20: 178-194.

Squires, D. (1987a): Fishing Effort: Its Testing, Specification, and internal Structure in Fisheries Economics and Management. *Journal of Environmental Economics and Management* 14: 268-282.

Squires, D. (1987b): Public Regulation and the Structure of Production in Multiproduct Industries: An Application to the New England Otter Trawl Industry. *RAND Journal of Economics* 18: 234-247.

Squires, D. (1987c): Long-run Profit Functions for Multiproduct Firms. *American Journal of Agricultural Economics* 69: 558-569.

Squires, D. (1988): Production, Technology, Costs, and Multiproduct Industry Structure: An Application of the Long-Run Profit Function to the New England Fishing Industry. *Canadian Journal of Economics* 21: 359-378.

Squires, D. (1992): Productivity Measurement in Common Property Resource Industries. *RAND Journal of Economics* 23: 221-236.

Squires, D. (1994a): Sources of Growth in Marine Fishing Industries. *Marine Policy* 18: 5-18.

Squires, D. (1994b): Firm Behavior under Input Rationing. *Journal of Econometrics* 61: 235-257.

Squires, D. and J. Kirkley (1991): Production Quotas in Multiproduct Fisheries. *Journal of Environmental Economics and Management* 21: 109-126.

Squires, D. (1995): Resource Rents from Single Multispecies individual Transferable Quota Programs. *ICES Journal of Marine Science* 52: 153-164.

Squires, D. (1996): Individual Transferable Quotas in a Multiproduct Common Property Industry. *Canadian Journal of Economics* 29: 318-342.

Strand, I. E., J. E. Kirkley and K. E. McConnell (1981): Economic Analysis and the Management of Atlantic Surf Clams. L. Anderson (ed.) *Economic Analysis for Fisheries Plans*, Ann Arbor Science, Ann Arbor, Michigan.

Tingley, D. and S. Pascoe (2003): Estimating the Level of Excess Capacity in the Scottish Fishing Fleet. Report prepared for the Scottish Executive Environment and Rural Affairs Department, CEMARE Research Report 66, University of Portsmouth, UK.

Thunberg, E. M., E. W. Bresnyan and C. M. Adams (1995): Economic Analysis of Technical Interdependencies and the Value of Effort in a Multi-Species Fishery. *Marine Resource Economics* 10: 59-76.

Vestergaard, N. (1999): Measures of Welfare Effects in Multiproduct Industries: The Case of Multispecies Individual Quota Fisheries. *Canadian Journal of Economics* 32: 729-743.

Vestergaard N. (Coordinator) (2002): Measuring Capacity in Fishing Industries using the Data Envelopment Analysis (DEA) Approach, Report to the EU Commission, University of Southern Denmark, Esbjerg.

Vestergaard, N., D. Squires and J. E. Kirkley (2003): Measuring capacity and capacity utilization in fisheries: the case of the Danish gillnet fleet. *Fisheries Research* 60(2-3): 357-368.

Walden, J. B., J. E. Kirkley and A. W. Kitts (2003): A limited economic assessment of the Northeast groundfish fishery buyout program. *Land Economics* 79(3): 426-439.

Watson, R. and D. Pauly (2001): Systematic distortions in world fisheries catch trends. *Nature* 414 (6863): 534-536.

Weninger, Q (1998): Assessing Efficiency Gains from Individual Transferable Quotas: An Application to the Mid-Atlantic Surf Clam and Ocean Quahog Fishery. *American Journal of Agricultural Economics* 80: 750-764.

Weninger, Q. and K. E. McConnell (2000): Buyback Programs in Commercial Fisheries: Efficiency versus Transfers, Canadian Journal of Economics, 33: 394-412.

Weninger, Q. and J. R. Waters (2003): Economic Benefits of Management Reform in the Northern Gulf of Mexico Reef Fish Fishery. *Journal of Environmental Economics and Management*, 46: 207-30.

Weninger, Q. and R. E. Just (1997): An Analysis of Transition from Limited Entry to Transferable Quota: Non-Marshallian Principles for Fisheries Management. *Natural Resource Modeling* 10: 53-83.

Wilen, J. E. (2000): Renewable Resource Economists and Policy: What Differences Have We Made? *Journal of Environmental Economics and Management* 39: 306-327.

Zellner, A. (1962): An Efficient Method for Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias. *American Statistical Association Journal* 58: 348-368.